CFD Modeling On the Factors Affecting the Suction Rate of the Blood Clot Removal Using GP Device

By

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Supervisors: Dr Anis Suhaila Shuib and Dr Ku Zilati Ku Shaari

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

Universiti Teknologi PETRONAS

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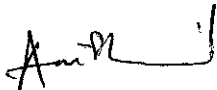
CERTIFICATION OF APPROVAL

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Approved by,

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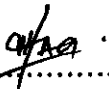
(Dr Anis Suhaila Shuib)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original works is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

....

(SYED MUHAMMAD ABDUL HAQ B SYED MAT DAUD)

ACKNOWLEDGEMENT

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Alhamdulillah, I grateful to Allah the Almighty because I manage to finish the project on time. Throughout the duration of the research, I has having a very good cooperation from all parties involved including personnel from the projects I chose as my case studies, researches, academician and public people. Without their helps, I think this project cannot be successful.

This acknowledgement is specially tribute to my supervisors: Dr Anis Suhaila Shuib and to Dr Ku Zilati Ku Shaari which had given full supervision, guidance, trainings and also inspiration to complete the project. Without their knowledge, experience and contribution, this project would not be accomplished.

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For those who has assisted me in completing the project, but the name is not mentioned here, I would like to thanks for all contribution and supports.

Thank you.

ABSTRACT

There are 40 000 Malaysians suffered stroke and stroke become the third major killer in Malaysia. Stroke happens when the blood supply which carries vital oxygen and nutrients are disrupted by the blood vessel wall ruptures or get clogged. The Gillian Pearce Mechanical Thrombectomy Device (GP MTD) is the device that can remove the blood clot with the concept of suction. However, the pressure must not cause the damage to the blood vessel. Computational Fluid Dynamic (CFD) will be used to simulate the flow in GP MTD. The movement of clot in blood is predicted using Navier Stokes Equation where two immiscible phases is considered. In the project, three geometry of GP Device has been designed with the different number of helical spiral which are zero, five and ten helical spiral. The suction pressure is varied to three conditions which are 40kPa, 50kPa, and 60kpa. Suction rate will increase when the suction pressure in increased. Suction rate also increase when less spiral is used but the pressure drop during the suction will increase. Lower pressure drop is desirable for the blood clot removal process to avoid artery rupture.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY (STROKE)

Stroke is a third major killer in Malaysia after heart diseases and cancer (NASAM, 2010). There are 40 000 people suffer strokes each year including children but the huge quantity of the cases affect adult. Stroke becomes the single most common cause of severe disability. The figure below is the percentage of factors that cause the stroke for low-mortality developing countries including Malaysia. (WHO, 2011)
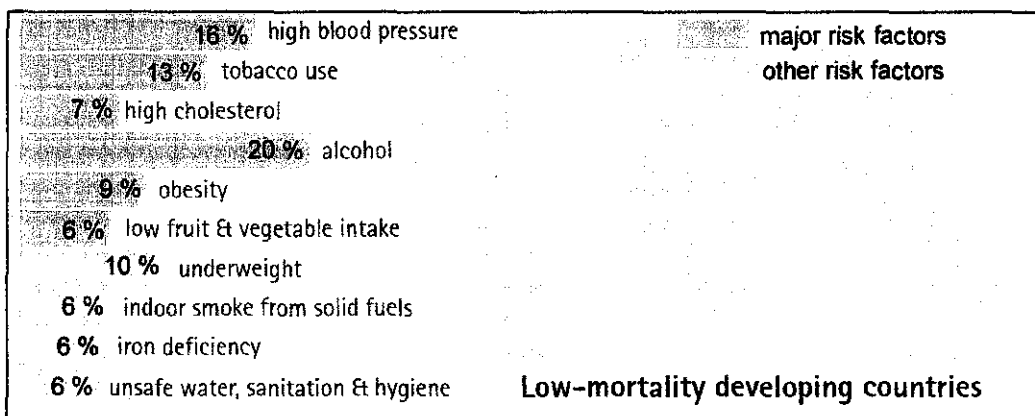
Figure 1.1 : Percentage of Factors That Cause Stroke For Low-Mortality Developing Countries

Stroke will attack brain and occurs when the supply of blood that containing oxygen and nutrients to the brain is disrupted. The brain is the main nerve center of the body. In order to continuously working, the brain needs constant vital oxygen and nutrients from the blood. That part of the brain starts to die when a blood vessel in the brain bursts or gets clogged.

Ischemic Stroke

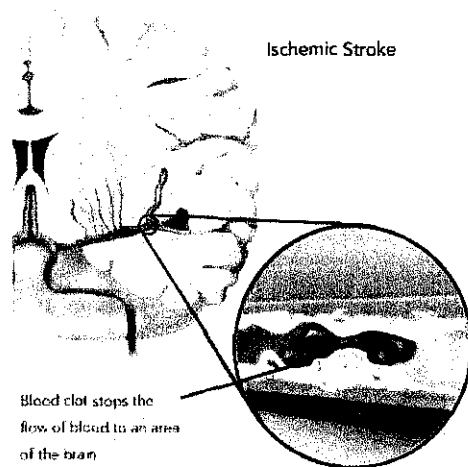Blood clot stops the
flow of blood to an area
of the brain

Figure 1.2 : Cause of Stroke; Blood of supply to the brain is disrupted.

Strokes may be divided into two essential types (EverydayHealth, 1999). First, there is Ischemic stroke. This type of stroke initiated when blood supply is interrupted. The interruption is caused by existence of blood clots in the artery. The blood clots will block the blood flow resulting in the stuck in the artery. The second is known as Hemorrhagic Stroke. It occurs when bleed or hemorrhage caused by the burst of a blood vessel in or around brain. Hemorrhagic happens because high blood pressure that left untreated gives a strain on the artery walls and finally increases the risk of bursting and bleeding. Artery burst results in the blood is forced into the brain tissue and will damage the cells and finally the brain malfunctions
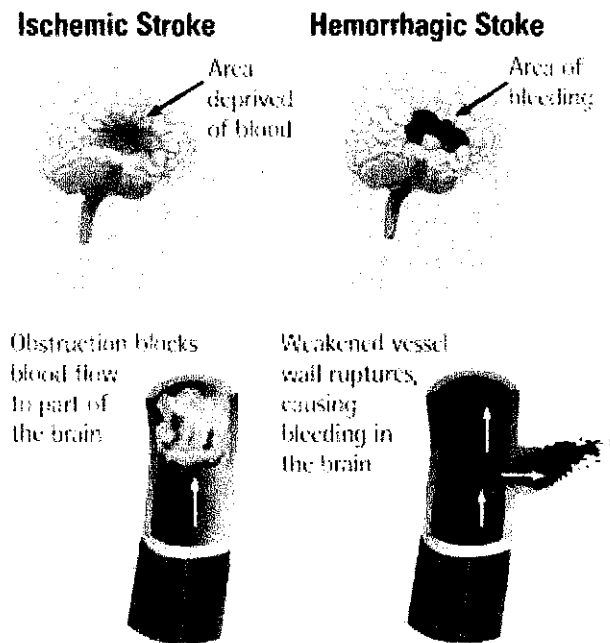
Ischemic Stroke **Hemorrhagic Stoke**

Figure 1.3 : The Types of Stroke : Ischemic Stroke and Hemorraghic Stroke

The treatments for stroke are divided to three categories (Pearce, 2009). First are thrombolytic like tissue plasminogen activator (tPA). The research by National Institute of Neurological Disorder and Stroke shows that the rate of death and disability was reduced if the recombinant (rt) –tPa was admistered within 3 hours onset of the symptom. Rt-rPa is still the most popular and well-known thrombolytic agent today. However, it cannot be used in patients who have undergone recent surgery, and it may cause bleeding at the site of the clot in some instances. In fact that it is only licensed for 3 hours poststroke usage.
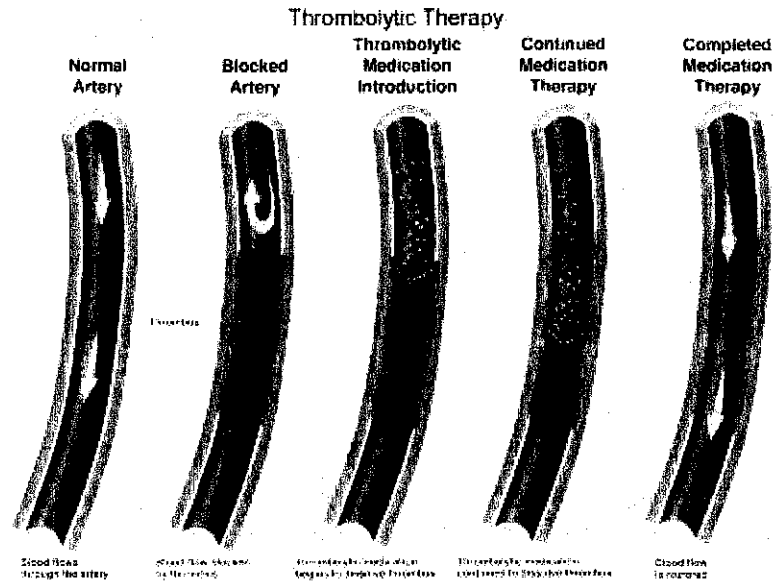
Figure 1.4 : Treatment for Stroke; thrombolytic. E xample :tissue plasminogen activator (tPA).

Second are the mechanical thrombectomy devices (MTD). The recently invented and patented "GP" MTD (Pearce, et al., ,2008) is a clot removal device uses the concept of suction, through a micro catheter, allows removal of thrombus even though without direct contact with the clot surface. The design of the device has a helical design, with the sectional force applied and less of moving parts. It will produce a vortex at the catheter tip to remove the blood clot.

Catheter arterial tubing   MTD attached at the end of the
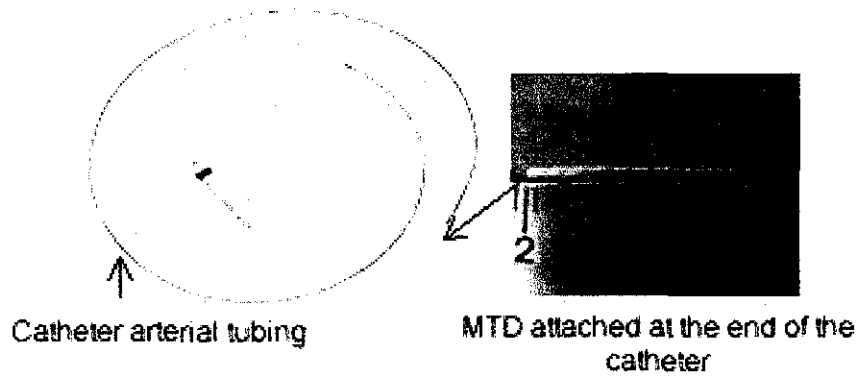   catheter

Figure 1.5 : Treatment for stroke : Mechanical Thrombectomy Device

Third, are neuroprotective agents however, none of the latter is yet licensed for use in human beings.

1.2 PROBLEM STATEMENT

Computational Fluid Dynamic (CFD) contributes a lot to build a computational model that represent GP device. The physics and chemistry of the flood flow can be applied to this virtual prototype. It will be the output a prediction of the fluid dynamic and related physical phenomena. Similarly, the blood clot phenomena in the artery can be stimulated using CFD technology (Pearce, et al, 2009). Instrumentation for designing GP device is extremely difficult as the flow measurement of the device is small and the operating conditions severe. Therefore it became essential to look at the flow by the computational methods.

Mechanical thrombectomy device (MTB), the second method for stroke treatment will be focused in this project. The recently invented and patented "GP" MTD (Pearce, et al., ,2008) will be specialized in this project.

Pressure and time taken for the device to gently remove the clot safely without damaging the artery wall need to be determined. In existing design, helical spiral will be able to gradually remove the clot and the pressure is gradually increased (Pearce, et al, 2009). The vortex generated eases the suction action.
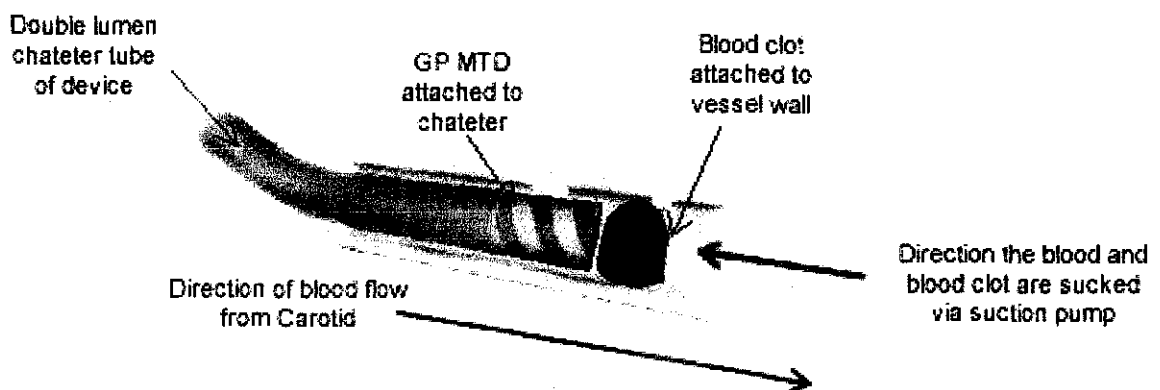
Double lumen chateter tube of device

GP MTD attached to chateter

Blood clot attached to vessel wall

Direction of blood flow from Carotid

Direction the blood and blood clot are sucked via suction pump

Figure 1. 6 : The illustration of GP MTD

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1.3 OBJECTIVES

The objectives of this project are :

- To determine the suction pressure and time taken to remove the blood clot
- To investigate the pressure distribution during suction.
- To characterize the velocity around the clot.

1.4 SCOPE OF STUDY

CFD Techniques have been recognized as an alternative specific experimental investigation and traditional mathematic modeling. Simulation of blood clot in an artery at laminar flow on the modern medical device like GP model is necessary and important for engineering problem

CHAPTER 2

LITERATURE REVIEW

Blood contain blood cells, platelets, mineral ions, protein glucose, oxygen and carbon dioxide which those are the nutrient and wasted to be transported. 40 % of the blood volume is the red blood cells. Because blood is a complex mixture, the blood does not show a constant viscosity at all flow rates compared to water. The blood is non-Newtonian in the microcirculary system in small branches or capillaries and the normal blood flow is laminar with secondary flows generated at curved or branches. The blood flow and pressure is unsteady because the pulsating conditions in all arteries created by the heart. The Reynolds number for the blood varies from 1 in small arterioles to approximately 4000 in largest artery. (Xu et al.,2008)

The objective of thrombolytic treatment is to dissolve blood clots at the same time reestablish the normal vessel functions. Serza(2005) said that the experimental results by Skharov and Rijken present that the fast blood plasma flow significantly improves blood flow dissolution under optimal biochemical dissolution. However, there is no a reliable theoretical model presented yet. The hypothesis shows that mechanical forces of flowing blood are strong enough to play the function in dissolution of blood clots in addition to the biochemical reactions that responsible for chemically degrading the clot. The forces from mechanical work can cause the strain deformations and surface vibrations, and faster chemically degrade it. When the blood is slow-laminar mechanical forces have a viscous origin and when blood is fast-turbulent mechanical forces have a kinematic origin.

During the dissolution process, the volume flow of the blood through the vessel is assumed to be constant. However, at the starting point of the dissolution process, the assumption may not be exactly correct because the blood clot will strongly obstruct blood movement and may pose the higher resistance to blood flow than other vessels. The assumption will simplify the model and the value will not really different from the real situation especially when the clot is well routed.(Sersa et al.,2005)
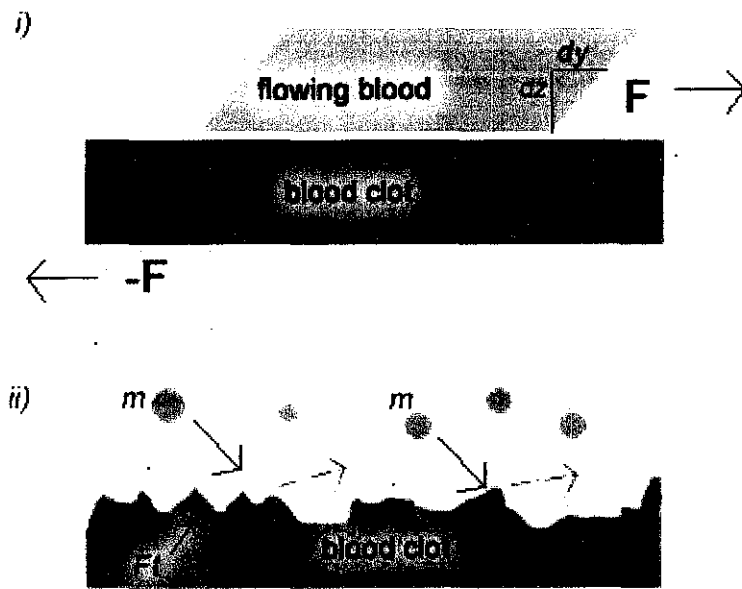

Figure 2.1 : Forces of the flowing blood to the surface of the clot in the flow channel are
s) viscous when flow is slow-laminar b) become kinematic

The GP MTD can be manufactured with two device positioning. First is by mounted on the catheter and second is by embedded within the chatterer. From the research (Pearce et al,(2006)) when accessing clot extraction time, there is almost no difference was observe between the device position. However, respect to fluid removal, the embedded device bring more effective and there are big differences observed between mounted device and embedded device. (Pearce et al, 2008)
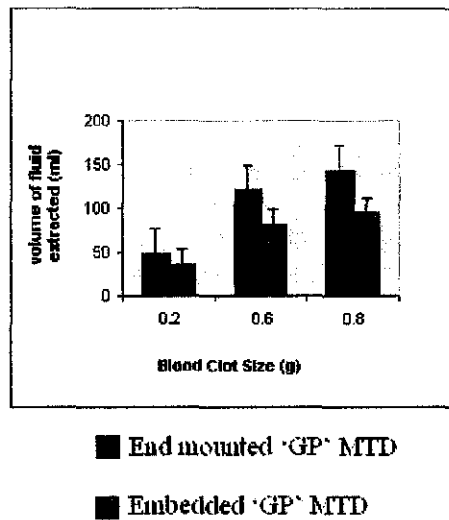
Figure 2.2 : Volume of fluid removed vs mass of blood clot for fluid flow rate of 10.6 ml/sec through the end mounted and embedded GP Device.

The effectiveness of GP MTD Device is based on the range of clot masses and size. For example, the 2.0-mm GP MTD Device is effective to remove a large clot in a porcine abattoir artery. There appears to be a relationship between clot removal times and clot length in the plastic tube and generalized relationship between the amount of the time for which the clot was resident in the tube respect to clot removal time (Pearce et .al, 2009)
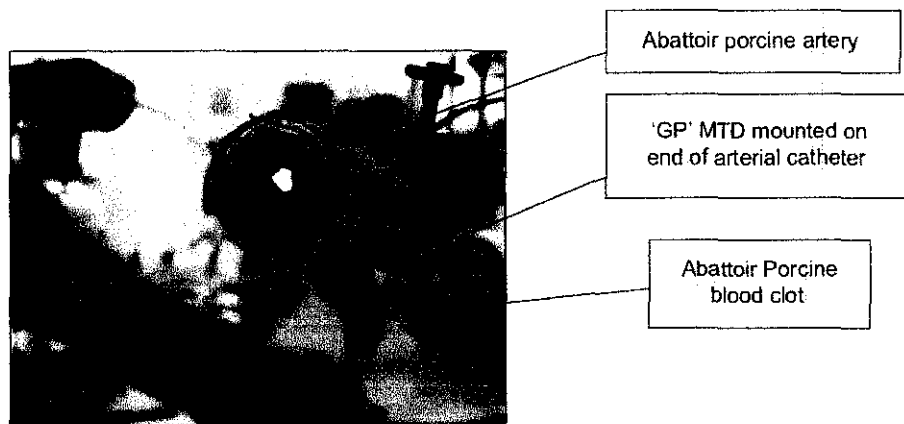
Figure 2.3 : Removal of 5-cm blood clot from abattoir artery using GP MTD 2.5 mm in diameter

The removal time of blood clot for GP MTD is related with the clot length in the plastic tube, and generalized relationship between the amounts of the for which the clot was residence in the tube with the respect to clot removal times. However, these results are only for plastics tubes artificial clots (Pearce et .al, 2009)
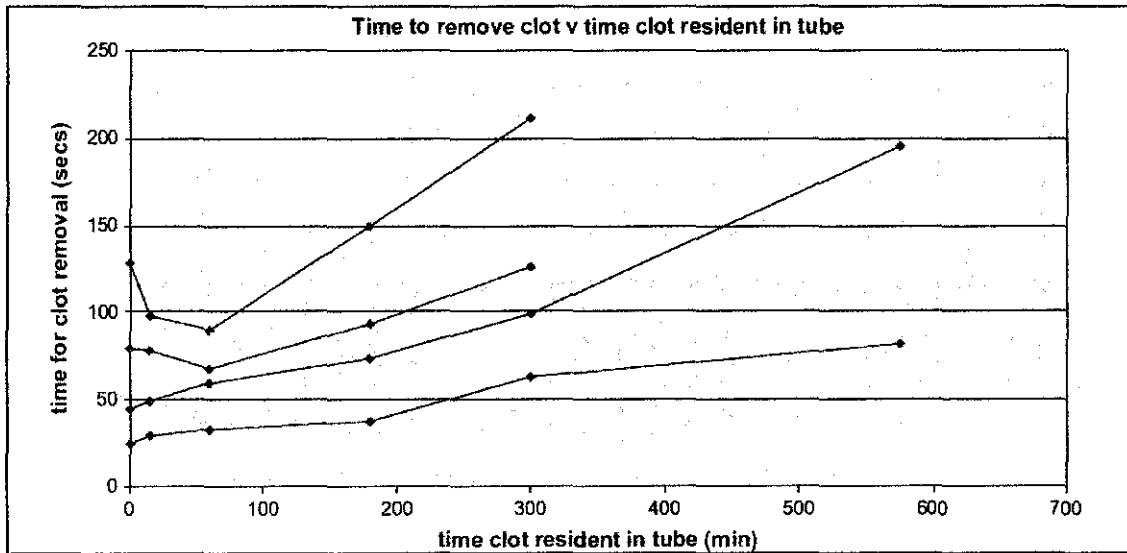
Figure 2.4 : Time for which clot resident in tube versus time taken to remove clot
(Lowest line to uppermost line 1-,2-,3- ad 5- cm clot length)

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

The project uses the ANSYS fluids dynamics solution to find the result of simulation as it can gain the trust result. A wide-ranging suite of advanced CFD modeling capabilities will be provided by ANSYS fluids dynamic technology, including advanced models for multiphase such as free surface, boiling, wet steam, slurries, real gas, noise, solidification and melting.

ANSYS fluids dynamics solutions are fully integrated into the ANSYS Workbench Platform. All the project workflows starting from pre-processing until the post processing already integrated in ANSYS Workbench Platform. The optimization and exploration of the design can be done are easily by using this platform. The Multiphysics requirements like fluid structure interaction studies, electromagnetic or fluid coupling also provided in this platform.

To represent the design, the simulation will start with geometry. This geometry can be designed in a computer-aided design (CAD) system or constructed from scratch. ANSYS DesignModeler software is the entrance to geometry handling for analysis with software from ANSYS. By using ANSYS DesignModeler, the parameters of the design can then be modified and the design updated, and any feature removal or simplification is maintained.

The most difficult part of engineering simulation is mesh generation. Too many cells will result in long solver runs, and too few cells will lead to inaccurate results. ANSYS Meshing technology provides a way to balance these needs and produce the right mesh for each simulation in the most automated way possible. ANSYS Meshing technology has been built on the strengths of stand-alone, class-leading meshing tools. The strongest aspects of these separate tools have been brought together in a single environment to produce some of the most powerful meshing available.

ANSYS Fluent software provides us wide physical modeling capabilities required in model flow, turbulence, heat transfer and also reactions for industrial application such as air flow over aircraft wing, combustion in furnace, semiconductor manufacturing and also blood flow. Advanced solver technology results in fast and accurate CFD results. By using ANSYS capable, user can easily manage the solver setup, do the calculation, examine the results, changing any setting and analyze the results.

PRE PROCESSING
- Draw the geometry
- Generate mesh

SOLVING / RUNING
- Specify operating condition, boundary condition, material
- Adapting the region of bloot clot
- Run the simulation

POST PROCESSING
- Display the result simulation
- Observe the blood clot deforma
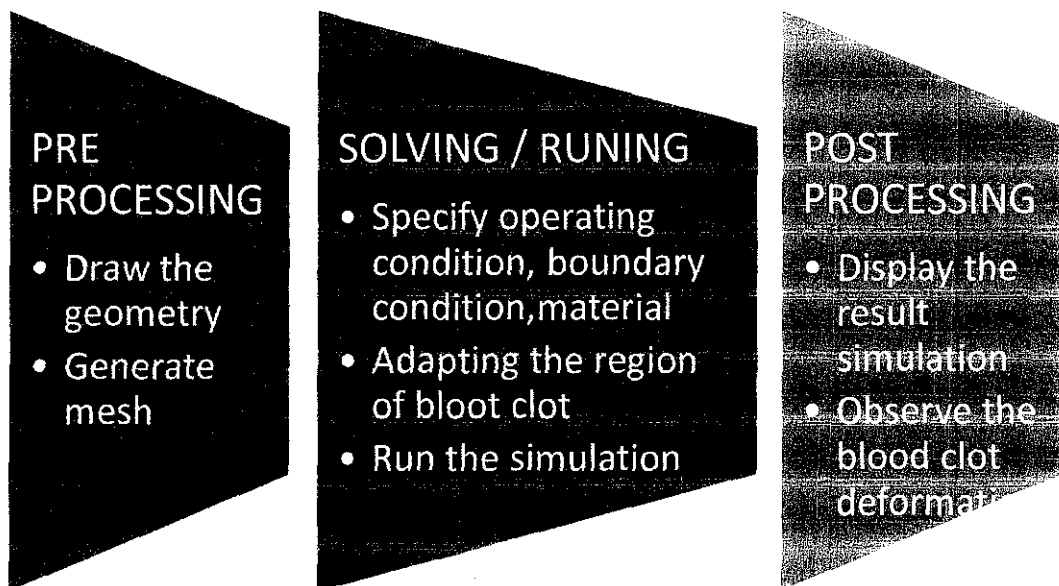
Figure 3.1 : Basic steps in CFD

3.2 PRE-PROCESSING

Before starting the simulation, the first step is to design the geometry by using the ANSYS DesignModeler software. The geometry must be draw in 3- dimensional since the deformation of the blood clot need to be observed during simulation process. All the tools in DesignModuler such as draw, sweep, extrude and dimension need to be handling wisely to design the desired geometry.

The design is developed based on the artery and the GP Device. For this project, the diameter of the artery is 3mm. The GP Device diameter is 1 mm and the length of the GP Device is about 20 mm. The GP Device contains a helical spiral with 12 mm length of its central axis. The catheter which contains the helical spiral is positioned with 3mm of the blood clot that is occluding the artery by 100%, so no blood is flowing out the artery. Below is the image of the geometry.
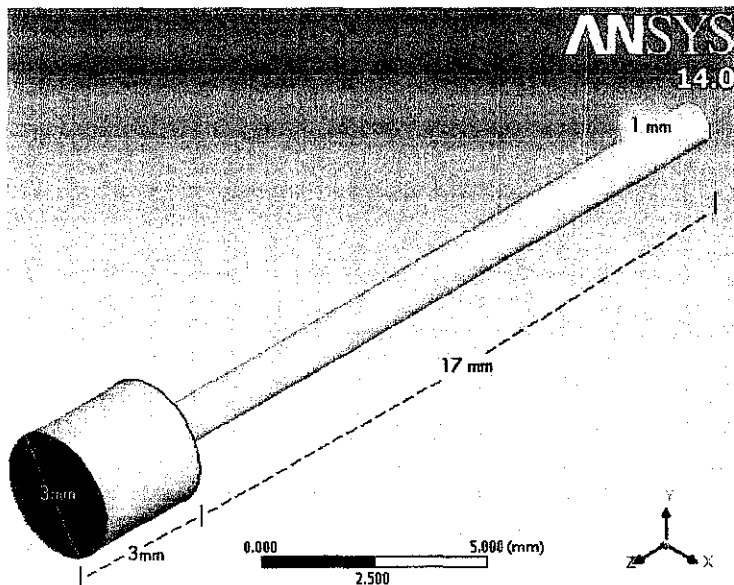
Figure 3.2 : The geometry of the artery and GP Device (no spiral)
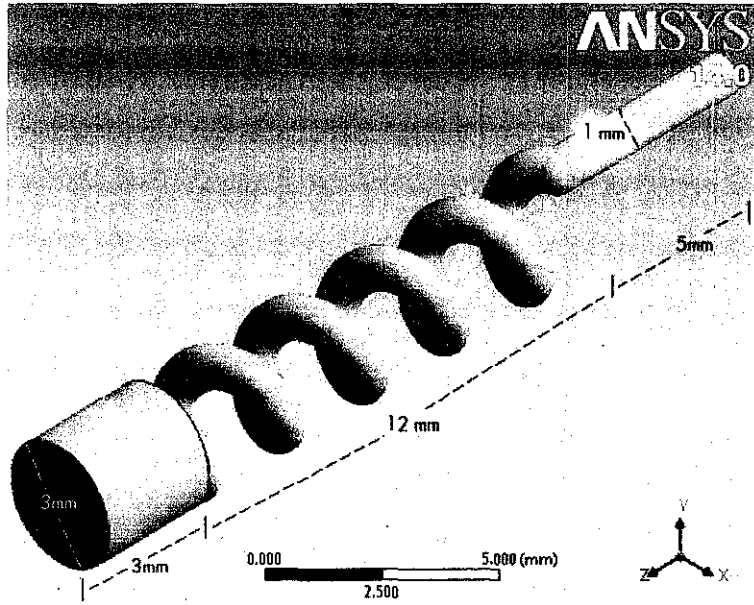
Figure 3.3 : The geometry of the artery and GP Device (5 spiral)
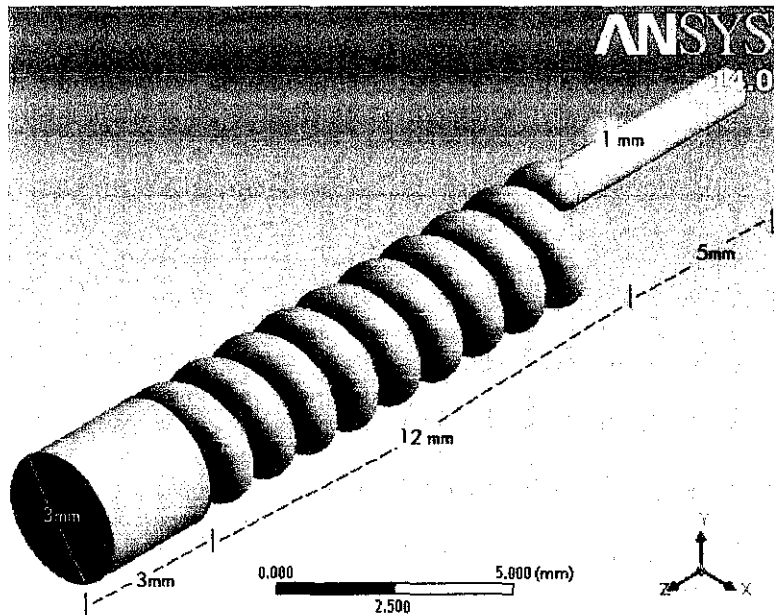
Figure 3.4 : The geometry of the artery and GP Device (10 spiral)

Once the geometry already drawn by DesignModuler, it can be load to ANSYS Meshing to generate the mesh. CFD will be the physics preference for the mesh and Fluent will be the solver. Six meshing methods are available for 3D geometries in ANSYS Meshing. There are Tetrahedron, Sweep, Multizone, Hex Dominant, CutCell mesh and Automatic. Pressure inlet, pressure outlet and wall are three identical faces presents in the mesh and all of them need to be set in Named Selection of the model. The quality of the mesh need to be checked up to avoid inaccurate results. The minimum value for orthogonal quality is important and should not fall below 0.05. The minimum for this mesh is acceptable.

3.3 RUNNING/SOLVING

Once the geometry is designed and the mesh already generated, running and solving processes of simulation will take place. During this step, the boundary condition, material and operating condition are specified based on the case of the simulation.

The main objective of this simulation was on study the behavior of blood clot when the number of helical spiral turn is different. The blood clot must be removed safely. Therefore, the solver to be used in the simulation is the solver for laminar, incompressible and unsteady-state flow of Newtonian fluid.

In the project, ANSYS Fluent is used to perform the simulation. The type of solver is *Pressure-Based* type. The velocity formulation of the solver is *Absolute* type and the time is *Steady* type. The formulation type operated is *Implicit*. *1st order Implicit Unsteady State* is used since the operating fluid is blood and its flow is intermittent due to heart pumping.

The main project of the project is *Multiphase* model and the primary model is *Volume Of Fluid*. The scheme of the volume fraction parameters is *Explicit*. The courant number is set up to 0.25 and the number of *Eulerian Phase* is two, which is blood and blood clot.

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There are two material used in the simulation which are blood clot and blood. The phase for both materials is fluid but the blood clot will is assumed to be gel-like phase. The blood clot is located at the inlet of GP Device. The properties of blood and blood clot are determined in the software. The density and viscosity for both materials are stated below.

Properties	Blood	Blood Clot
Density (kg/m3)	1060	1080
Viscosity (kg/s)	0.0035	0.05

Table 3.2: The properties of blood and blood clot

Then, the two phases are defined. Blood is the primary phase and the blood clot is the secondary phase. Other parameter such as wall adhesion, shear stress and surface tension can be applied during the simulation. Next, the operating condition such as pressure inside the vessel and its reference location is set based on the findings.

Now, the blood clot in the blood vessel needs to be specified. The process can be done by adapting the region for this blood clot. Once, the blood clot emerges, it is patched inside the blood vessel resulting in two different phases. Below is the image of the region of the blood clot

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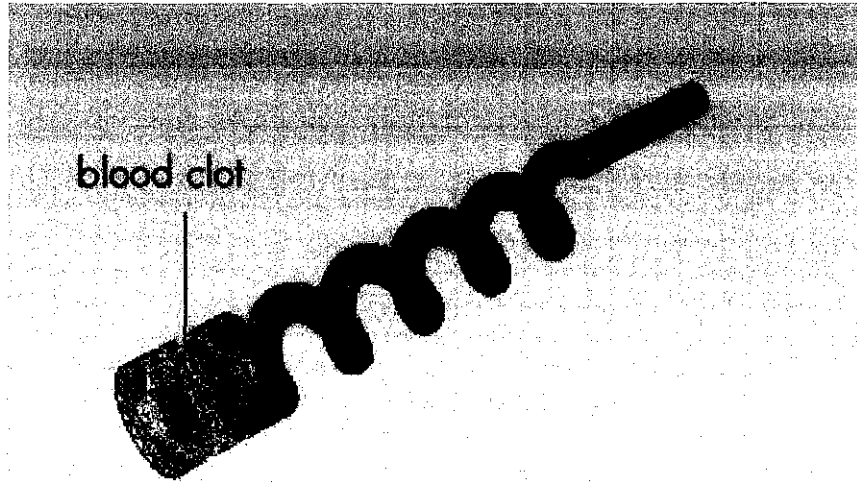
Figure 3.3 : The region of the blood clot

After all the parameters of simulation have been set up, the simulation is ready to be solved. Some input need to be inserted in the solver setting. The setting are below

Equation	Flow, Volume Fraction
Pressure-velocity coupling	PISO
Pressure	PRESTO!
Momentum	QUICK
Volume Fraction	First Order Upwind

Table 3.2: The solver parameters setting for the simulation.

3.4 POST PROCESSING

Once the model is iterated and solved based on desired parameters, the results of the simulation can be observed quantitatively. Contours, vectors and line/rake pathlines are among the general method that usually used during the post processing steps.

The post-processing step is the most important step in the entire simulation. At this step, blood deformation in the blood vessel can be studied by observing the movement of blood clot when the pressure is applied to it. It can be done by help of moving frames or animation properties in ANSYS Fluent. When the calculation or solving process is finished, the software will create the date file (.dat) at each time step that has been set up. The data files are used as a frame and need to combine with other frames to create the animation sequence. Once the animation sequence is prepared, Fluent will convert it to media format known as *.mpeg*.

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CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT

In this project, the objective is to observe the blood clot deformation and it behavior when the different number of helical spiral used at the certain pressure applied. Then, the media file containing sequence of frames is saved. Table 4.1-4.9 shows the sequence of blood deformation in the GP Device at certain time when a pressure of 40kPa,50kPa and 60kPa are applied at the outlet of the device, respectively.

We will notice that the blood start to deform as soon as the pressure applied at the outlet of the device. It was shown when using the minimum pressure of 40kPa; the blood clot still can be sucked.

Table 4.1: Image of blood clot in the zero helical spiral device at time, t with suction pressure, $\Delta P = 40$kpa

	0.00 s	0.01 s	0.02 s	0.03 s
0 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

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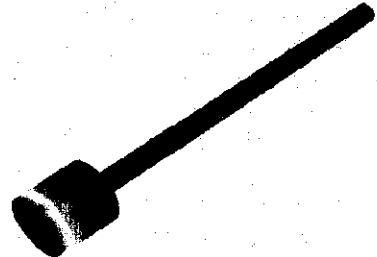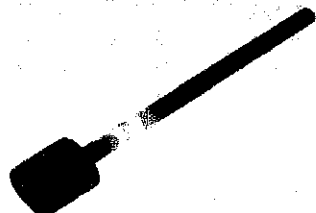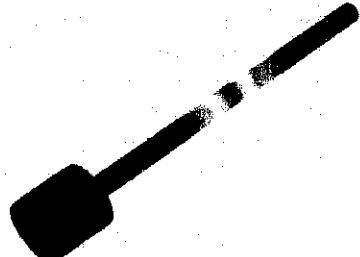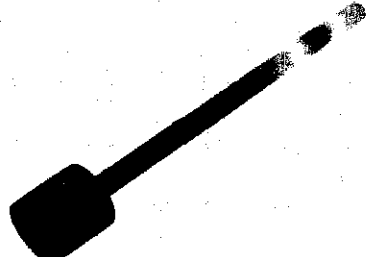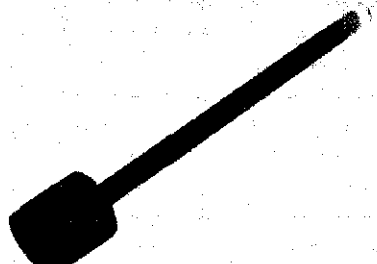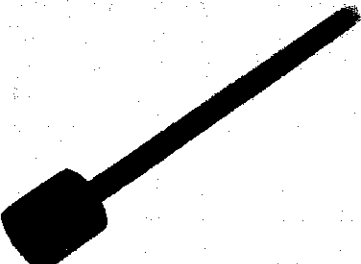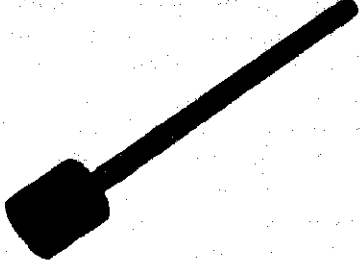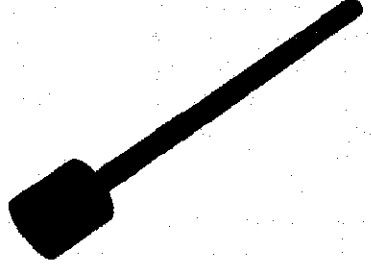
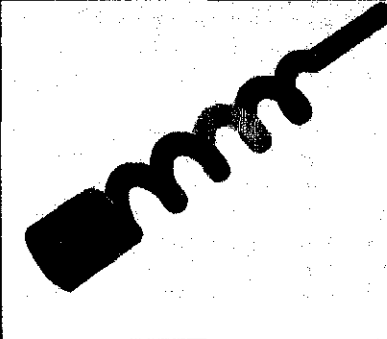Table 4.2: Image of blood clot in the zero helical spiral device at time, t with suction pressure, $\Delta P = 50$kpa
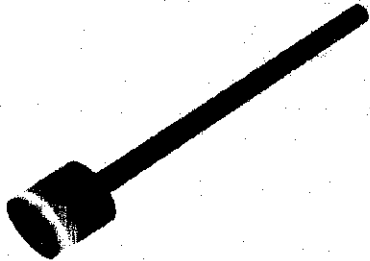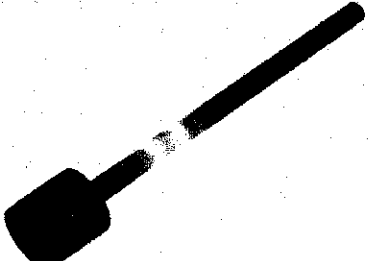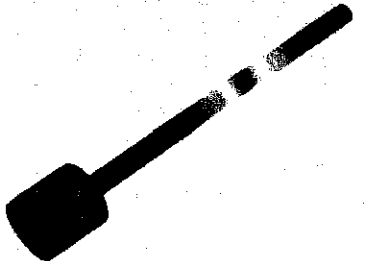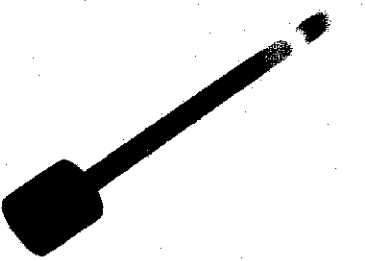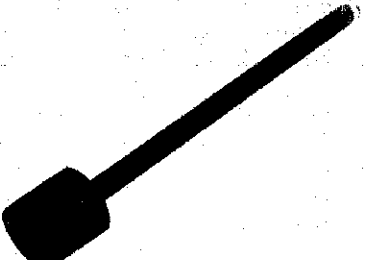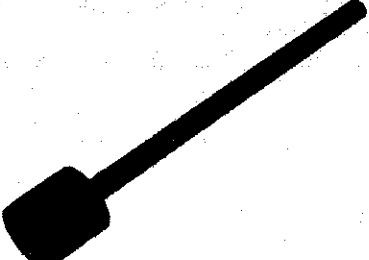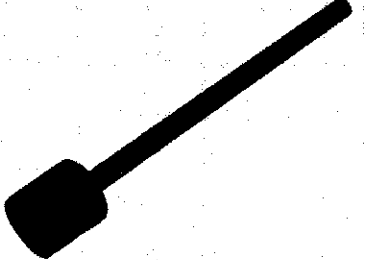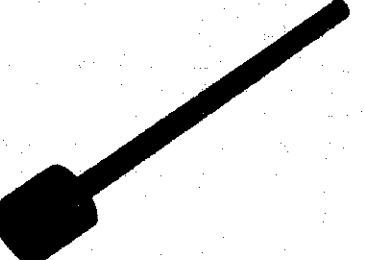
	0.00 s	0.01 s	0.02 s	0.03 s
0 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

Table 4.3: Image of blood clot in the zero helical spiral device at time, t with suction pressure, $\Delta P = 60$kpa
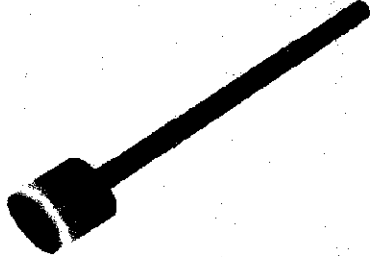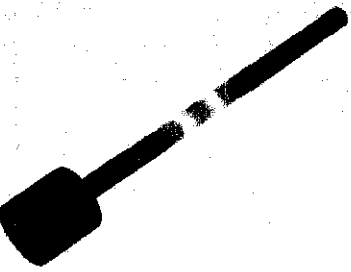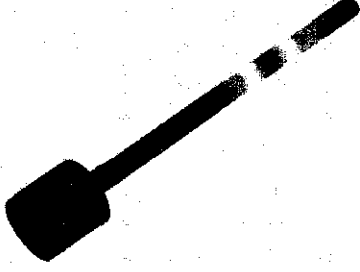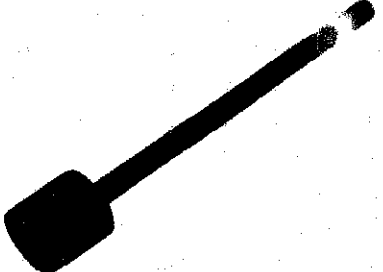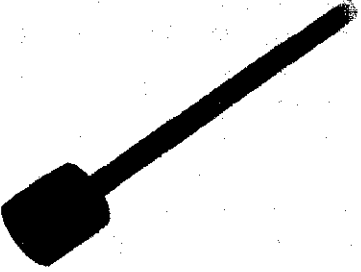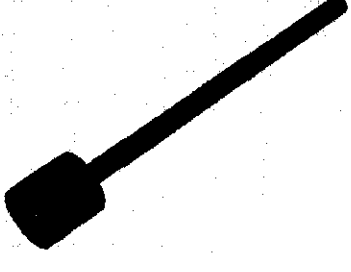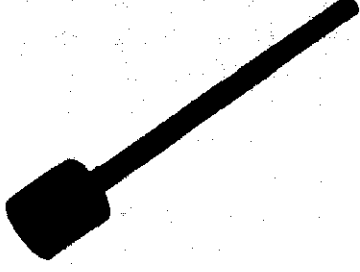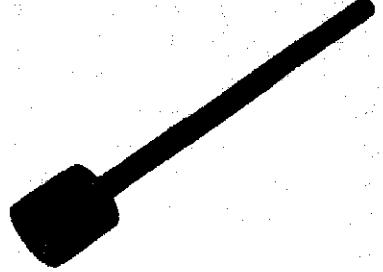
	0.00 s	0.01 s	0.02 s	0.03 s
0 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

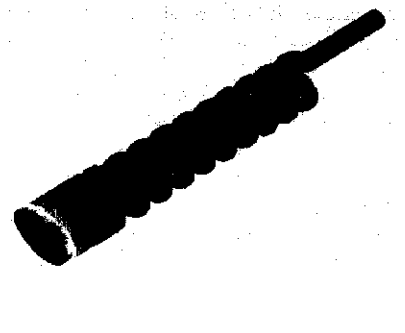Table 4.4: Image of blood clot in the 5 helical spiral device at time, t with suction pressure, $\Delta P = 40$kpa
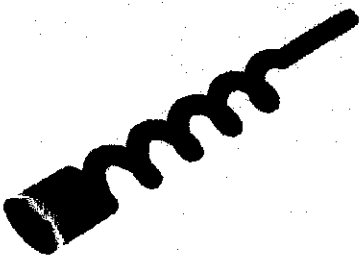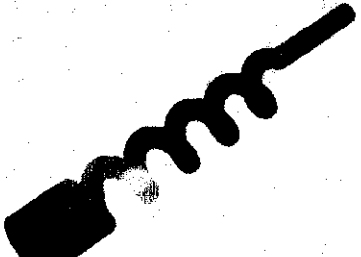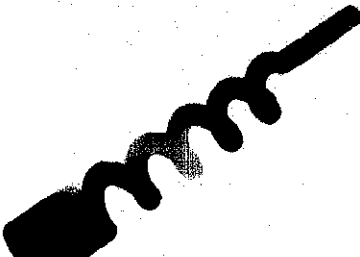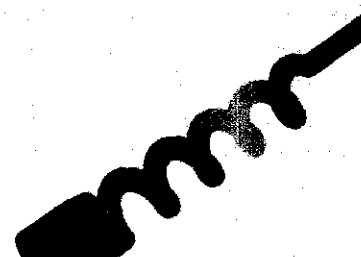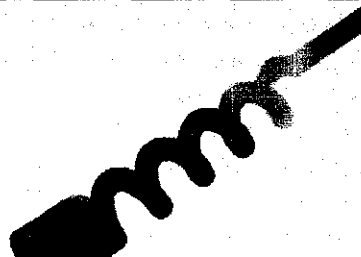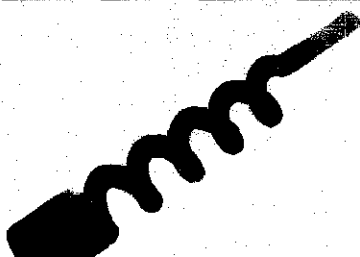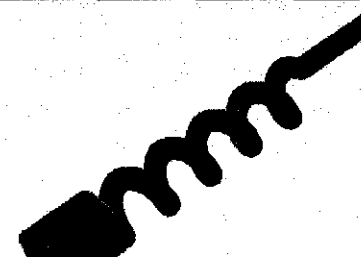
	0.00 s	0.01 s	0.02 s	0.03 s
5 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

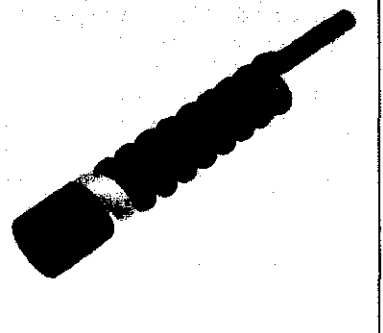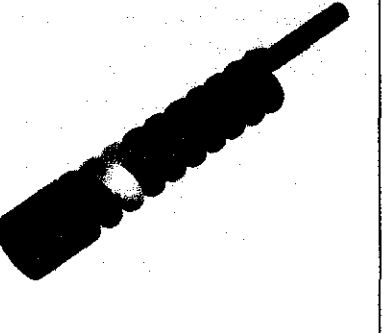Table 4.5: Image of blood clot in the 5 helical spiral device at time, t with suction pressure, $\Delta P = 50kpa$
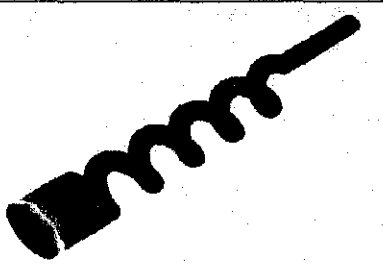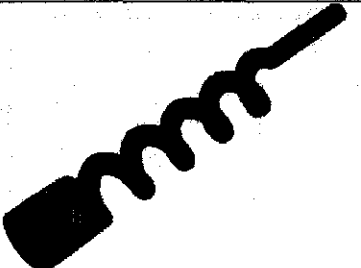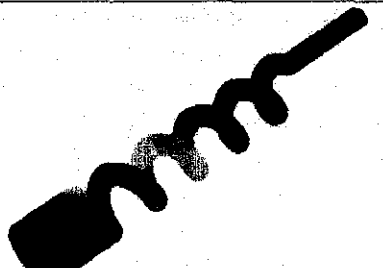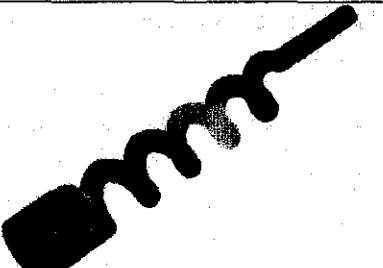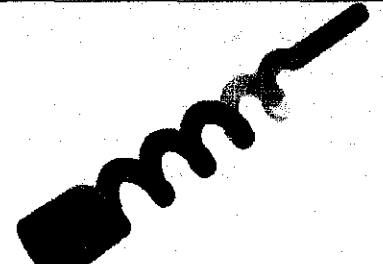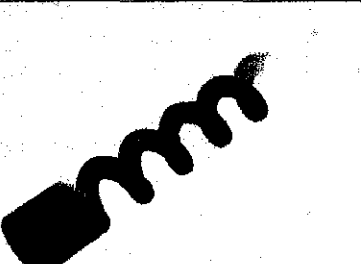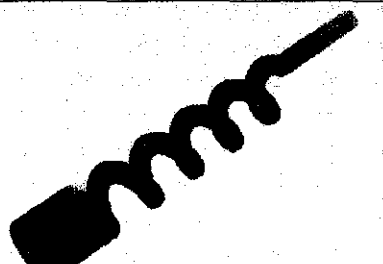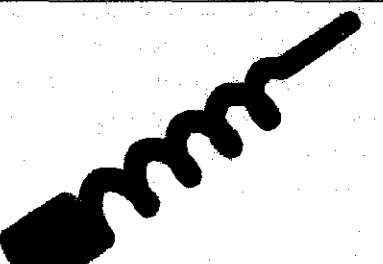
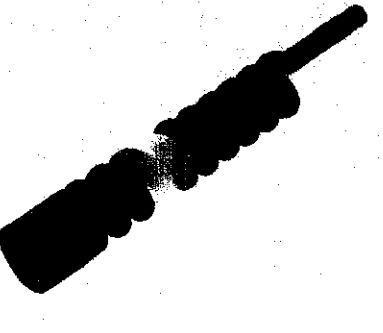Table 4.6: Image of blood clot in the 5 helical spiral device at time, t with suction pressure, $\Delta P = 60$kpa

	0.00 s	0.01 s	0.02 s	0.03 s
5 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

26
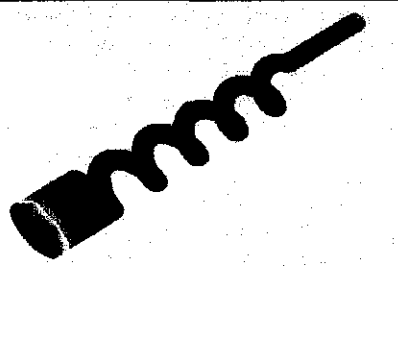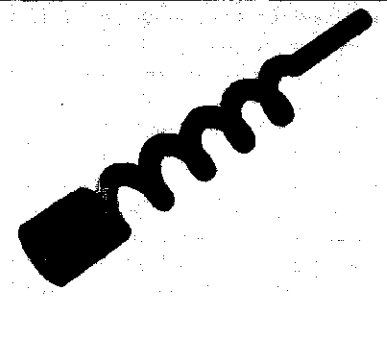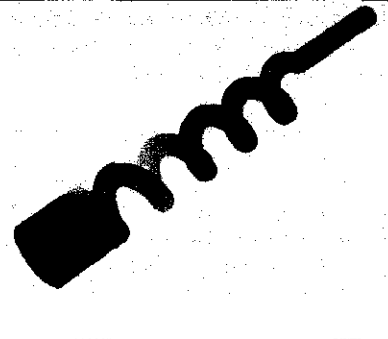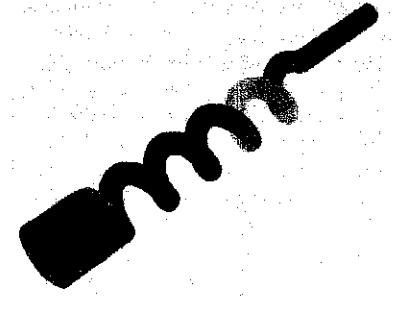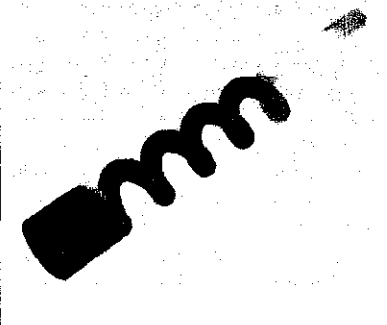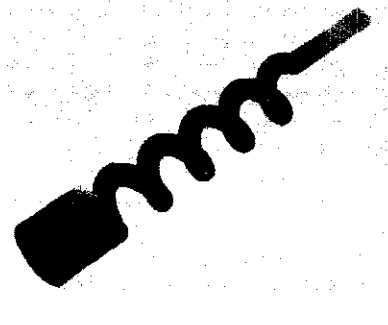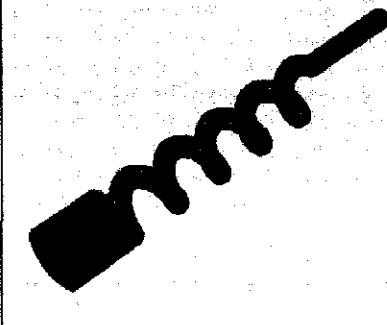
Table 4.7: Image of blood clot in the 10 helical spiral device at time, t with suction pressure, ΔP = 40kpa
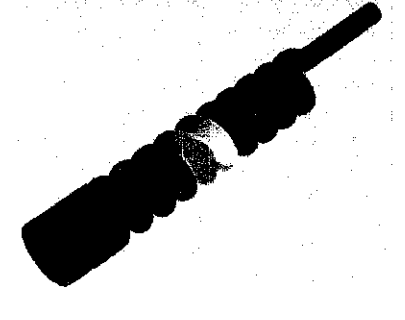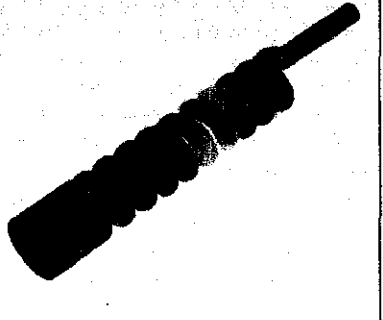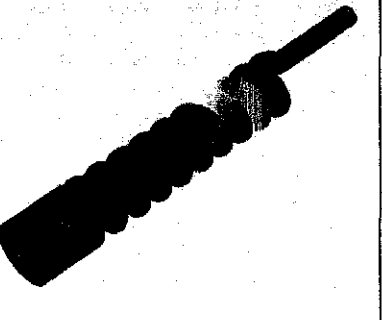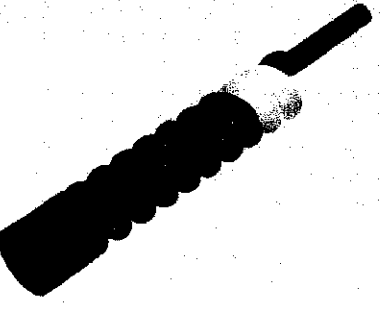
	0.00 s	0.01 s	0.02 s	0.03 s
10 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

Table 4.8: Image of blood clot in the 10 helical spiral device at time, t with suction pressure, $\Delta P = 50$kpa
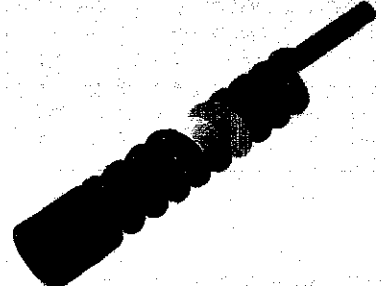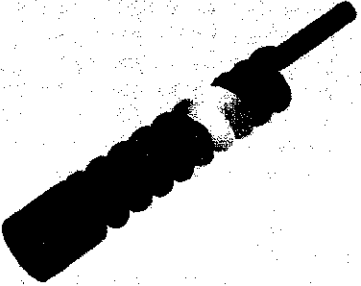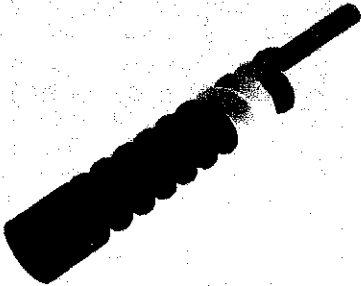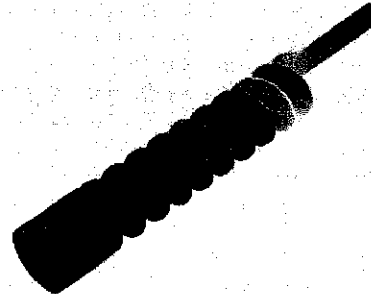
	0.00 s	0.01 s	0.02 s	0.03 s
10 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

Table 4.9: Image of blood clot in the 10 helical spiral device at time, t with suction pressure, ΔP = 60kpa
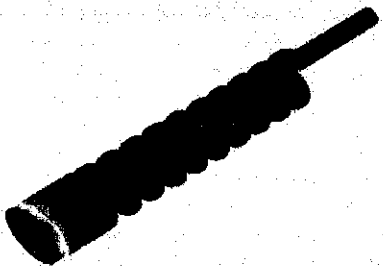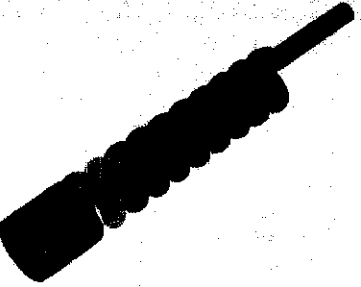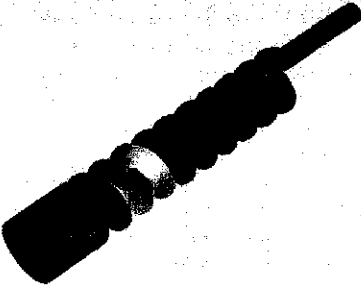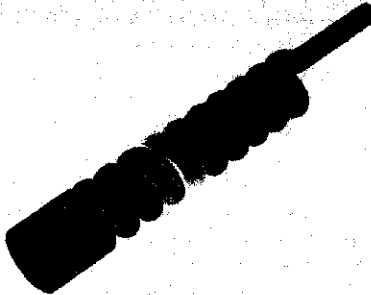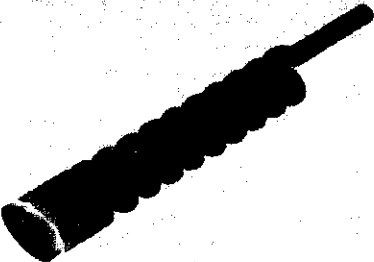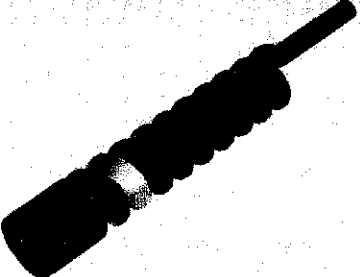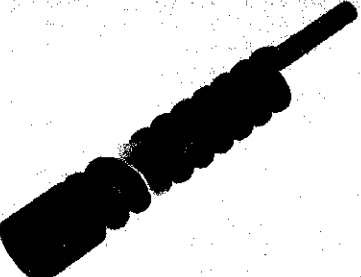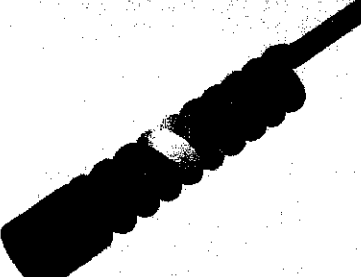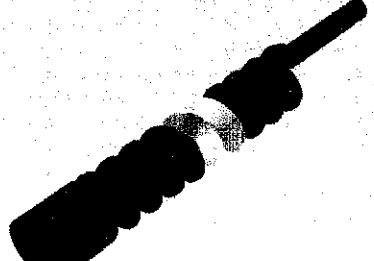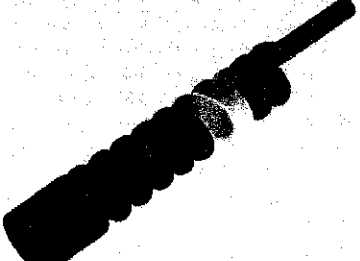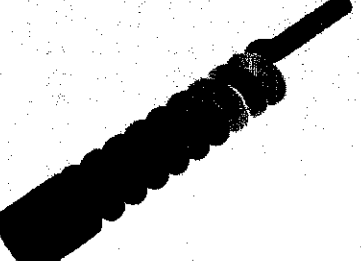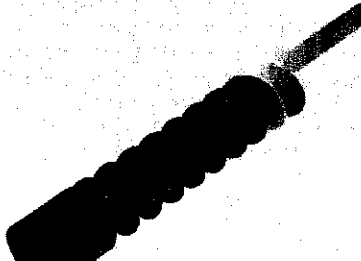
	0.00 s	0.01 s	0.02 s	0.03 s
10 Spiral				
	0.04 s	0.05s	0.06 s	0.07 s

Figure 4.1: Time taken to remove the blood clod versus the suction pressure of GP Device
(zero spiral)
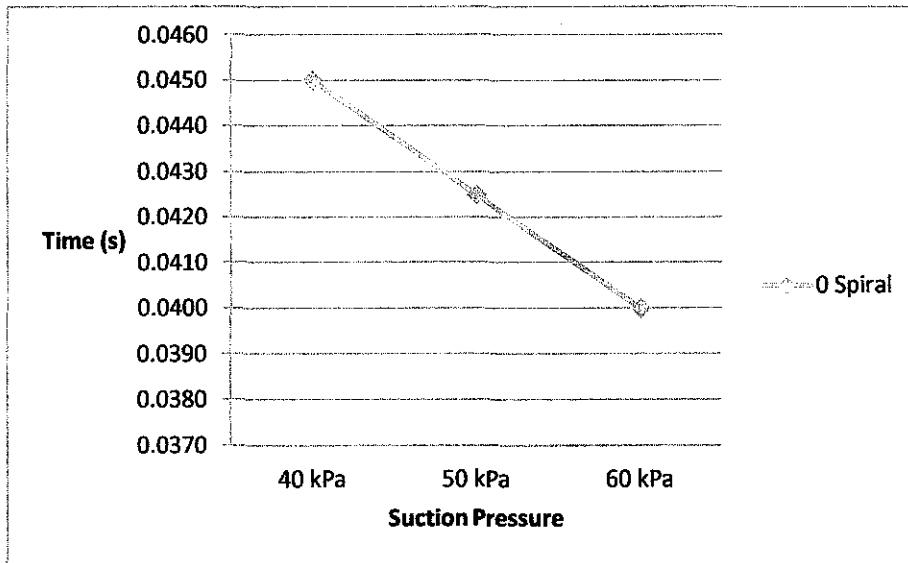
Figure 4.2: Time taken to remove the blood clod versus the suction pressure of GP Device
(5 spiral)
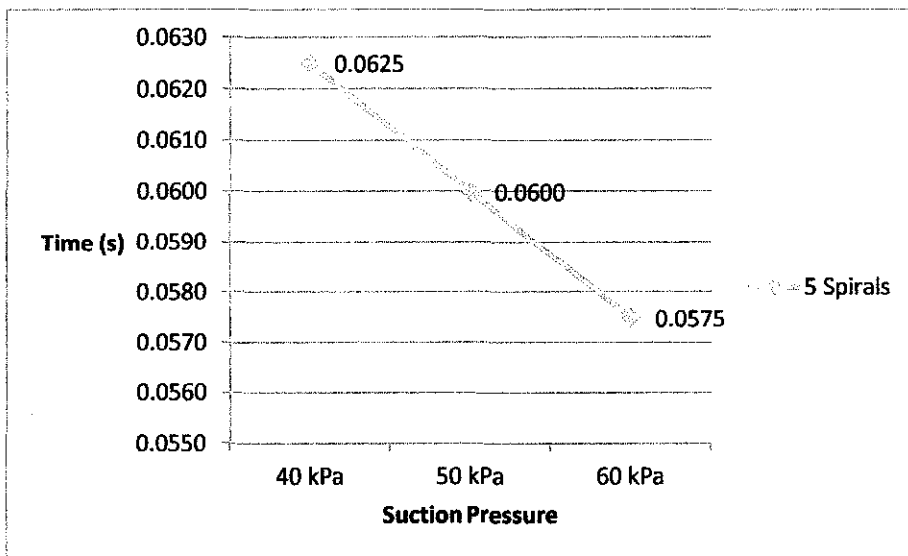
Figure 4.3: Time taken to remove the blood clod versus the suction pressure of GP Device
(10 spiral)
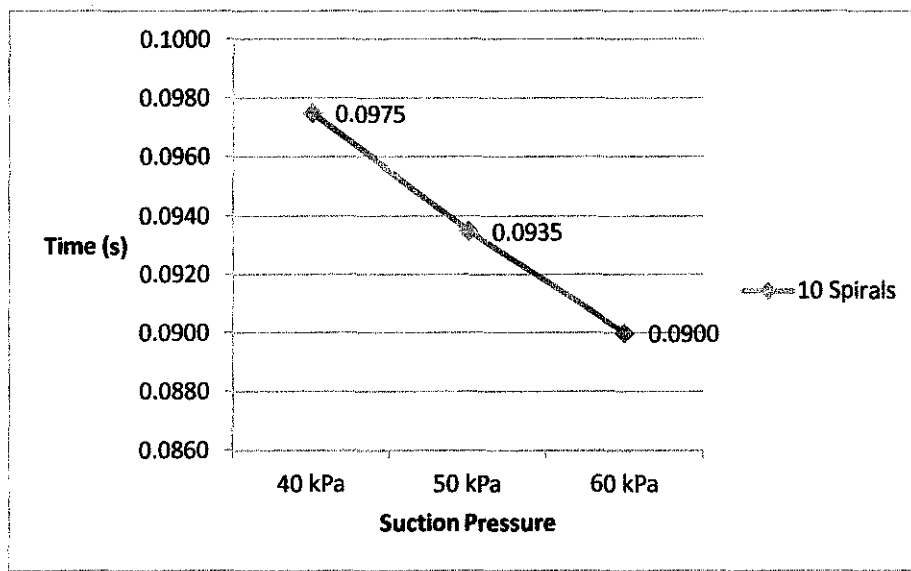
From the Figure 4.1, 4.2 and 4.3, the deformation rate of the blood clot is greater when higher pressure is applied at the end of the catheter. GP Device with different number of helical spiral will completely remove the blood in the fastest when using the highest pressure. The deformation rate is highest when using the pressure of 60 kPa , following by 50kPa and 40kPa.

Although the blood clot can be sucked out with the less of time with the higher force but this is true that the higher pressure tend to suck out with the greatest force. The greater force tends to cause an injury to the blood vessel. So for this project, GP Device with the suction pressure of 40kPa to be applied in the real situation as it can avoid the risk of blood ruptures during the treatment.

From the previous discussion, the GP Device with the suction pressure of 40kPA is preferable to be used in the treatment. From the table 4.1-4.9, it shows that the GP Device with no helical spiral can completely sucked out the blood clot very fast following by the GP device with the 5 and 10 helical spiral. Although the blood clot can be sucked out very fast without using the helical spiral, but the spirals will provide the safe precaution measurement to suck the blood safely.

Table 4.6, 4.6 and 4.7 shows the maximum pressure founded during the first 0.01 second of the removal process ,and the pressure is taken at the end of the GP Device.

Figure 4.4 : The maximum pressure founded in the artery at the end of the GP Device (0 Spiral) for first 0.01s removal process.
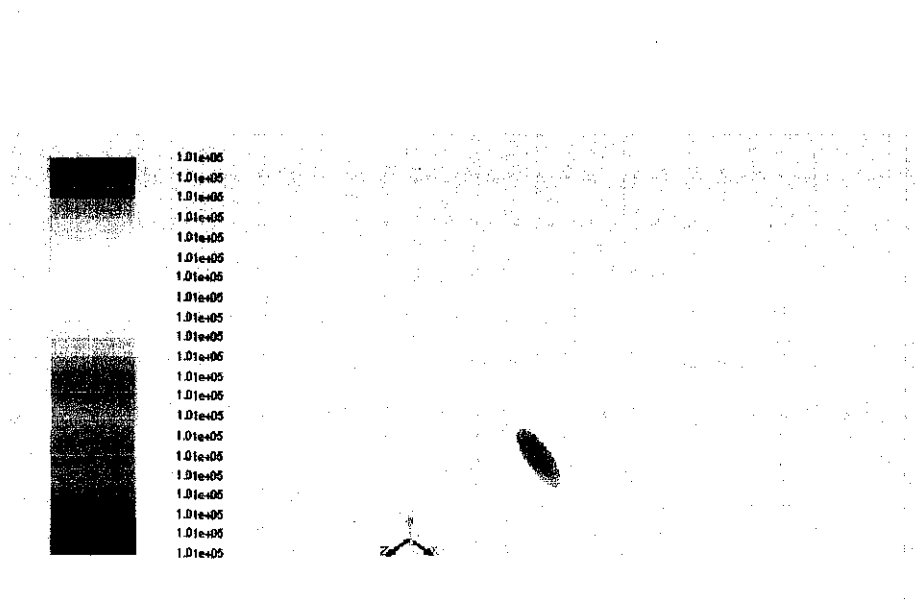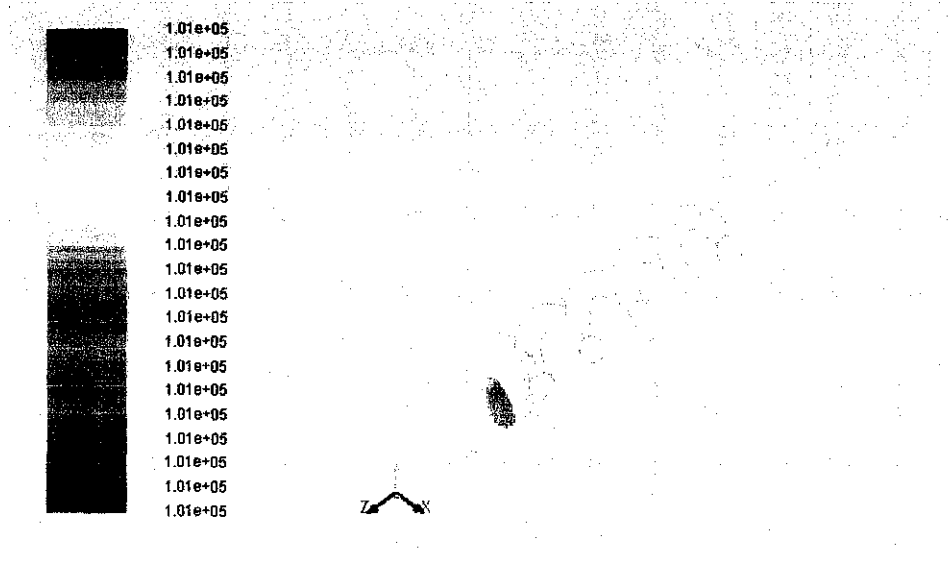
Figure 4.5 : The maximum pressure founded in the artery at the end of the GP Device
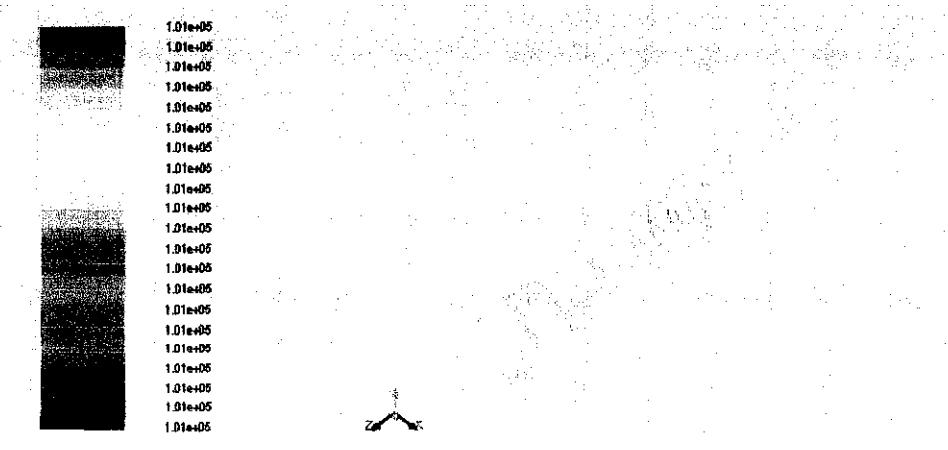(5 Spiral) for first 0.01s removal process.

Figure 4.6 : The maximum pressure founded in the artery at the end of the GP Device
(10 Spiral) for first 0.01s removal process.

From the maximum pressure founded in the artery at the end of the GP Device, the maximum pressure drop in the artery during the first 0.01s of the suction process can be determined. The maximum pressure drop is the different pressure between the normal pressure in the artery and the maximum pressure founded during the suction process in the artery. Lower pressure drop is desirable for the blood clot removal process to avoid artery rupture. From the Figure 4.7, the 10 spiral of GP Device is desirable for the blood clot removal process.
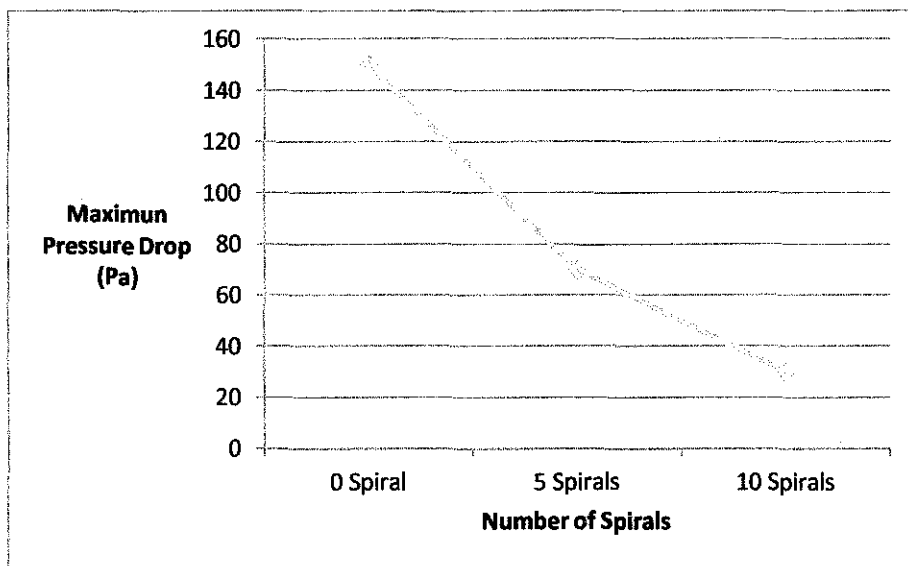
Figure 4.7 : The maximum pressure drop founded in the artery at the end of the GP Device for first 0.01s removal process.

Besides that, the spirals of the device will create the sort of vortex that will assist to decrease the pressure drop during the suction process. From the Table 4.8-4.9 , the velocity vectors of the fluid inside the vessel will moves in the helical form. There is no helical movement observe in for GP Device with no helical spiral. But the helical movement or the vortex are easily be observed for device with five and 10 spirals. When the number of helical is increase, the vortex created also increased.
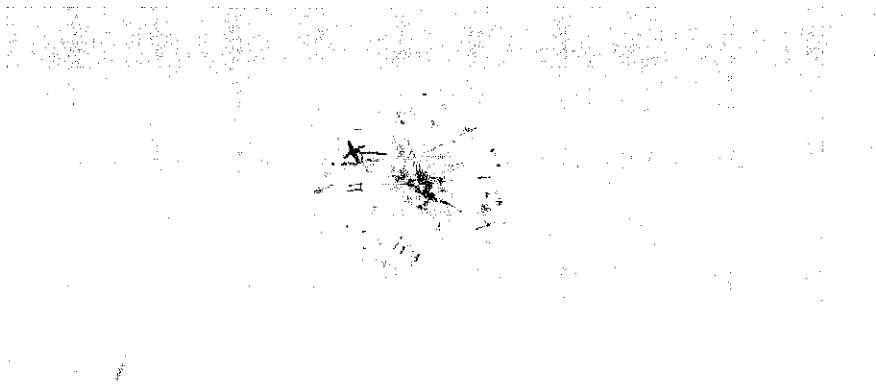
Figure 4.8: Image of Blood Clot Velocity in the Zero Helical Spiral Device at Time, t with suction pressure, P = 40kPa
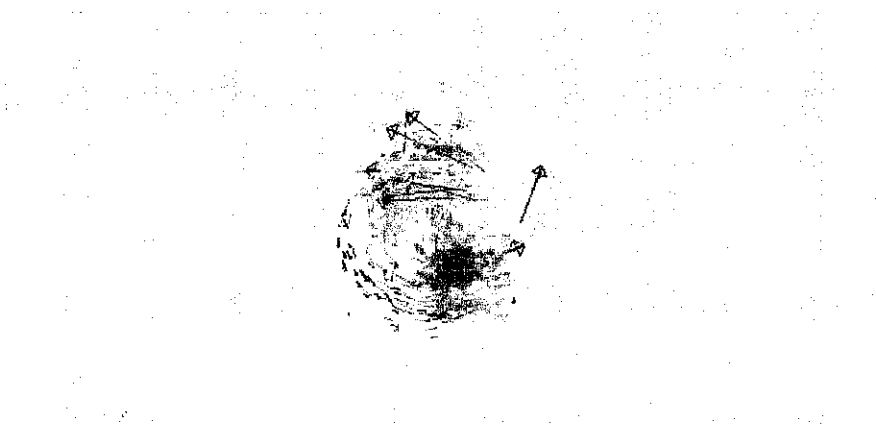
Figure 4.9: Image of Blood Clot Velocity in the 5 Helical Spiral Device at Time, t with suction pressure, P = 40kPa
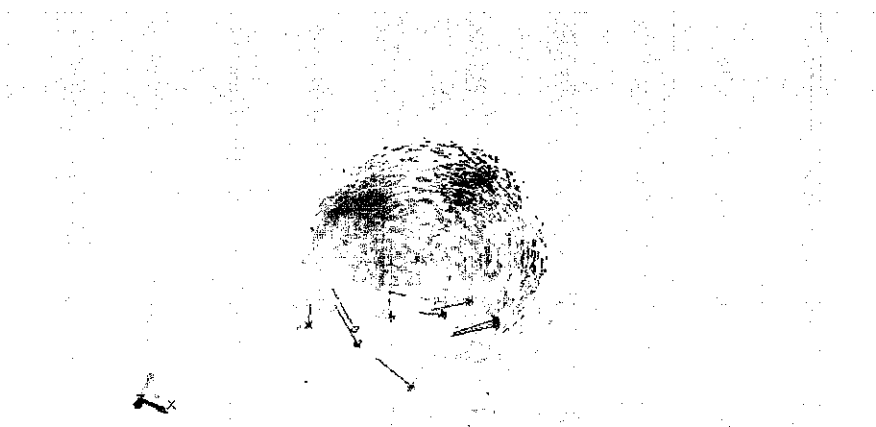
Figure 4.10: Image of Blood Clot Velocity in the 10 Helical Spiral Device at Time, t with suction pressure, P = 40kPa

CHAPTER 4

CONCLUSION AND RECOMMENDATION

4.1   CONCLUSION

In order to predict the blood clot removal from blood artery, we need to study on hydrodynamic behavior when designing blood clot removal system .The project will evaluate the suction pressure and also the time taken to extract it. The effects of the number of helical spiral on the suction rate also need to be examined.

All the objectives of this project are achieved. The conclusions are:

- The suction pressure and time taken to remove the blood clot has been determined. When the suction pressure is increased, suction rate for clot removal will increase.

- Suction rate also increase when less spiral is used but the pressure drop during the suction will increase.

- Lower pressure drop is desirable for the blood clot removal process to avoid artery rupture.

- Spirals of the device will create the sort of vortex that will assist to decrease the pressure drop during the suction process. When the number of helical is increase, the vortex created also increased.

4.2   RECOMMENDATION

The project has to be done in 2 semesters of study only. Therefore, the time for the research to be done is quite limited. Therefore, in order to have advancement for this project in the future, instead of using VOF model as the selected model in ANSYS Fluent, the study can be further enhanced by using different multiphase model to compare the accuracy of result. There are few other model such as Discrete Phase Model (DPM), Mixture model and Eulerian Multiphase model.

Besides that, the study also can be done by taking into the consideration about the component in blood. In blood, there are other component such as red blood cells, white blood cells, platelet and etc. Therefore, the real condition of blood can be simulated.

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