FAILURE ANALYSIS OF CEREBRAL ANEURYSM

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I certify that the project entitled "*Failure Analysis of Cerebral Aneurysm*" is written Mohd Yusrizal B. Mohd Yusoof. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

(Mohd Fadzil bin Abdul Rahim) ....
Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

The aneurysm is the abnormal bulging of a portion of an artery due weakness in the cerebral at the circle of Willis brain. Nowadays, cerebral aneurysm is the one of the disease which have killed the people very quickly. This occurs when the mechanical behavior exceeds the strength of the tissue. This study is focused on cerebral aneurysm. Investigations on the changes of flow phenomena and the mechanical behavior in cerebral aneurysm have been studied. By using the simulation tools, the stress behavior on this region has been analyzed. The normal size of cerebral diameter is about 3-7 mm and aneurysm can bulge and reach until 10 mm. The velocity profile, nodal pressure distribution, displacement of wall and the stress at the wall had been identified at locations of aneurysm. As the size of an aneurysm increases, there was a potential of rupture of aneurysm. This can result in severe hemorrhage or even worst, fatal event. The studies are proceed based on numerical approach. The result shown that mechanical behaviors inside aneurysm region would be different compare to the normal blood vessel. It was proved that the maximum velocity had been obtained is 0.192 m/s. The maximum displacement of wall aneurysm at the neck is 0.00005 mm and the maximum affective stress at the aneurysm is 21.70 MPa. For the pressure distribution, the highest pressure at the aneurysm is 15.6 KPa. This study would help to predict cerebral aneurysm and provide better understanding about the cerebral aneurysm.

ABSTRAK

Aneurisme merupakan satu salur darah dibahagian kepala yang mengalami keadaan bengkak. Gejala ini memberi kesan yang buruk kepada pesakit yang boleh menyebabkan salur darah tersebut menjadi lemah. Pada masa kini penyakit ini telah menyerang dan membunuh manusia dengan begitu cepat. Perkara ini terjadi apabila keadaan mekanikal telah melebihi keadaan asal pada salur darah tersebut. Ini kerana para doktor masih tidak dapat menyelesaikan masalah ini. Simulasi akan dijalankan dengan mengambil model salur darah ditengah otak. Kajian ini telah menfokuskan kepada keadaan mekanikal pada salur darah. Saiz normal salur darah di bahagian tengah otak adalah 3-7 mm dan pembengkakkan boleh berlaku sehingga 10 mm. Apabila saiz aneurisme meningkat, terdapat potensi untuk aneurisme pecah. Ini boleh menyebabkan pendarahan atau lebih teruk, iaitu kematian. Kajian ini hanya dijalankan dengan pendekatan pengiraan matematik tanpa melibatkan sebarang eksperimen. Berdasarkan kajian telah ditunjukkan bahawa sifat-sifat mekanikal di dalam bahagian aneurisme adalah berbeza dengan salur darah yang normal. Jelaslah terbukti bahawa halaju pada aneurisme adalah 0.192 m/s. Anjakan paling tinggi adalah 0.00005 mm dan tekanan paling tinggi adalah 21.70MPa. Tekanan berkesan paling tinggi adalah 15.6 KPa. Dengan mengkaji sifat-sifat mekanikal di bahagian salur darah aneurism yang sebenar dapat memberikan maklumat-maklumat yang berguna mereka untuk lebih memahami keadaan aneurisme yang sebenar.

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CA	Cerebral Aneurysm
CFD	Computational Fluid Dynamics
FEA	Finite Element Analysis
FSI	Fluid Structure Iteraction

CHAPTER 1

INTRODUCTION

1.1 CEREBRAL ANEURYSM

Cerebral aneurysms are localized dilatations of the intracranial arterial wall that usually occur on or near the circle of Willis as shown in Figure 1.1. Rupture of intra-cranial aneurysms is the leading cause of subarachnoid hemorrhage and often causes significant mortality and morbidity. Solid biomechanical analysis of patient-specific cerebral aneurysms and estimations of wall stress distribution can provide useful in-sights into the disease process and help quantify geometric features within a physics-based framework. Investigations on solid biomechanics of intracranial aneurysms (ICA) have been scarce unlike for abdominal aortic aneurysms (Wang et al., 2009). The bio-mechanics of aneurysm has been studied with great interest since aneurysm rupture is a mechanical failure of the degenerated aortic wall and is a significant cause of death in developed countries (David et al., 2006). Rupture of cerebrovascular lesions does not occur very frequently, but when the disease has severe consequences for the individual. Thus, there is an urgent need to understand the etiology of these lesions and to establish reliable criteria by which surgeons can predict the risk of rupture and thus the need for operation (Austin et al., 1993). Besides that, the infection can lead the body to wide ill-ness. The greatest danger of an aneurysm is rupture, which is often a fatal event.

Cerebral aneurysms are frequently observed in the outer wall of curved vessels. They are found in the internal carotid artery, near the apex of bifurcated vessels includ-ing the anterior communicating artery (ACA), anterior cerebral artery and the middle cerebral artery (MCA). Cerebral aneurysms disease has been reported to affect around one to five percent of the population.

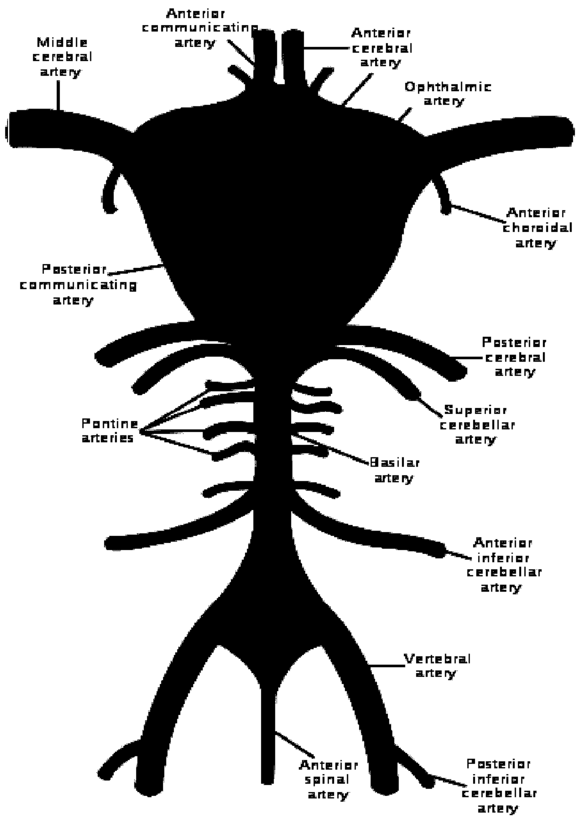

Figure 1.1: Circle of Willis

Source: Paal et al., 2007

Although many cases of this disease are unruptured, the catastrophic consequences of subarachnoid hemorrhage (SAH) following rupture of cerebral aneurysms make optimal treatment of patients. Rupture of a cerebral aneurysm can be dangerous for a patient and occurs most commonly between 40 and 60 years of age. When an aneurysm ruptures, blood leaks from the ruptured wall into the subarachnoid space, or the brain itself, potentially causing serious damage. Aneurysm growth and rupture depends on multiple factors; geometrical factors such as aneurysm size and shape or the ratio of the aneurysm dome height to the neck width, biological factors such as decreased concentration of structural proteins of the extracellular matrix in the intracranial arterial wall; and hemodynamic factors, especially wall shear stresses

Aneurysms come in a variety of shapes and sizes. The most common type is a berry aneurysm as shown in Figure 1.2 and Figure 1.3. It is round likes a berry and connected to the artery by a stem or neck. There are two general types of aneurysms, fusiform and saccular. A fusiform aneurysm is spindle-shaped without a neck. The saccular aneurysms are the most frequent cerebral aneurysms showing a berry like outpouching of the vessel wall: they often develop at the curved side of the vessels or at the apex of bifurcations. A giant aneurysm is like a berry aneurysm, but it is large about one and half inches or three centimeters or more in diameter.

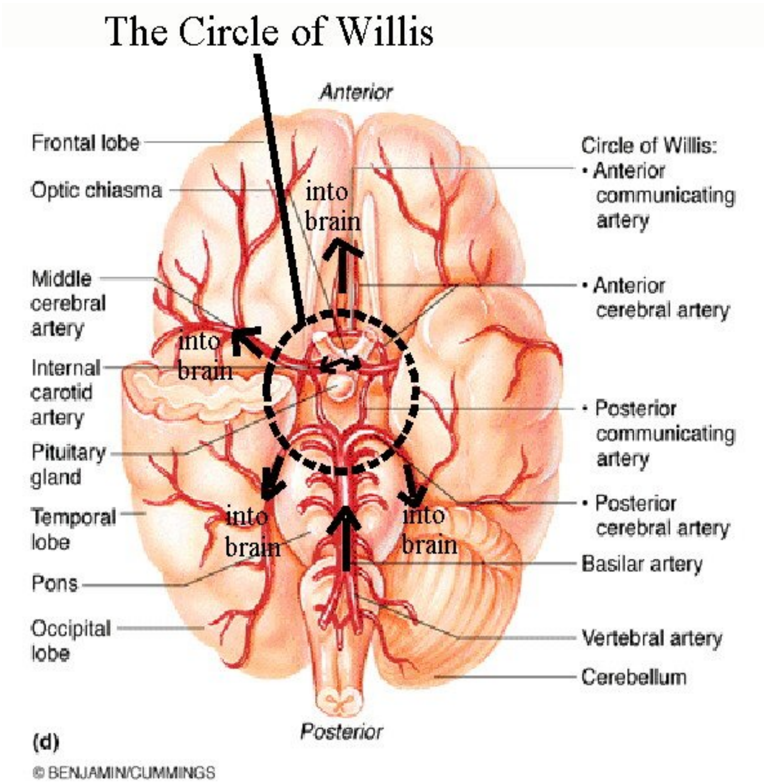

Figure 1.2: Circle of Willis

Source: Paal et al., 2007

1.2 ANEURYSMS

Aneurysms are blood-filled dilation (balloon-like bulge) of a blood vessel caused by disease or weakening of the vessel wall. Aneurysms most occur in arteries at the base of the brain (the circle of Willis) and in the aorta (the main artery coming out of the heart, a so-called aortic aneurysm). A sign of an arterial aneurysm is a pulsating swelling that produces a blowing murmur on auscultation (the act of listening for sounds in the body) with a stethoscope.

There are four main locations where aneurysms always happen that are Cerebral Aneurysms or Brain, Aorta Aneurysms, Abdominal Aneurysms and Thoracic Aortic Aneurysms. As the size of an aneurysm increases, there is an increased risk of rupture, which can result in severe hemorrhage or other complications including sudden death. Severe bleeding can occur if the aneurysms break or rupture. Not all aneurysms are life-threatening. But if the bulging stretches the artery too far, this vessel may burst, causing a person to bleed to death. An aneurysm that bleeds into the brain can lead to stroke or death. Aneurysms usually appear in either fusiform or saccular as shown in Figure 1.3.

A fusiform aneurysms is spindle shaped without a neck. While, the second type of aneurysms is saccular. The saccular aneurysms are the most frequent cerebral aneurysms showing a berry like outpouchings of the vessel wall: they often develop at the curved side of the vessels or at the apex of bifurcations.

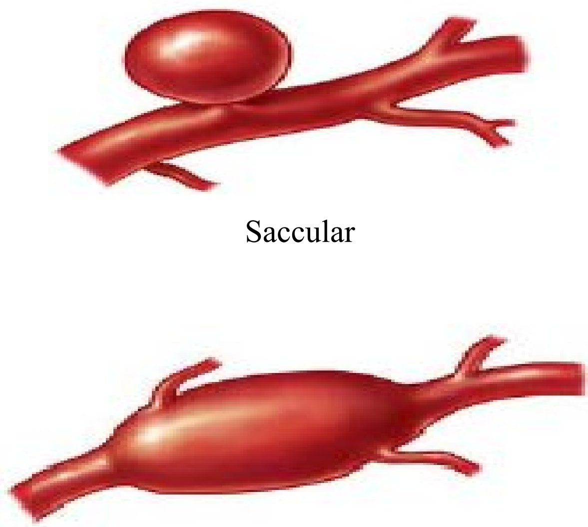

Figure 1.3: Types of Aneurysms

Source: Paal et al., 2007

1.2.1 Symptoms of Cerebral Aneurysm

Symptoms will depend upon the location of the aneurysm. Common sites that aneurysms occurred include the abdominal aortic artery, the intracranial muscles (supplying blood to the brain), and the aorta (supplying blood to the chest area). Many aneurysms are present without symptoms and are discovered by feeling or on x-ray films during a routine examination. When symptoms occur, they include a pulsing sensation, and there may be pain if the aneurysm is pressing on internal organs. If the aneurysm is in the chest area, for example, there may be pain in the upper back, difficulty in swallowing, coughing or hoarseness. A ruptured aneurysm usually produces sudden and severe pain, and depending on the location and amount of bleeding, shock, loss of consciousness and death. Emergency surgery is necessary to stop the bleeding.

In some cases, the aneurysm may leak blood, causing pain without the rapid deterioration characteristic of a rupture. Also, clots often form in the aneurysm, creating danger of embolisms in distant organs. In some cases, the aneurysm may dissect into the wall of an artery, blocking some of the branches. Dissecting aneurysms usually occur in the aortic arch (near its origin, as it leaves the heart) or start in the descending thoracic portion of the aorta after it gives off the branches to the head and arms. Symptoms vary according to the part of the body that is being deprived of blood; they are usually sudden, severe and require emergency treatment.

1.2.2 Risks of Aneurysm

It is not clear exactly what causes aneurysms. However some theories and risk factors had been defined. The condition that causes the walls of the arteries to weaken can lead to an aneurysm.

i. Genetic factor.
ii. Smoking
iii. High blood pressure
iv. High cholesterol
v. Gender factor. Male gender is likely to have aneurysm than female.

vi. Obesity

Aneurysms develop slowly over many years and often have no symptoms. Sometimes people do not realize they have an aneurysm that can lead to rupture. The symptoms of rupture include:

i. Abdominal mass
ii. Abdominal rigidity
iii. Headache
iv. Anxiety
v. Clammy skin
vi. Nausea and vomiting
vii. Pain in the abdomen or back, severe, sudden, persistent, or constant.
viii. Ringing in the ears
ix. Pulsating sensation in the abdomen
x. Rapid heart rate when rising to a standing position
xi. Shock

1.3 PROBLEMS STATEMENT

Nowadays, the case of rupture of celebrals is increasing every years and it often occurs without any preceding symptoms. The rupture occurs when the stress acting artery on the brain exceeds the strength of the artery wall itself. It was necessary to establish reliable criteria of the rupture risk assessment procedures in cerebral for these lesions, and criteria based on the mechanical field. Besides that, the prediction of rupture happens is not available yet. The stress distribution caused by pressure in the artery is one element factor that influenced the rupture of aneurysm. So it was necessary to study the behavior of these elements to better understanding of aneurysms.

1.4 OBJECTIVE

The objectives of this research are;

- To determine maximum displacement at the wall cerebral aneurysm.
- To determine stress distribution in cerebral aneurysm.
- To determine the maximum pressure in the cerebral aneurysms.

1.5 PROJECT SCOPE

This project is to investigate the condition of wall ruptured in cerebral with ADINA software. A model of cerebral with shape was created with geometry in 3D. The flow and structure of model of cerebral aneurysm are analyzed by using Fluid-Structure Interaction of ADINA software. The flow in cerebral, only the aneurysm from artery brain area were selected. For this case, the project is focused on steady state of analysis of fluid structure iteration.

CHAPTER 2

LITERATURE REVIEW

2.1 CEREBRAL ANEURYSMS

Arterial aneurysms are localized dilatations of blood vessels caused by a congenital or acquired weakness of the media. A variety of characteristic geometries can be distinguished. In the cerebral arteries the most common type is the saccular aneurysm, having a bubble-like geometry. Most cerebral aneurysms are asymptomatic and therefore remain undetected (Johnston, 2002). Autopsies have revealed that many as 25% of the population older than 55 years undetected saccular aneurysms are found (Rubin and Farber,1999). In the general population approximately 5% is likely to harbor these aneurysms and 15-20% of these persons have multiple lesions (Kyriacou, 1996; Lieber et. al., 2002). Cerebral aneurysms are highly uncommon in people younger than 20 years and very common in older people, especially above 65 years old (Lieber et al., 2002). This indicates that not every aneurysm is life threatening. However, rupture of an intracranial aneurysm results in subarachnoid hemorrhage (SAH), with 35% mortality during the initial hemorrhage (Rubin et al., 1999). In case of subsequent hemorrhage the prognosis is even worse. A total 50 to 60% of the patients with SAH will die or suffer severe morbidity (Lieber et al., 2002). Not more than one third of the patients eventually return to their previous occupation due to severe neuropsychological disabilities (Lieber et al., 2002).

According to (Koivisto et al., 2000) no significant difference was detected in the outcome one year after surgical or endovascular treatment of ruptured cerebral aneurysms. The first outcomes of the ongoing International Subarachnoid Aneurysm Trial (ISAT), a large scale trial on ruptured aneurysms involving 42 centers in Europe and America, reported that the relative risk of death or significant disability for endovascular patients is 22.6% lower than for surgical patients. In unruptured aneurysms coil embolization resulted in significantly less complications than surgical clipping (Johnston, 2000).

The decision whether intervention is recommended depends on the balance between the risk of rupture and the risk related to the intervention itself. The mechanical properties and loading state of the arterial wall are most important in the determination whether rupture of the aneurysm is a serious threat. Since both parameters not be determined adequately *in vivo*, accurate estimation of the risk of rupture is not possible yet. At present, the risk of rupture is mainly associated with the maximum dimension of the lesion even though there is controversy over the 'critical size' (Kyriacou et al., 1996).

The loading state of the arterial wall depends on the pressure load and shear stress. In contrast to shear stress, the pressure load is similar throughout the arterial system. The shear rate introduced by intra-aneurysm blood flow is known to affect the endothelial cells covering the lumen. This induces adaptation, or in aneurysms, degradation of the arterial wall. Since the shear rate can be determined from the intra-aneurysm flow, the development of efficient methods for *in vivo* flow measurements is of interest. X-ray systems have great potential in becoming an important non-invasive method to determine the flow properties (Kyriacou et al., 1996). However, injection of contrast agents is required in X-ray flow visualization techniques. Knowledge on the influence of these injections is indispensable for proper interpretation of the X-ray images, and can be acquired via computational studies. As the intra-aneurysm flow patterns are complex, *in vitro* validation is needed to obtain insight in its accuracy and limitations. Recent studies have introduced Fluid Structure Interface (FSI) simulations using isotropic wall properties to map regions of stress concentrations developing in the aneurismal wall as a much better alternative to the current clinical criterion Detailed hemodynamic in cerebral aneurysms have been investigated experimentally and computationally to understand better the mechanisms contributing to the aneurysm progression (Kyriacau et al., 1996). However, the mechanisms causing aneurysm still remain to be unveiled. One of the main findings regarding aneurysm hemodynamic so far is the sensitivity of the blood flow to the vascular morphology. In addition using FSI analysis from the previous study, dynamic change in vascular morphology and hypertensive blood pressure, which is one of the risk factors in subarachnoid hemorrhage, affects the hemodynamic. Thus, the importance of FSI in cerebral aneurysms is still debated because the human intracranial arteries are stiffer than the other arteries (Paal et al., 2007), and it was asserted in an earlier computational angiographical study that the impact of vascular motion on the hemodynamic is not crucial.

2.2 FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis is a powerful computer-based tool widely used by engineers and scientists for understanding the mechanics of physical systems. Finite element analysis consists of a computer model of a material or design that is stressed and analyzed for specific results. Mathematically, the finite element analysis is used for finding approximate solutions of partial differential equations as well as of integral equations. In order to present unlimited degrees of freedom of structures by limited degrees of freedom, the structures are divided into many elements (Rachel et al., 2007). These elements are connected by joint called node and make a grid named mesh. Several modern finite element packages include specific components such as thermal, fluid flow, electrostatic and structural working environments.

Generally, there are two types of analysis that is two-dimensional and three-dimensional analysis. The structural of finite element analysis usually consist either linear or nonlinear and it does generally characterize the elements. Usually finite element models contain tens of thousands and possibly hundreds of thousands of elements, resulting in hundreds of thousands of simultaneous equations (Venkatasubramaniam et al., 2004). Usefulness of the finite element analysis result depends highly on the pre-processing stage. Thus, defining an appropriate physical model (mathematical model, geometrical simplifications, material properties, boundary conditions and loads) and an adapted mesh in accordance with simulation goals is a very difficult and time-consuming task. In practice, the modeling assumptions are still mostly based on the user's experience (Bellenger et al., 2008). By using this tool, it