A study of computational modeling of abdominal aortic aneurysm

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ABSTRACT

Abdominal Aortic Aneurysm is caused by changes to the blood flow pattern due to the change of the elasticity and shape of the blood vessel. This type of aneurysm had been placed at the 10th highest cause of deaths of white males aged between 65 and 74 in the U.S.A, in the year of 2000.(National Center for Health Statics)

Abdominal Aortic Aneurysm is generated due to the unbalance of the enzyme which controls the aortic wall. The continuing expansion of the aortic wall drastically increases due to the mechanical quality change of the vessel. And ruptures occur, ultimately.

The cause of aneurysm has not been known exactly yet, but smoking is being given attention as the largest cause. And other causes are hypertension, family history and gender in statistically.

This study analyzes blood flow patterns and observed the movement changes according to the diameter of the abdominal aortic aneurysm. It was confirmed that as the expansion part gets larger, the blood flow focuses on the top of the expansion part. And the flow velocity at the bifurcation point which connects to the common iliac artery increases.

In this study, we tried to specify the process element of the abdominal aortic aneurysm based on the analysis results, that the increase of the expansion part due to the aneurysm was viewed as change of the blood flow.

Keywords: Velocity Profile, Blood Flow Patterns, Abdominal Aortic Aneurysm (AAA), Computational Fluid Dynamics

1. INTRODUCTION

The Aorta is the largest artery of human body, an important organ which carries the necessary elements such as oxygen and nutrients throughout the body in the cardiovascular system from the heart to the peripheral vessels.

The abdominal aorta is the last part of the aorta, following the vertebra in the chasm of the diaphragm to the front of 4th lumbar vertebra and branches to the iliac arteries. (*Medifocus Guidebook*, Abdominal Aortic Aneurysm, Medifocus.com, Inc., 2008).

Abdominal Aortic Aneurysm, which is one of major blood vessel diseases as a cause of death in the cardiovascular system, is a disease which is generated by the expansion of part of the abdominal aorta. If the vessel is ruptured, it can lead to death. According to the statistics published by U.S. National Center of Health Statistics in 2000, deaths by abdominal aortic aneurysms and artery incisions are 15,810, and the cause of the deaths was ranked at the 10th among the people aged between 65 and 74 (Anderson RN, 2002).

In general, the diameter of the abdominal aorta is 1.7-2.4cm, depending upon genders and ages. The abdominal aortic aneurysm is when a lesion is 50% larger than the normal diameter. Generally, it is abdominal aortic aneurysm of expansion size is 3cm or larger.

This study analyzes the blood flow patterns according to the change of the diameter of the abdominal aortic aneurysm, thus observing the flow in the expansion part through a symmetrical shape. And we obtain the flow trend which was depends on the diameters based on the result.

2. MATERIALS AND METHODS

2.1. Abdominal Aortic Aneurysm Size

Aneurysm can be formed anyplace in blood vessels, but mainly in the aorta. An aneurysm is an abnormal expansion of an artery with an increase of greater than 1.5 times the normal diameter. The aneurysm which is formed in the lower part of the renal artery is called the abdominal aortic aneurysm (Fig.1) (William H Pearce 2007).

The cause of the abdominal aortic aneurysm has not been exactly known, but various factors are suspected.

The strongest risk factor is smoking. About 90% of the patients with abdominal aortic aneurysm had smoked or were smoking. Smoking results in the increase of the process rate of aneurysm, and the rate is higher among males than females. Family history of abdominal aortic aneurysm is asked in the diagnosis, and determines its connection with the disease process (*Medifocus Guidebook*, Abdominal Aortic Aneurysm, Medifocus.com, Inc., 2008)(Frank A 1997). Other causes of the AAA are hypertension,

Table 1: Relationship of expansion size to rupture in 473 non-resected abdominal aortic aneurysm

Size(cm)	Ruptured	Unruptured	Total	% Ruptured
≤ 5.0	34	231	265	12.8
> 5.0	78	116	194	40.0
No size recorded	6	8	14	43.0
Total	118	355	473	24.9

previous vascular surgery, chronic obstructive pulmonary disease, etc.

The size of the expansion is the priority factor for the determination of surgery. It is judged that as the expansion diameter increase, the possibility of rupture increase (*Medifocus Guidebook*, Abdominal Aortic Aneurysm, Medifocus.com, Inc., 2008).

The rupture risk based on the diameter of 5cm showed that 12.8% for up to 5cm, 40.0% for 5cm or larger, about a three times higher (Table 1) (Darling, R.C. 1977). The rupture risk is different depending upon situations, but it is confirmed that if the size is 5cm or larger, the risk increases rapidly. The relationship between the size of AAA and rupture is reported every year based on clinical cases, and there are various engineering approaches to it.

In this study, we have gradually increased maximum diameter of the abdominal aortic aneurysm, from 17mm to 64mm, based on standard model (Fig. 2) Blood vessel model was designed as a cylindrical form, and incremental ratio were applied as a maximum diameter of each model (Fig. 3)

2.2. Blood Flow in Abdominal Aorta

Aneurysm can be formed anyplace in blood vessels, It was assumed that the blood is an incompressible newtonian fluid, and the blood density which changes according to changes of pressure.

Figure 1: Abdominal Aortic Aneurysm CT image

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Table 2: Parameters of the abdominal aortic aneurysm

Parameters	Abdominal Aorta	Iliac Artery
Top Diameter	1.7cm	1.7cm
Bottom Diameter	1.7cm	1.1cm
Length	11.0cm	5.5 / 5.7cm (R / L)
Bifurcation Angle	-	52.45°
Center of Curvature	-	2.9 / 3.9cm (R / L)

The viscosity (μ) was determined as 0.003696 kg/m·s, and the normal state was assumed to solve the Navier-Stokes Equations.

The blood flow in the aorta goes in a certain shape, and is circulated to the iliac artery in a time-dependent similar shape. A certain wave form of blood flow is formed due to the difference between the pressures of the contraction and the release period. A physiologic wave form was composed for the analysis of the flows (Mette S. Olufsen 2000). To measure the mass flow by using MRI and ultrasound waves, studies assumed the relationship between section area and flow speed (Eq. 1).

$$Q_i(t) = A_i(t) \cdot V_i(t) \qquad \text{(Eq. 1)}$$

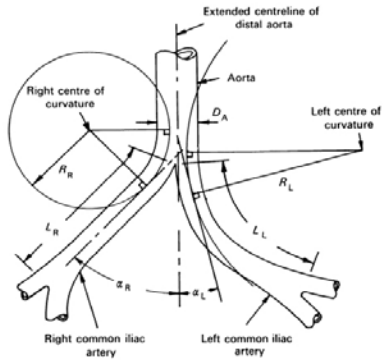


Figure 2: Standard model of abdominal aortic aneurysm

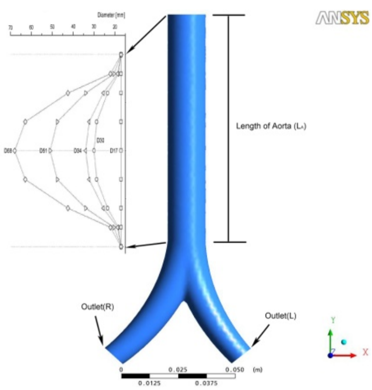


Figure 3: Diameter of each models

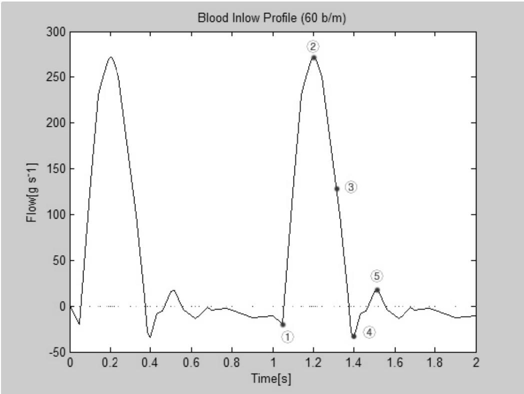


Figure 4: Adapted Blood Inflow Profile

①:1.05s(50ms), ②:1.20s(200ms), ③:1.30s(300ms)

④:1.40s(400ms), ⑤:1.52s(520ms)

The Mass Flow Profile, obtained from the model of the blood vessel tree structure, was applied to the movement model (Mette S. Olufsen 2000) (Fig. 4).

Fig. 5 shows variance of the blood flow dependent to time on abdominal aortic aneurysm, and the similar results were derived from the blood inflow profile as shown in Fig. 4 (Vieli A. 2000)

The average flow was 78.169 g/s, the period was 1.0s, and the heart rate was 60.

To suppose the continuing period of the input condition in simulation, two wave forms were applied, and the data of the only second one were used in the result.

2.3. Simulation of AAA

The geometry of the abdominal aorta based the values measured from 100 cadavers as the normal model (P.M.Shah 1978)(Irving Geller 1961), and each parameters are shown in Table 2.

In the model of the normal abdominal aorta without an expansion part, five models of from 1.7 up to 6.4cm were designed with symmetrical expansions

The diameter of expansion was determined as 3.0, 4.2, 5.3, 6.4cm. The initial 3.0cm is the ordinary size of an aneurysm. An aneurysm with a diameter of 6.4cm, about 3.8 times larger than the normal vessel model, was designed as the model of the greatest rupture risk.

3. RESULTS

3.1. Sectional Flow of the Abdominal Aortic Aneurysms

In this study, the geometry presented a symmetric model. To observe the flow movement, each sections were divided (Fig. 6-10). The upper part and lower part of Line 2 are divided as follows.

At 200ms, the flow draws a stream line according to the shape of the abdominal aorta. At the greatest diameter of expansion increases, the gaps of the steam

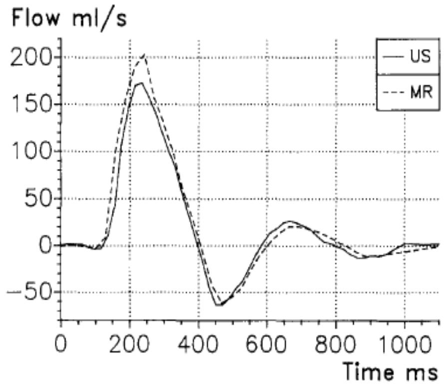


Figure 5: Flow curve (Vieli A. 2000)

tracking lines change. But other vortices are not observable in the aneurysms.

At 400ms, vortices are divided into the upper and lower part of Line 2. The greatest diameter of the expansion becomes 42mm or larger, the upper vortices were concentrated around the upper part of aneurysm. And as the diameter increases, the concentration of vortices becomes severer. The lower vortices can be formed due to bifurcation that is branches of iliac artery.

The bifurcation angle of both iliac arteries shows a little difference between the right and left, and the vortices generated thereby occur relatively more in the left iliac artery. Vortices, if severe, ascend to Line 2.

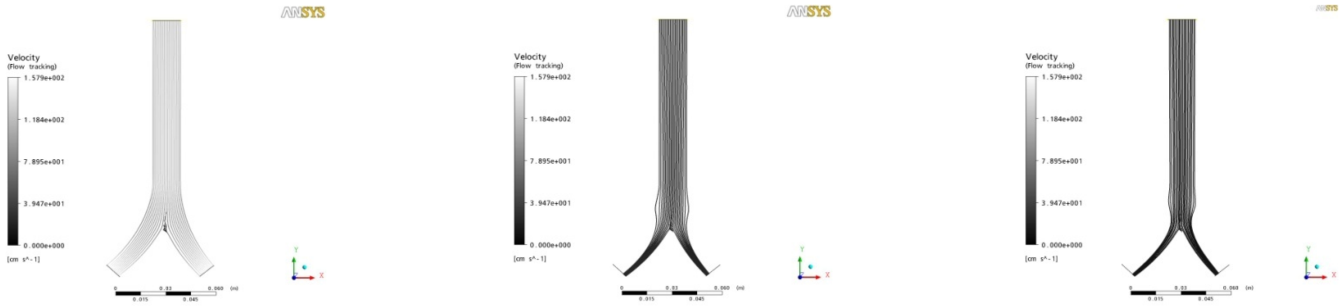
In each figure, at 200ms (a), the blood flows running the shape of the abdominal aorta, and at 400ms (b), vortices occur in the upper and lower parts. As the diameter increases, the vortices concentrate to the upper part.

In each figure, the lower vortices are disappeared at 520ms (c), and flows concentrate around the center of the bifurcation. The upper vortices show a concentrating more.

3.2. Sectional Flow Upper and Lower Line 2

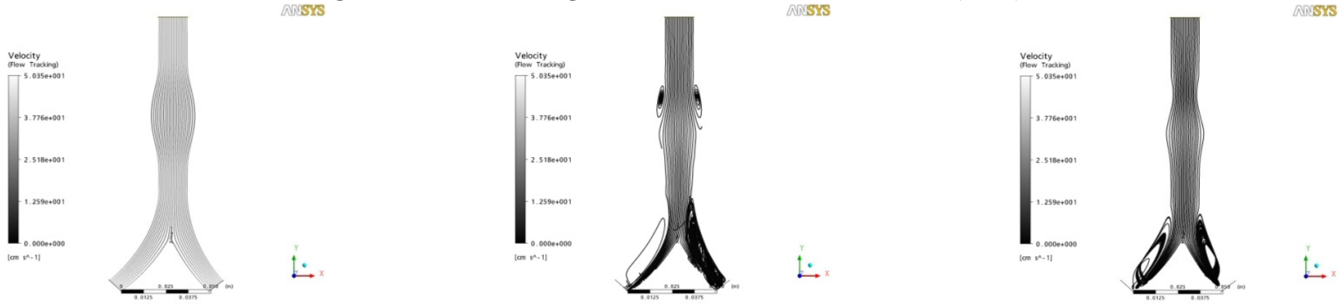
The flow in the lower part of Line 2 changes very fast as time passes, concentrated more to the right common iliac artery than the left. The flow at the bifurcation point runs in a different stream line as dispersing in both directions.

In the size of the expansion part increases, the flow under line 2 relatively shows a higher velocity in the left iliac artery than in the right. The shape of the flow at the bifurcation point affects the blood flow velocity entering into the iliac artery according to the size of the expansion of the abdominal aortic aneurysm. As the expansion size increases, the maximum flow velocity in the contraction period in the lower part of Line 2 increases (Fig. 11) (A. Vieli 1989).



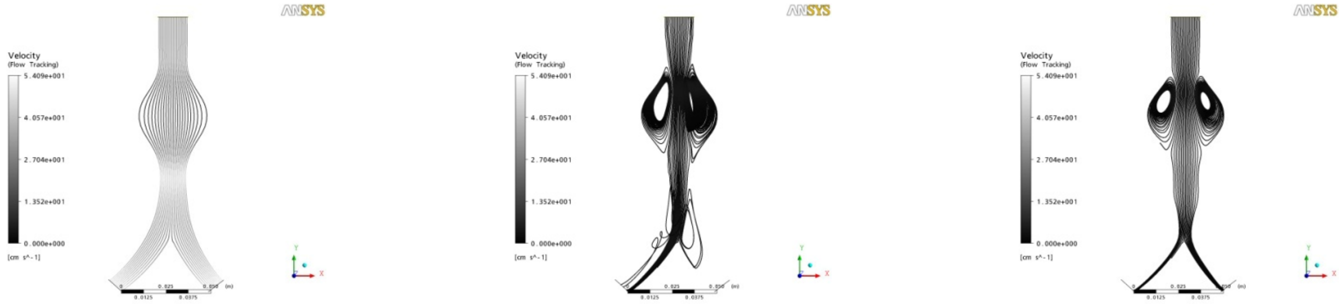
(a) 200ms (b) 400ms (c) 520ms

Figure 6: Flow Tracking Line of Normal Abdominal Aorta (D:17)



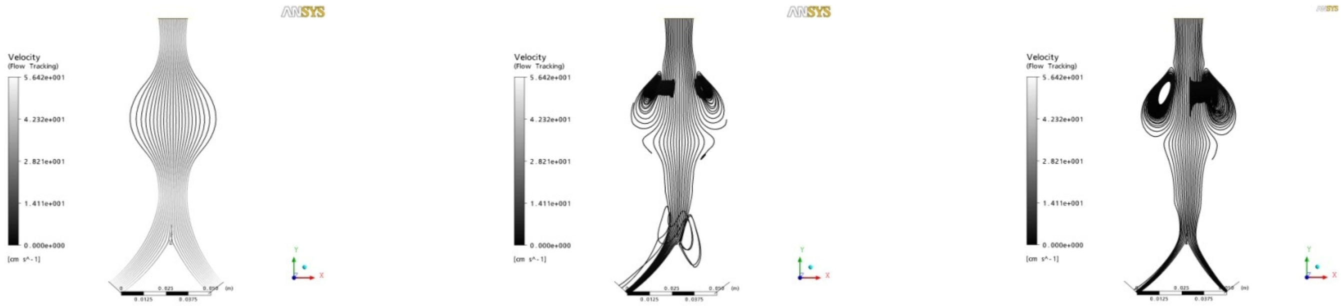
(a) 200ms (b) 400ms (c) 520ms

Figure 7: Flow Tracking Line of Normal Abdominal Aorta (D:30)



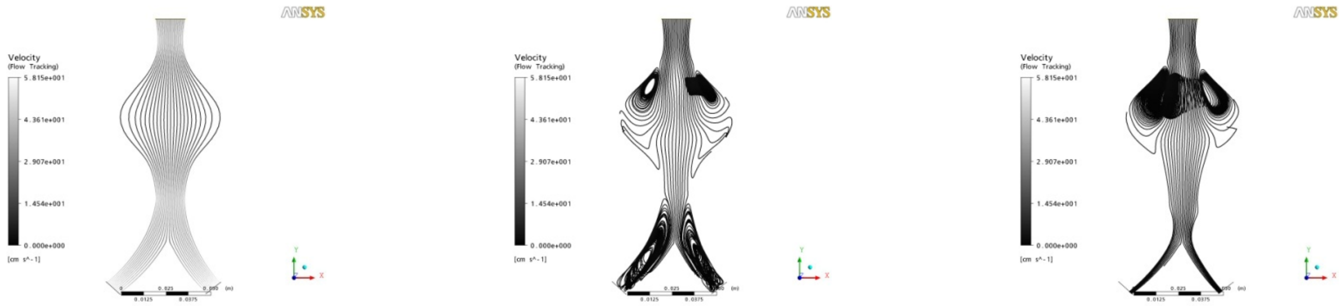
(a) 200ms (b) 400ms (c) 520ms

Figure 8: Flow Tracking Line of Normal Abdominal Aorta (D:42)



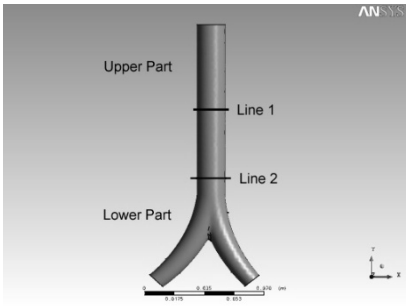
(a) 200ms (b) 400ms (c) 520ms

Figure 9: Flow Tracking Line of Normal Abdominal Aorta (D:53)

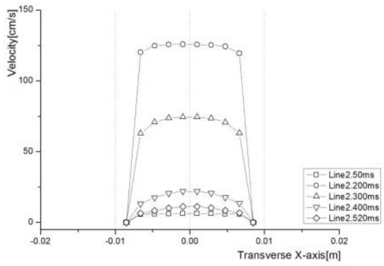


(a) 200ms (b) 400ms (c) 520ms

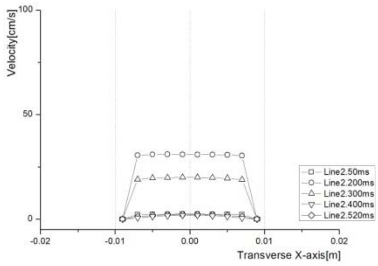
Figure 10: Flow Tracking Line of Normal Abdominal Aorta (D:64)



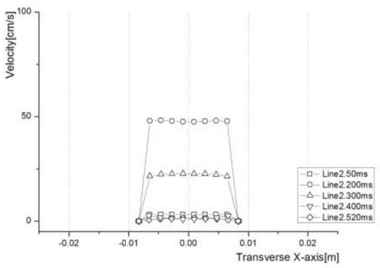
(a) Line 2 for midline velocity profile



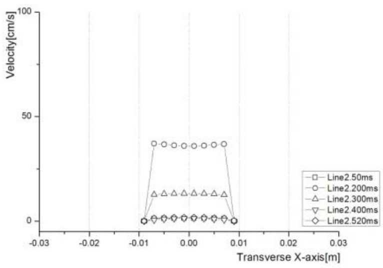
(b) at diameter 17mm



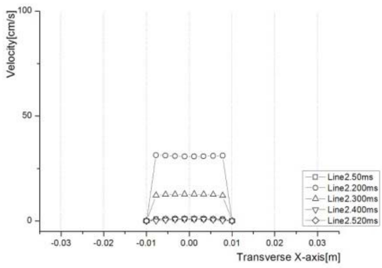
(c) at diameter 30mm



(d) at diameter 42mm



(e) at diameter 53mm



(f) at diameter 64mm

Figure 11: Velocity profile at line 2

4. CONCLUSION

When the blood flows in a vessel, the flow gets loss due to friction with the vessel wall, the change due to the size, shape, and direction of the section, and also due to changes of the entrance, exit and internal shape.

This study did not take into account thrombosis, plaque, vessel elasticity, vessel vibration by waves, etc., but observed only the flow as time passes in each section at expansions of different sizes.

The flow depended on time, the velocity and stream line changed in this study, are important factors for observing energy losses.

The flow stream in the upper and lower parts of Line 2 has great correlations with the expansion size and vessel section area of the abdominal aorta. The velocity change at a certain point becomes smaller as the vessel section area becomes larger.

This study formed symmetrical models to analyze the flow pattern of the abdominal aorta. And we observed the velocity change. As a result, the diameter change of the abdominal aortic aneurysm has great effect on flow, and as the diameter increases, vortices concentrate to the upper part. It is judged that a velocity change by initial vortices of an aneurysm can cause the expansion of the aneurysm.

5. DISCUSSION

In this study, we looked for the factors that related the process of an aneurysm by the flow of the upper expansion parts. The phenomenon that the velocity changes and vortices by diameter concentrated in the upper part is one of the factors which generate the process of an aneurysm in the symmetric geometry.

To realize a flow pattern in the aneurismal space, we used symmetric models. But the actual abdominal aortic aneurysm processes in an anterior asymmetrical shape due to the spinal cord. However, according to previous studies (David A. Vorp 2007)(Zhonghua Li 2007), flow concentrated in the upper part in the asymmetrical model. It is similar to us.

The change to the neck angel and thrombosis were found to be another factors to the process of the abdominal aortic aneurysm. In this study, the flow pattern by diameter change can predict the directional characteristic of the abdominal aortic aneurysm which processes through the abnormal shape.

For actual analysis, based on the analysis of the flow pattern by using symmetrical models, we are conducting an analysis of the flow patterns of the abdominal aortic aneurysm realized by CT, thereby specifying the process factor of the abdominal aortic aneurysm based on the shape like this.

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