Hemodynamic features of cerebral aneurysms that influence to rupture

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Cerebrovascular diseases are one of the three major mortalities, such as the rupture of cerebral aneurysm. The formation and growth mechanism of the cerebral aneurysm has not been clearly understood. Treatment decision of incidental intracranial aneurysms is complex. Currently, however, there is no certain quantitative method to eval- uate risk of rupture. We utilized Computational fluid dynamic (CFD) technology to understand difference of hemodynamic condition between stable unruptured aneurysms and those that ruptured during the observation that followed. The hemodynamic characteristics; energy losses (EL), were calculated under 100 aneurysms and the results indicated that there are more than five times difference from ruptured and unruptured aneurysms. According to flow visualization, the flow inside ruptured aneurysms appeared stronger impact on the aneurysm wall. On the contrary, the flow inside unruptured aneurysms passed smoothly and quickly through the aneurysms. The mean average recirculation time of ruptured aneurysm was two times higher than that of the unruptured ones. These results indicate that EL and recirculation time may be an useful parameter to quantitatively esti- mate the risks of ruptured of cerebral aneurysm.

Introduction

Cerebral aneurysms are pathological dilations of the arterial wall that frequently occur near arterial bifurcations. The most serious conse- quence is their rupture and intracranial bleeding into the subarachnoid space, with an associate high mortality and morbidity rate(1). Cere- brovascular diseases are one of the three major high mortalities. However, currently the prognosis methods for subarachnoid hemor- rhages (SAHs) are still not developed enough. The mechanism of cerebral aneurysm's genesis, growing, and rupture are not competi- tively understood. Although the evolution of cerebral aneurysms are affected by variety reasons; such as pathological, hemodynamic and other factors, a better understanding of the blood patterns pass through the aneurysm and physically analysis the progression of aneurysms vessel wall will provide to aneurysm surgery a lot of valuable references to understand relationship between the patho- physiological aspects and aneurysms progression depending on its geometry and local hemodynamics. It will be critically support aneurysm surgery to understanding aneurysm growth, preparing treatment, and predicting the risk of its regrowth after treatment.

The hemodynamic analysis of cerebral aneurysms have been developed using numerical and experimental methods(2). The rela- tionship between flow patterns and diseases development, particularly the WSS, have been motivated in several of the researches in recent years. However, most of the studies have focused on particularly wall shear stress (WSS), has been proposed for flow characterization of cerebral aneurysms. All these findings as an addition have no quan- titative expression and are difficult for use in predicting rupture. Therefore, the challenge for aneurysm's hemodynamic analysis using the computational numerical methods are; validation with large numbers and specific geometries of aneurysms from clinical records, specification the blood flow boundary conditions at performing vessel domain, and availability to create a predicting criterion to recognize the risk of cerebral aneurysm before rupture.

Our studies are to develop an efficient transfer system to convent the clinical image data into computational available vessel shape geometries, to computationally validate blood flow patterns, and as well to analyse flow characteristics (see Fig. 1).

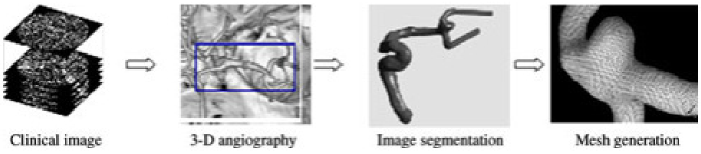

Fig. 1 A data transfer system for aneurysm geometry generation

Methods

Patient specific image data was segmented by using image DICOM format clinical image into three dimensional vessel surface format data. Image segmentation software was developed based on Insight Toolkit (ITK) and open source software 3DSlicer. The segmentation process was validated by using our in vitro mock circulation system. The STL format geometry was transferred into mesh generation software ICEM (ANSYS) to generate volume mesh for fluid simu- lation. The flows in this study was assumed as an incompressibility, Newtonian and laminar flows. Navier-Stocks governing equations solved basing on Finite Volume Method (FVM), was introduced as a main solver. All simulations were performed under a personal com- puter. The silumated results were validated by PIV measurements.

The energy (E) was calculated follow equation. The simulations of the non-aneurysm cases were carried out with the same flow condi- tions as that of the with-aneurysm cases.

$$E = \left(P_i + \rho \frac{1}{2} v_i^2 \rho g h_i\right) Q_i - \left(P_o + \rho \frac{1}{2} v_o^2 \rho g h_o\right) Q_o$$

where, using Bernoulli's equation, E [W] is energy calculated from total pressure in the artery domain inlet and outlet at the average of heart pulse. The EL was calculated by difference between with and non-aneurysm.

Results

In Fig. 2. A high speed recirculation and flow attachment on the bleb can be observed around the bleb edge. In generally, the bleb on aneurysm is judged as one of highest risk at cerebral aneurysm clinical diagnose. From observations of the flows within aneurysms, the flow pattern appeared very complex, with the occurrence of jet flows, swirling and separating flows, and flow attachment. This hemodynamic energy transfer is assumed to be one of the major factors in the development, growth and final rupture of aneurysms. The EL for ruptured aneurysms was around 5 times (p \ 0.001, N = 100) higher than for unruptured (Fig. 3). The energy loss might be transferred into physical stimulus, force and stress, to load on the pathological aneurysm surfaces.

Conclusions

A new approach using EL to estimate the risk of aneurysm rupture was performed by hemodynamic simulation. Flow energy loss in aneurysms was significantly different between ruptured aneurysm and unruptured aneurysm.

References

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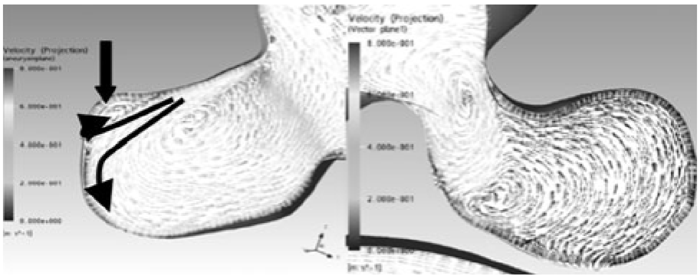

Fig. 2 Blood flows aneurysm (*ruptured right, unruptured left*)

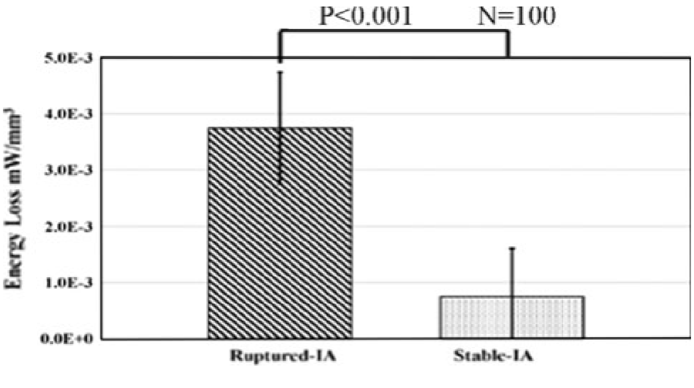

Fig. 3 Energy loss