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Predicting the presence of degenerative changes in middle cerebral artery aneurysms using computational fluid dynamics

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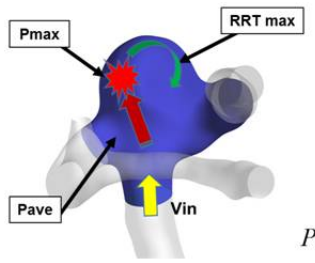
Introduction

Hemodynamic stresses play an important role in the generation, growth, and rupture of cerebral artery aneurysms. Thin-walled regions (TWR) and atherosclerotic regions (ASR) of the aneurysm dome represent areas of focal weakness that may lead to aneurysm rupture. Our group previously reported on the correlation of Pmax (spatial and temporal maximum pressure) and aneurysm dome TWRs as well as RRTmax (relative residence time) and ASRs in unruptured middle cerebral artery (MCA) aneurysms using computational fluid dynamic (CFD) analyses in a retrospective manner.

Methods

We validated the correlation of those abnormal hemodynamic parameters and degenerative wall regions in unruptured MCA aneurysms intraoperatively, and then focused on the characteristic of hemodynamic parameters on rupture points in ruptured MCA aneurysms by using CFD. Using 3-dimensional digital subtraction or computed tomographic angiography, PDmax and RRTmax were determined with a fluid-flow formula under pulsatile blood flow conditions. Maximum pressure (Pmax) was calculated as the highest area of pressure at the aneurysm wall, both spatially and temporally. Average pressure (Pave) was also calculated as the mean value of pressure in the domain. For comparisons of aneurysms, the pressure difference (PD) was defined as the degree of pressure elevation at the aneurysm wall at the Pmax area by subtracting Pave from Pmax. This value was divided by the dynamic pressure at the aneurysm inlet side for normalization. We calculated the relative residence time (RRT) introduced by Himburg et.al as a marker of low or oscillatory WSS. TWRs were identified as red and translucent areas of the aneurysm dome relative to healthy proximal parent vessels. ASRs were also identified as yellow areas. Surgical treatment and CFD analyses were performed separately, and the correlation between PDmax and TWRs, RRTmax and ASRs were assessed.

CFD analysis condition



Software	ANSYS CFX ver15.0
Working Fluid	Blood（Newtonian Fluid） Density 1,100 [kg/m3] Viscosity 0.0036 [Pa・s]
Inlet Condition	Pulsatile flow condition
Outlet Condition	Fixed static pressure（0 [Pa]）

$$Pd = \frac{P\,max - Pave}{\frac{1}{2}\rho\, V_{in}{}^2}$$

$$RRT = \frac{1}{(1 - 2 \times OSI) \times TAWSS}$$

Pmax: maximum pressure [Pa], Pave: average pressure [Pa], Density:1100 [kg/m3], Vin: mean velocity of the aneurysm inlet [m/s],RRT: maximum relative residence time [Pa],OSI: oscillatory shear index, TAWSS: time average wall shear stress [Pa]

Results

Between January 2016 and July 2016, 12 patients (10 unruptured, 2 ruptured) with MCA aneurysms underwent microsurgical clip occlusion. Based on CFD analyses, Pmax areas were identified in 6 unruptured aneurysms, 5 of which (83.3%; PD=1.24±0.62) were seen to correspond to TWRs during surgery (Figure 1). In addition, RRTmax areas were identified in 9 unruptured aneurysms, 7 of which (77.7%; RRT=5.43±5.65) were seen to correspond to ASRs during surgery. In the 2 ruptured cases, RRTmax (RRT=7.42, 36.67) areas corresponded with the presumed aneurysm rupture point (Figure 2).

Conclusions

Pmax and RRTmax areas may predict degenerative aneurysm walls. These factors may be critical in predicting aneurysm degeneration and ruptured risk, and CFD has the potential for clinical use in the treatment algorithm of cerebral aneurysms.

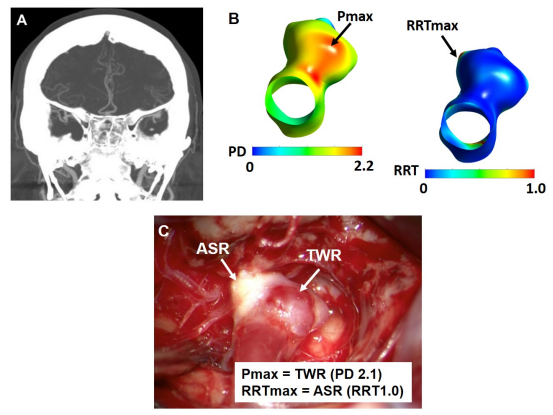


Figure1;Right MCA unruptured aneurysm, Pmax(PD=2.11), RRTmax(RRT=1.00)

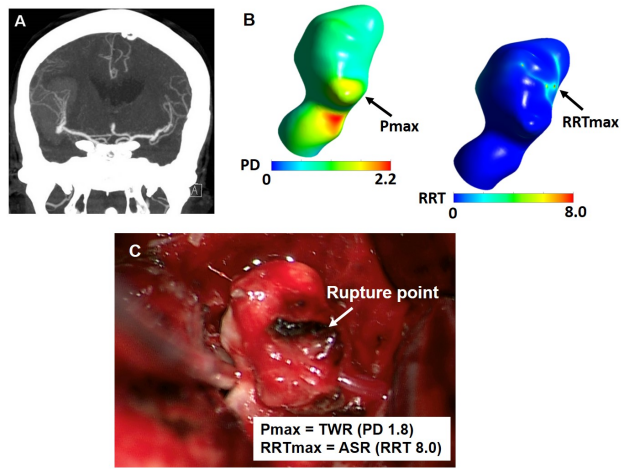


Figure2;Right MCA ruptured aneurysm, Pmax(PD=1.84), RRTmax(RRT=7.42)

References

·Suzuki T et.al Determining the Presence of Thin-Walled Regions at High-Pressure Areas in Unruptured Cerebral Aneurysms by Using Computational Fluid Dynamics. Neurosurgery.2016 Oct;79(4):589-95 ·Sugiyama S et.al Relative residence time prolongation in intracranial aneurysms: a possible association with atherosclerosis. Neurosurgery.2013 Nov;73(5):767-76