Understanding the Dangers of Aneurysms

Simulation is used to validate measured blood flow in cerebral aneurysms.

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Cerebral aneurysms are arterial outpouchings in the brain that result from weak spots in the vessel wall. 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. This may lead to major permanent neurological deficits or even death. While it is estimated that approximately 3 percent to 6 percent of the general population have cerebral aneurysms, there is a rupture in only eight in approximately 100,000 person-years. The overall prognosis is poor for the patients with aneurysm rupture — 50 percent will die one month after rupture and an additional 20 percent will be unable to live on their own.

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. While patients with unruptured aneurysms may have symptoms such as headache, peripheral visual deficits, loss of balance and coordination, or other neurological deficits (depending on the location of the aneurysm), often cerebral aneurysms are asymptomatic, especially if they are small in size.

When an aneurysm is detected, treatment options other than conservative management include surgical clipping or minimally invasive therapy that approaches and occludes, or blocks, the aneurysm using endovascular techniques. Both treatment options are associated with an overall morbidity and mortality of about 11 percent. Because not all aneurysms will rupture and bleed, it would be highly beneficial to understand the underlying mechanisms that lead to rupture in order to minimize risk to the patient. Currently, there is no medical imaging modality that can provide complete quantitative information about hemodynamic parameters, such as wall shear stresses and dynamic pressure.

In order to better understand the dynamic forces of blood flow within an aneurysm and the conditions that may cause rupture, an interdisciplinary team of researchers at The Methodist Hospital Research Institute (TMHRI) in Houston, Texas, is studying hemodynamics using computational fluid dynamics (CFD) simulations with FLUENT software.
specifically, this group has performed unsteady computational fluid dynamics simulations of an anterior communicating artery (AComA) aneurysm and has calculated pathlines and velocity profiles at different time points in the cardiac cycle. The results obtained with the CFD analysis were compared with blood velocity measurements performed using phase-contrast magnetic resonance imaging (pcMRI), a noninvasive imaging technique that allows the visualization of velocity patterns of flowing blood and the quantification of the volumetric blood flow rate.

At first, researchers created a stereolithographic (STL) file of the surface of an AComA aneurysm. This model was based on both a 3-D dataset of the cerebral vasculature of the patient acquired with time-of-flight magnetic resonance imaging (MRI TOF) and a 3-D dataset acquired with digital subtraction angiography (DSA). Afterward, this STL file was imported into GAMBIT software and the model was meshed using 61,663 tetrahedral volume elements.

Researchers then defined inflow boundary conditions as velocity inlets and outflow boundary conditions as pressure outlets. The values of the volumetric flow rate for inflow into the aneurysm were based on the volumetric flow rate waveform measured with pcMRI in combination with the noninvasive optimal vessel analysis (NOVA) system, a technology for the quantification of volumetric blood flow rates. Also, researchers recorded the outflow of the aneurysm and velocity profiles inside the aneurysm at two perpendicular planes, or cross sections, using the same technique.

For the CFD simulation, blood was modeled as an incompressible Newtonian fluid with a density of 1,050 kg/m³ and a viscosity of 0.004 kg/ms. To ensure elimination of initial transients in these unsteady cases, the researchers simulated five cardiac cycles. Results are reported from the fifth cardiac cycle. Mathematical cross sections were defined inside the CFD mesh at the same locations at which the velocity profiles were measured using the NOVA system. The CFD simulation illustrated the pathlines in the aneurysm during average inflow and also showed a swirling motion of the flow inside the aneurysm, a flow pattern that is typical of these vascular pathologies.

The CFD results showed the same main features in the velocity profiles as the ones measured with pcMRI. Regions with opposite directions of blood flow velocity could be identified in both the profiles measured with pcMRI and the cross sections derived from the CFD simulations. These regions reflect the multi-directionality of the blood flow inside the aneurysm, corresponding to the rotational flow motion. The absolute values of the measured velocities were lower than the ones calculated with CFD in both cross sections, a fact that most likely is due to an inherent measurement uncertainty caused by partial volume averaging, in which the MRI signal is averaged over the slice thickness of the scan plane (5 mm), while the CFD cross sections are mathematical planes with zero thickness.

In conclusion, the TMHRI group showed that the velocity values calculated inside a cerebral aneurysm by CFD with patient-specific input boundary conditions were in good qualitative and quantitative agreement with actual velocity values measured with pcMRI and NOVA. These results are encouraging and point to the huge potential of CFD simulations to better understand the hemodynamic effects in cerebral aneurysms that lead to rupture so as to assist in making clinical decisions about the need for surgery.