

Blood Flow through Cerebral Aneurysms

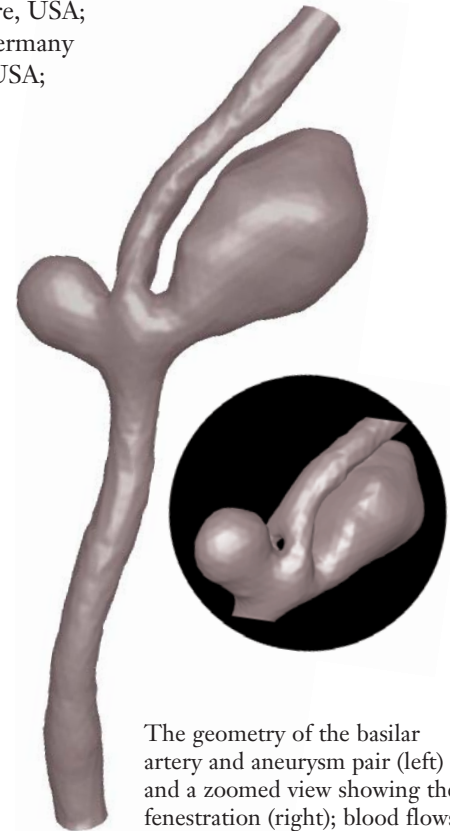
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During the past twenty years, high quality diagnostic imaging equipment has become a common fixture in medical centers. Today it is not uncommon for a doctor to order a brain scan for a patient complaining of dizziness or persistent headaches. One unanticipated outcome of the increase in brain scan procedures is that more cerebral aneurysms are being detected than ever before, forcing doctors and patients to make difficult decisions about whether or not to treat them. Among cerebral aneurysms, some clearly do not pose a health risk to the patient and some clearly do. Unfortunately, the largest group of aneurysms falls somewhere in between.

The use of CFD is now being explored by a few groups of medical researchers around the world to see if it can provide guidance for surgical intervention decision-making in some of the more questionable cases.

A group has formed in Lebanon, NH involving researchers from the Dartmouth Hitchcock Medical Center,

MMS (a medical imaging company), Dartmouth College, and Fluent Inc. to see if CFD can help assess the risk of rupture of patient-specific cerebral aneurysms. Brain scans are performed at the medical center using either CT (computed tomography) or MR (magnetic resonance) imaging. If an aneurysm is present, the MR or CT data is passed to MMS, where it is converted to a special geometry format. That geometry is then passed to staff at Fluent and Dartmouth to construct a CFD mesh and obtain a flow solution. Characteristics of the flow field are then collated with the knowledge of whether or not the aneurysm ruptured. After dozens of cases have been studied, it is hoped that one or more links can be drawn between the CFD results and the actual patient outcomes.



The geometry of the basilar artery and aneurysm pair (left) and a zoomed view showing the fenestration (right); blood flows from bottom to top



Pathlines colored by fluid pressure illustrate how the fenestration causes a bottleneck to the flow that extends, by way of increased pressure, into both aneurysms

One finding is that the flow pattern in any given aneurysm does not appear to change much during the cardiac cycle. It does increase in strength, however, as the blood pressure and associated flow rate fluctuate between the maximum (systole) and minimum (diastole) values. This finding means that a steady-state calculation of the flow field at systole is about the same as a transient calculation that leads to this condition after one or two cardiac cycles. Thus, a larger number of aneurysms can be studied using a steady calculation at maximum flow rate than would be possible if transient calculations were required.

Another finding, and perhaps the most intriguing one so far, is that it is not simply the size and shape of the aneurysm that matters. Instead, the morphology of the network of vessels upstream of the aneurysm also seems to play an important role. Consider, for example, the aneurysm pair shown on these pages. The aneurysms, 5 and 13mm in size, were detected on either side of the basilar artery, which enters the brain near the spine. Closer inspection reveals that there is a hole, or fenestration, in the basilar artery, which is just visible from the side.

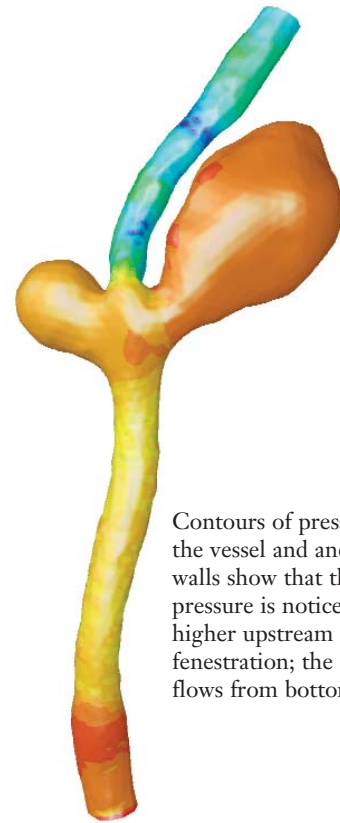
The fenestration causes increased pressure in the upstream artery, and may have been the cause for the aneurysms to develop in the first place. Pathlines, colored by the time of transit of the fluid, suggest that some of the blood enters the large aneurysm first, after which it either reenters the vessel or passes to the smaller aneurysm. If the pathlines are colored by the fluid pressure, the sudden drop in pressure as the blood

passes the fenestration becomes very apparent. Clearly, the fenestration causes a bottleneck in the flow field that causes increased pressure everywhere upstream of it.

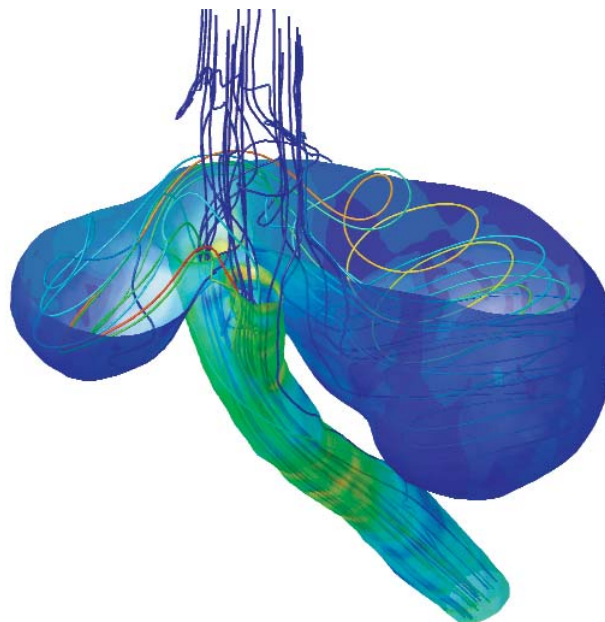
CFD graphics can also be used to examine the flow from inside the vessel. From this view, the solid boundary in the middle of the vessel and its effect on the local flow field can be seen more clearly.

The use of CFD and analysis techniques such as these will hopefully someday allow medical professionals to determine if an aneurysm is at risk of rupture. Other flow-related qualities are also being assessed by the team, such as the importance of wall shear stress and the shear-thinning property of blood. Plans are also underway to model the growth of an aneurysm and to examine the importance of wall motion. ■

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Contours of pressure on the vessel and aneurysm walls show that the pressure is noticeably higher upstream of the fenestration; the blood flows from bottom to top



A cutaway view of the aneurysm from the upstream side (with blood flow from top to bottom) shows wall shear stress in the vicinity of the fenestration; pathlines colored by residence time show circulating flow in the aneurysms