

COMPARISON OF THE PERFORMANCE OF NOVEL ENDOVASCULAR TREATMENT TECHNIQUES FOR CEREBRAL ANEURYSMS

Gábor Cantón*, Juan C. Lasheras*, David I. Levy**

**Department of Mechanical and Aerospace Engineering, University of California, San Diego, USA*

***Department of Neurosurgery, Kaiser-Permanente Medical Center, San Diego, California, USA*

Summary

Cerebral aneurysms result from a complex interplay between mechanical stresses and pathophysiological changes occurring in the arterial wall. In order to reduce the hemodynamic forces acting on the aneurysmal wall, new endovascular treatments have been developed involving the exclusion of the aneurysm from the intracranial circulation. A comparative study of the performance of three of these techniques is reported here. Digital Particle Image Velocimetry (DPIV) is used to perform in vitro measurements of the velocity and stress fields inside a model of cerebral aneurysms.

BACKGROUND ON CEREBRAL ANEURYSMS

Cerebral aneurysms result from the abnormal dilatation of one of the large blood vessels that supply the brain. They pose a health risk from the potential for rupture and subsequent bleeding into the brain and/or the fluid-filled space that surrounds the brain. In fact, these aneurysms are the most common cause of spontaneous subarachnoid hemorrhage (the deadliest form of stroke) in the adult population, with a maximal incidence (80%) in the 4th and 5th decades of life [1].

The great majority of cerebral aneurysms arise at bifurcations, usually at an acute angle, at the origin of small branches from larger arteries, or on the side wall of a vessel with sharp curvature. They are consistently found in certain positions on the Circle of Willis (*circulus arteriosus cerebri*) and the arteries that supply it: the two internal carotid and the basilar arteries. Approximately 85% of all cerebral aneurysms arise on the anterior (carotid-artery derived) circulation, the rest lie along the posterior half of the circle of Willis. The most common position in the posterior half of the circle of Willis is the tip of the basilar artery. This distribution seems to be due to unbalanced hemodynamic stresses resulting from the fact that approximately 80% of the blood supply to the brain comes from the internal carotid arteries, whereas only 20% comes from the basilar artery. The Circle of Willis does not have a fixed anatomy; on the contrary, it exhibits anatomic variations from one individual to another. These variations may range from un-closed circles to non-symmetric shapes, to multiply-connected branches. It has been postulated that these variations could play a role in the development of intracranial aneurysms due to the changes in the distribution of stresses that they generate [2].

Although genetic factors are known to play a key role in the etiology of cerebral aneurysms, the prevailing hypothesis is that the origin, growth, and eventual rupture of cerebral aneurysms is a result of abnormal hemodynamic stresses on the walls of large cerebral arteries [3, 4].

ENDOVASCULAR TREATMENT TECHNIQUES

Unruptured cerebral aneurysms are potentially treatable to stop their growth and to avoid the consequences of their rupture. The main objective in the treatment of cerebral aneurysms is to reduce the hemodynamic forces acting on the aneurysmal wall in an effort to minimize the risk of rupture. The standard approach of treatment involves the exclusion of the aneurysm from the intracranial circulation while preserving the parent vessel. This is currently done by either surgery or through an endovascular technique. The surgical procedure, called neurosurgical clipping, involves performing a craniotomy (removing a section of the skull) and placing a surgical clip at the neck of the aneurysm. Looking for a less invasive procedure, endovascular treatments have been developed over the past decade. Their goal is to prevent the blood from flowing inside the aneurysmal sac by means of an embolic agent. A microcatheter is introduced into the arterial system through the femoral artery in the patient's groin and is tracked through the blood vessels up into the site of the brain aneurysm. Once the tip of the catheter is properly positioned, the embolic agent is placed into the aneurysm, packing it; or across its neck. This can be done with the aid of a balloon to hold the agent in place until the procedure is finished. In this paper, we report on comparative measurements of the velocity and shear stresses when the aneurysm is packed either with a polymer or with coils; and when stents are placed across its neck.

The Guglielmi Detachable Coil (Boston Scientific/Target) system consists of a soft platinum coil soldered to a stainless steel delivery wire. When the coil is positioned within the aneurysmal sac, an electrical current is applied to the delivery wire detaching the coil by means of electrolysis. The delivery wire is then removed, leaving the coil in place. The process of inserting coils continues until the aneurysmal sac is densely packed with them. A thrombus or clot soon forms around the coils. The coils have been also found to promote the development of connective (scar) tissue inside the aneurysm, which seals it off from arterial blood flow, reducing the risk of rupture.

In order to reduce the number of coils needed to pack the aneurysmal sac, MicroVention, Inc. has developed a new type

of coils called HydroCoils[®]. They are platinum helical coil coated with a hydrophilic, acrylic polymer (hydrogel). This polymeric material is capable of swelling in the presence of blood, expanding up to three times its initial volume.

Onyx Liquid Embolic System (*OnyxLESTM*) is a biocompatible liquid embolic agent consisting of ethylene vinyl alcohol copolymer (EVOH) dissolved in the solvent DMSO. Once this solution is injected inside the aneurysm the polymer solidifies through a process of precipitation when Onyx comes into contact with an aqueous solution (e.g., blood). The solvent DMSO rapidly diffuses out of the polymer mass and is washed away by the blood flow. The resulting precipitation of the polymer forms a spongy mass which fills the aneurysmal sac.

The stents (wire mesh tube) are introduced into the arterial system in the same fashion as the above embolic agents. However they are not positioned inside the aneurysmal sac, but across the aneurysmal neck. Although these stents are highly porous, they are able to redirect the flow away from the aneurysmal sac.

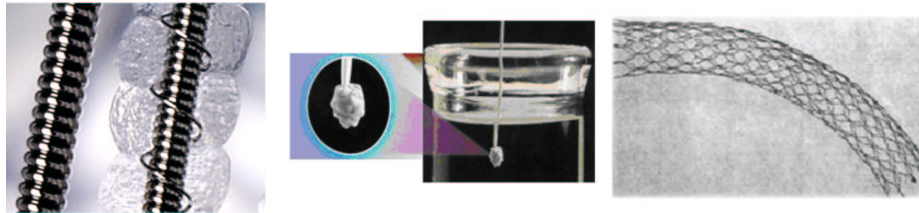


Figure 1. Aneurysmal treatment techniques considered in this report: Coils and Hydrocoils[®] on the right, OnyxTM at the center, and a stent on the left

RESULTS

A Digital Particle Image Velocimetry (DPIV) system was used to measure in vitro the velocity field inside silicon flexible models of an anterior communicating artery and a posterior communicating artery aneurysms. Measurements were made for an "untreated" case (reference case) as well as for models "treated" with the embolic agents mentioned above. Physiologically accurate pulsatile flow conditions were input to the arterial model through a programmable pump. The fluid used was a blend of 40% ethylene-glycol and 60% water with a viscosity of 2.50cp.

The measurements show that all treatment techniques lead to a reduction in the flow inside the aneurysmal sac. Regions of flow stasis are observed at the neck of the aneurysm when embolized with coils, due to the uneven shape of this packing agent at the aneurysmal neck. These regions are potential areas of thrombus formation, which may end up in microemboli. The effect of HydroCoils[®] on the hemodynamics is the same as that of platinum coils. However, the number of HydroCoils[®] required to form a stable thrombus inside the aneurysm is reduced compared to the platinum coils. Also, our measurements indicate that increasing the packing density up to 98% does not affect the endosaccular pressure. Filling the aneurysmal sac with *OnyxTM* presents the same problems as in the case of the coils, the uneven shape of the polymer at the neck may lead to clot formation. However, if a balloon is used when delivering the polymer, the vessel is reshaped at the neck, re-establishing the flow in the parent vessel. Still, using a balloon has some disadvantages. The polymer may be spilled out of the sac and over the parent vessel walls, thus it may occlude secondary vessels or lead to inflammatory processes. Finally, multiple stents were placed across the aneurysmal neck and measurements were taken after placing each stent. We observed a small but measurable decrease of the flow velocity, which was more noticeable at the diastolic phase. Our measurements also indicate that the stiffness to bending of the stents can be used to modify the arterial geometry at the region where the aneurysm arises, redirecting the flow away from it.

CONCLUSIONS

Each one of the treatment techniques for aneurysms considered in this report leads to different modifications of the flow in the parent vessel which may have consequences related to potential for thrombus formation. The aneurysmal filling procedure appears to be crucial to avoid regions of flow stasis that lead to this life-threatening complication.

References

- [1] A.H. Kaye. *Essential Neurosurgery*. Churchill Livingstone, 1997.
- [2] K. N. T. Kayembe, M. Sasahara, and F. Hazama. Cerebral aneurysms and variations in the Circle of Willis. *Stroke*, 15(5):846–850, 1984.
- [3] G. J. Hademenos. The physics of cerebral aneurysms. *Physics Today*, 48(2):24–30, 1995.
- [4] E. Soliman. Cerebral aneurysm. *eMedicine Journal*, 2(9), 2001.