Resection of a large temporooccipital parenchymal arteriovenous fistula by using deep hypothermic circulatory bypass

Case report

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The authors believe this to be the first published case in which a deep hypothermic cardiopulmonary bypass was used to facilitate resection of a large parenchymal arteriovenous fistula. The use of this procedure facilitated resection of the lesion by allowing compression and manipulation of large venous varices that were overlying the deeper arterial feeding vessels. The surgical rationale, technique, and intra- and postoperative management are discussed.

KEY WORDS • cerebral arteriovenous fistula • hypothermia • circulatory arrest

Because of a host of complications resulting from rudimentary extracorporeal pump technology and anticoagulation techniques, the use of deep hypothermic circulatory arrest (DHCA) was abandoned after the pioneering work of Uihlein, et al.,12 Drake, et al.,1 and Patterson and Ray.6 However, advances in cardiac surgery, including the management of systemic anticoagulation, prompted a reappraisal of this technique, with published reports demonstrating good results. Most recently, work by Solomon, et al.,10 among others9,11 has confirmed that DHCA can be used routinely for treatment of complex aneurysms with excellent results.

Currently, there is only one published report of the use of DHCA during resection of arteriovenous malformations (AVMs).14 That report of two cases was discouraging because of severe complications from postoperative hemorrhage and edema. We present a case in which deep hypothermic circulatory bypass was used successfully to facilitate resection of a large parenchyma-based arteriovenous fistula (AVF). The advantages of treatment with low-flow circulatory bypass in this case, along with the hemostatic manipulations used, are analyzed.

Case Report

History. This 29-year-old right-handed woman had a long history of migraine headaches with visual auras that had commenced in high school. Several years ago, she began to develop new, severe headaches consisting of retroorbital pain occurring 2 to 3 times per week. In addition, the patient’s family had noticed her increasing forgetfulness over the last year. There were no other symptoms. Because of her recent history of headaches, her family physician obtained magnetic resonance (MR) images and MR angiograms, which demonstrated a complex left temporoparietooccipital vascular malformation (Fig. 1). The patient was referred to the Mayo Clinic for evaluation.

The patient’s medical history was significant for closure of a patent arterial duct in 1973. She also had a history of paroxysmal ectopic atrial tachycardia that was treated with a radiofrequency ablation in December 1992. Prior to neurosurgical intervention, echocardiography was performed; this showed normal left ventricular function and mild aortic regurgitation.

Neurological Examination. The patient’s neurological examination was significant for diffuse Grade 2 of 6 cervical and orbital bruits. Her motor, sensory, and reflex examinations were normal except for an elicitable left Hoffman’s sign on stimulation. A funduscopic examination demonstrated slight blurring of the right optic disc. The results of her mental status examination were significant, with a score of 33 of 38, with some deficits in calculation and recall.
Profund hypothermia and parenchymal AVF

Treatment Course. The patient underwent diagnostic digital subtraction (DS) angiography and a left amytal test. The bilateral carotid and vertebral DS angiograms demonstrated a parenchymal AVF along the left temporoparietal region extending deep and abutting the trigone (Fig. 2). The arterial blood supply to the fistula was derived from a large left occipital branch and two posterior temporal branches off the left posterior cerebral artery (PCA) and the angular branch of the left middle cerebral artery (MCA). The draining veins flowed through a large varix that drained antegrade into the left transverse sinus. There was also retrograde drainage into the right transverse sinus. The DS angiogram also demonstrated the presence of a 12-mm left posterior communicating artery (PCoA) aneurysm associated with fusiform aneurysm dilation of the left paracallosal carotid artery. An amytal test during this initial diagnostic angiogram indicated that the left hemisphere was dominant.

We initially thought that the best approach to this lesion would be multiple staged embolizations aimed at its cure or to prepare for subsequent surgical resection. However, the anatomy of the AVF made the deposition of embolic material impossible. Unlike most AVFs, which have a localized segment of vascular narrowing at the site of the fistula, the feeding artery and draining vein of this AVF enlarged progressively from the proximal to distal areas. The feeding artery to the fistula parasitized the blood supply from posterior temporal branches of the left PCA and the angular branch of the left MCA. Likewise, the draining vein did not have any focally stenotic areas until it divided into several smaller draining veins remote from the site of the fistula. The draining veins were large enough to allow the passage of a 10-mm-diameter nontachable balloon into the transverse sinus. After general anesthesia and systemic hypotension were induced in the patient, embolization was attempted twice. It was not possible to place a nontachable balloon at the site of the fistula because of the progressively enlarging diameter of the vessel. After attaining proximal flow control by inflating a nontachable balloon in the proximal parietooccipital artery, an attempt was made to place electrolytically detachable coils at the site of the fistula or in the proximal aspect of the draining vein. Despite proximal flow arrest and systemic hypotension, detachable coils larger than 10 mm in diameter passed into the distal venous outflow of the fistula because arterial blood was still supplied to the lesion via the distal posterior temporal and angular arteries, which connected with the parietooccipital artery distal to the occluding balloon. The detachable coils were not placed.

Surgical Decision Making

Because the embolization was unsuccessful, we concluded that surgical resection of the AVF would be a relatively high-risk procedure given the anatomy of the high-flow arterial feeding vessels and the location of the lesion within eloquent cortex. Specifically, three of the arterial feeding vessels were located deep along the tentorial edge with the multiple venous varices lying on top or more superficially. Therefore, gaining access to the arterial feeding vessels would require retraction of the thin-walled venous varices, increasing the risk of an inadvertent tear to a varix, which would be quite difficult to control.

To study the patient’s surgical anatomy further, a full-head volumetric MR image was obtained to capture the entire brain and outer skin surface, and a full-head MR angiogram captured the cerebrovascular structures. The MR angiogram was spatially coregistered with the MR image by using a surface-matching algorithm. The skin surface was segmented by using the thresholding technique, and an image of the entire brain was extracted by means of an automated three-dimensional (3-D) mathematics methodology technique. The brain was further segmented into the cerebrum, cerebellum, brainstem, and ventricles. The cerebral vessels were segmented from the MR image with the thresholding technique and 3-D connectivity analysis. All components were integrated and assigned color and visibility attributes that controlled their appearance in the visualizations. A volume-rendering algorithm was used to generate a variety of visualizations, including transparency, rotations, and cutting planes that could be interactively adjusted to modify the view of the spatial extent of the brain while rendering the full extent of the vessels. This provided synergistic visualizations of all important structural components from the two separately acquired images. These visualizations were viewed and manipulated interactively to study the anatomical relationships preoperatively and to plan the surgical approach (Fig. 3).

We considered two surgical approaches. The first was resection after induction of hypotension, after an initial subtemporal approach to occlude the PCA feeding vessels. The second was the use of deep hypothermic circulatory bypass, in which it was thought that the venous varices could be collapsed, thereby allowing easier access to the arterial feeding vessels with less risk of hemorrhage and retraction of eloquent cortex. Furthermore, this...
technique could be immediately converted to DHCA in the event of uncontrollable hemorrhage. The downside of deep hypothermic circulatory bypass included the potentially deleterious consequences of systemic anticoagulation and postoperative hyperperfusion.

Anesthesia Management

Anesthesia. The patient underwent sedation in the operating room with 100 μg of fentanyl and 1 mg of midazolam. Routine electrocardiography, noninvasive blood pressure, and pulse oximeter monitors were placed and a radial artery catheter was inserted. Anesthesia was induced with sodium thiopental (6 mg/kg) and muscle relaxation was achieved with vecuronium (1.5 mg/kg). Esmolol (1 mg/kg) and lidocaine (1.5 mg/kg) were administered to blunt the hemodynamic response to laryngoscopy. Isoflurane, in an air/oxygen mixture, and fentanyl (32 mg/kg in total for the 12-hour operation) were used for maintenance of anesthesia. Pancuronium was used to maintain muscle relaxation. A pulmonary artery catheter was inserted into the right subclavian vein to minimize the risk of jugular venous thrombosis impeding cerebral venous outflow. The pulmonary artery catheter provided information about left ventricular filling pressures during surgery and the postoperative period of induced hypotension.

Bleeding Prophylaxis. Aprotinin (full Hammerschmidt dose) was used to minimize bleeding secondary to cardiopulmonary bypass. The test and bolus doses administered prior to surgical incision were followed by a continuous infusion until the surgery was completed. Heparinization was monitored with a heparin titration test (> 2 μg/ml heparin) and activated clotting time (> 400 seconds).

Cardiopulmonary Bypass. Because of the echocardiographic findings of aortic insufficiency, a sternotomy as opposed to a femoral approach was chosen for the bypass. After the patient underwent full heparinization, the ascending aorta and right atrium were cannulated. Cardiopulmonary bypass and cooling were instituted prior to removing the bone flap to ensure a quick conversion to DHCA in case the AVF was inadvertently torn during the craniotomy. A vent catheter was placed via the right superior pulmonary vein and advanced to the left ventricle to prevent distention caused by regurgitant flow through an incompetent aortic valve during hypothermic bypass, when the heart was fibrillating or in asystole. The patient’s core temperature, as measured via bladder, nasopharyngeal, and pulmonary artery catheters, was lowered to 16°C. An induction dose of thiopental was administered to augment cerebral protection. During the cooling phase, pH-stat blood gas management with a target PaCO2 of 60 mm Hg was used to facilitate even and thorough brain cooling. Hemodilution of hemoglobin levels to 7 g/dl was used to avoid increases in viscosity associated with low-flow hypothermia. Furosemide (30 mg) and mannitol (25 g) were administered to maintain urine output. A renal dose of dopamine (2 μg/kg/minute) was also infused.

Management During Clipping of the AVF. During surgical exposure, the AVF was decompressed by lowering the mean arterial blood pressure (MABP) to 30 mm Hg by reducing the cardiopulmonary bypass flow to 1.5 L/minute/m² or lower for short periods. An induction dose of thiopental was administered to augment cerebral protection. The patient’s temperature and MABP were maintained at 17°C and 30 to 40 mm Hg, respectively, during the manipulation and resection of the lesion.

Bypass Management After Clipping of the AVF. After clipping of the major feeding vessels, bypass flow was increased to at least 2.4 L/minute to achieve an MABP of 50 to 60 mm Hg for evaluation of hemostasis. However, even after raising bypass flow as high as 2.8 L/minute, the MABP remained low, possibly because of cold-induced vasomotor paralysis of the vascular smooth muscle. A phenylephrine infusion was required to achieve an MABP of 50 mm Hg. Rewarming was instituted gradually, with
the difference between the bladder and perfusate temperatures not allowed to exceed 10˚C. Alpha-stat blood gas management with a target PaCO2 of 30 mm Hg was used to minimize cerebral hyperthermia during core rewarming. An additional dose of mannitol (12.5 g) was administered at the beginning of the rewarming period to minimize reperfusion brain edema. When the patient’s nasopharyngeal temperature reached 30˚C, red blood cells were added to raise the hematocrit to 30%. Sinus rhythm was restored by a single 20-J defibrillation. The heart resumed spontaneous sinus rhythm at 37˚C. Cardiopulmonary bypass was discontinued without difficulty after 306 minutes.

Postcardiopulmonary Bypass Management. After decannulation of the right atrium, heparinization was reversed with protamine. Three units of fresh-frozen plasma and 6 U of platelets were infused. At the end of surgery anesthesia was continued in the patient with propofol (40 μg/kg/minute), muscle paralysis was maintained with pancuronium, and the patient was mechanically hyperventilated (PaCO2, 25–30 mm Hg).

Surgical Resection

After the patient’s MABP was lowered to 30 mm Hg during deep hypothermic bypass, the bone flap was turned with a bone drill (Midas Rex, Fort Worth, TX). A high-speed air drill with a diamond burr was used to fashion the lower cut along the transverse sinus. The dura was then tacked to the bone margins and incised distal to the AVF. This allowed the dura to serve as a handle for rotating the AVF to provide exposure at the junction of the fistula with the brain parenchyma. At a low-flow systolic blood pres-
lesion was successfully manipulated and resected without resorting to full circulatory arrest. Studies of cerebral metabolism support the concept that low-flow cardiopulmonary bypass with profound hypothermia is better tolerated than DHCA because of continued substrate delivery to support metabolic demand.\textsuperscript{2,3} Furthermore, the probability of safe DHCA at 18°C begins to decline sharply after 40 minutes, limiting operating time.\textsuperscript{4}

A report by Williams, et al.,\textsuperscript{14} warned of the difficulties encountered during AVM resection after induction of DHCA. They described severe morbidity and mortality in two patients suffering from postoperative hemorrhage and edema. We enhanced hemostasis with aprotinin, hypotension, adequate heparin reversal, and empirical platelet and fresh-frozen plasma administration. Avoiding or decreasing cerebral edema formation in the postoperative period was managed by manipulating cerebral blood volume and brain water. To limit excessive brain water formation, furosemide, mannitol, and isotonic intravenous fluids were administered. A slightly elevated head position, deliberate hypotension, hyperventilation, and propofol were all used to decrease cerebral blood volume. Additionally, the pulmonary artery catheter was inserted into the subclavian vein to avoid the possibility of jugular venous obstruction and/or thrombosis and impairment of venous drainage. In this manner, optimum conditions for cerebral protection and surgical manipulation were provided, and proved crucial to the successful outcome of the case.

One of the problems reported by Williams, et al.,\textsuperscript{14} was the difficulty in identifying residual AVM because of the lack of perfusion during circulatory arrest. We did not encounter this problem because a low-flow state was maintained and because the lesion itself was primarily an AVF as opposed to an AVM. Accordingly, identification of the major arterial feeding vessels was not unusually difficult. In summary, the use of deep hypothermia low-flow circulatory bypass may prove to be a useful adjunct technique when resecting large AVFs that are technically difficult to reach.

Acknowledgment

The authors are indebted to Ms. Mary Soper for the preparation of the manuscript.

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Manuscript received May 14, 1997. Accepted in final form August 1, 1997. Address reprint requests to: Fredric B. Meyer, M.D., Department of Neurosurgery, Mayo Clinic, 200 First Street SW, Rochester, Minnesota 55905.