BrainPath-Mediated Resection of a Ruptured Subcortical Arteriovenous Malformation

**BACKGROUND:** Although tubular retractor systems have gained popularity for other indications, there have been few reports of their use for arteriovenous malformation (AVM) surgery. A patient was diagnosed with a ruptured 1.2-cm subcortical AVM after presenting with intracerebral hemorrhage in the right frontal lobe and anterior basal ganglia. The characteristics of this AVM made it amenable to resection using a tubular retractor.

**OBJECTIVE:** To demonstrate the feasibility and safety of AVM resection using a tubular retractor system.

**METHODS:** Resection of the ruptured 1.2-cm subcortical AVM was performed utilizing the BrainPath™ (NICO corp, Indianapolis, Indiana) tubular retractor system.

**RESULTS:** The BrainPath™ approach provided sufficient visualization and surgical freedom to permit successful AVM resection and hematoma evacuation. Postoperative imaging demonstrated near total hematoma removal and angiographic obliteration of the AVM. There were no complications, and the patient made an excellent recovery.

**CONCLUSION:** Tubular retractors warrant consideration for accessing small, deep, ruptured AVMs. The nuances of such systems and their role in AVM surgery are discussed.

**KEY WORDS:** Arteriovenous malformation, Cerebral hemorrhage, Craniotomy, Minimally invasive surgical procedures, Case report

**Operative Neurosurgery** 0:1–7, 2017
DOI: 10.1093/ons/opx186

**SUPPLEMENTAL DIGITAL CONTENT**

**ABBR EVIATIONS:**
- ACA, anterior cerebral artery
- ALIC, anterior limb of the internal capsule
- AVM, arteriovenous malformation
- CT, computed tomography
- ICH, intracerebral hemorrhage
- IVH, intraventricular hemorrhage
- NIH, National Institutes of Health
- SLF, superior longitudinal fasciculus

Supplemental digital content is available for this article at www.operative Neurosurgery-online.com.
stroke score was 11. CT angiography demonstrated a subtle cluster of abnormal vessels along the medial edge of the hematoma, adjacent to the anterior edge of the frontal horn of the right lateral ventricle (Figure 2). He underwent a diagnostic cerebral angiogram that showed a 1.2-cm AVM adjacent to the anterior right lateral ventricle (Figure 3). Arterial input was from the right anterior cerebral artery (ACA), and venous drainage was via a prominent vein that traveled posteriorly toward the vein of Galen. The Spetzler–Martin grade\(^1\) was III (nidus <3 cm, eloquent location, and deep venous drainage), and the supplementary AVM grade\(^2\) was III (age >40, hemorrhagic presentation, and compact nidus). Continuous EEG (electroencephalography) monitoring revealed a nonclinical seizure originating from the right frontal region. There were no further seizures after 2 antiepileptic drugs were initiated, and his left hemiparesis gradually improved.

**METHODS**

Written informed consent was provided by the patient’s surrogate. IRB approval was not required for a single case report. AVM resection using a BrainPath\(^\text{TM}\)-mediated (NICO corp) transulcal approach was
planned. A volumetric magnetic resonance image with contrast was obtained to plan the optimal trajectory (Figure 4). Eight days after admission, the patient underwent surgery to resect the AVM. After general anesthesia was induced, the patient was positioned supine with the head turned slightly to the left and secured in 3-point fixation. The frameless stereotactic navigation system was registered and used to locate the entry point, which was located in the right frontal region at the superior temporal line, approximately 2 cm superior and 2 cm posterior to the keyhole. A curvilinear frontotemporal incision was made just behind the hairline. The temporalis muscle was incised and the myocutaneous flap was reflected anteriorly in the submuscular plane. A 4.0-cm circular craniotomy centered over the entry point was made. A 1.5-cm cruciate dural opening was made over the entry point, which exposed the inferior frontal sulcus. The arachnoid over the sulcus was opened sharply and dissected over a short distance to allow for entrance of the tip of the tubular retractor into the sulcus. Using stereotactic navigational guidance, a 50-mm BrainPath™ sheath with obturator was advanced through the sulcal entry point along the planned trajectory and stopped just before reaching the AVM nidus. The obturator was removed, and the microscope was introduced, revealing a subacute hematoma (Figure 5A). The hematoma was removed with gentle aspiration revealing the AVM nidus, which was adjacent to the ependymal surface of the frontal horn (Figure 5B). Circumferential dissection was performed around the margin of the nidus, using suction, bipolar coagulation, and microscissors. Multiple small feeding arteries along the medial margin were coagulated and divided (Figure 5C). The ventricle was opened to provide access to the posterior margin of the nidus, revealing a single large draining vein exiting the posterior edge of the nidus and travelling posteriorly within the ventricle (Figure 5D). After the nidus had been dissected circumferentially, the only remaining point of attachment was this draining vein, which was subsequently coagulated and divided (Figure 5E). The nidus was removed en bloc. The cavity was irrigated and careful inspection revealed adequate hemostasis. The BrainPath™ sheath was removed slowly while inspecting the brain tissue along the walls to verify that there was no residual hematoma or AVM and no active bleeding.

RESULTS

The BrainPath™ sheath (NICO corp) facilitated resection of the AVM by providing sufficient visualization and surgical freedom, which is demonstrated in Video, Supplemental Digital Content. After the sheath was removed, there was minimal disruption of the overlying brain tissue (Figure 5F). A postoperative angiogram revealed no residual AVM nidus or arteriovenous shunting (Figure 6), and CT demonstrated near total hematoma removal and minimal disruption of surrounding brain tissue (Figure 7). There were no perioperative complications. The patient was doing well at a 6-wk follow-up visit, with no focal neurological deficit. He has no significant disability, and his seizures remain well controlled.

DISCUSSION

Brain AVM rupture is associated with significant morbidity. Previous rupture is the strongest risk factor, and the annual risk of hemorrhage is approximately 2.2% annually if unruptured and 4.5% if ruptured.3 AVM treatment is aimed at reducing the long-term hemorrhage risk, and the decision to treat is best made on a case-by-case basis depending on patient- and lesion-specific factors. Treatment options include radiosurgery, transcatheter embolization, resection, and combinations of these. Of these options, surgical resection leads to the highest probability of angiographic obliteration, provides the greatest protection from future hemorrhage,4,5 and has an immediate protective effect. A multimodality approach has been recommended for Spetzler–Martin grade III AVMs.6 Our recommendation for surgical resection in this case was based on the angioarchitectural features and hemorrhagic presentation. We did not feel that observation
or radiosurgery were optimal treatments for this lesion because it was recently ruptured and therefore at higher risk for rupture with observation or during the latency period that precedes radiosurgical obliteration. The potential surgical morbidity was reasonable given the small size, compact shape, and the presence of an adjacent hematoma. Grade III AVMs were associated with a 16% risk of neurological decline or death in Spetzler’s series.\(^1\) However, according to Lawton’s subclassification of grade III AVMs, this lesion belongs to the lowest risk subtype for microsurgical resection (III-, or S1V1E1), with only 2.9% surgical morbidity.\(^7\) Preoperative embolization is a useful adjunct to make resection safer for some AVMs. In the present case, embolization was not pursued because the angiographic appearance was not suggestive of a high-flow lesion, and the feeding arteries originating from the ACA were too small to permit selective catheterization.

Most supratentorial AVMs are based on a pial surface, and the craniotomy and surgical approach are designed to provide access to this surface, from which resection commences. The approach to subcortical AVMs is more complex and may require the surgeon to make a corticectomy and traverse normal brain tissue before reaching the lesion. This provides a narrow working corridor that requires retraction of the overlying brain tissue to provide adequate visualization. One common retraction strategy is to use a fixed blade retractor system. Alternatively, one can employ dynamic retraction with the surgical instruments (eg, suction and bipolar forceps) applied intermittently to the brain. More recently, tubular retractor systems have emerged as an alternative. The first intracranial tubular retractor system described by Kelly and colleagues\(^8\) was affixed to a stereotactic frame. Other descriptions of tubular retractors have involved spinal retractor systems adapted for intracranial use\(^9-13\) and retractors constructed

---

**FIGURE 5.** Intraoperative views through the BrainPath\textsuperscript{TM} (NICO corp) sheath. A. Introduction of the sheath and removal of the obturator reveal a dark, gelatinous hematoma (H). B. After removing the hematoma, the lateral and anterior surfaces of the AVM nidus (N) are visualized, and the frontal horn ependyma (E) is seen along its posterior margin. C. A feeding artery (A) along the deep/medial margin is coagulated and divided. D. After opening the ventricle posterior to the nidus, the arterialized draining vein (V) is visualized as it exits the posterior edge of the nidus and travels posteriorly within the ventricle. E. After complete circumferential dissection of the nidus (N), the previously arterialized vein (V) now appears smaller and darker. The vein was coagulated and divided, and the nidus was removed en bloc. F. A photograph taken after removal of the sheath (which has a diameter of 1.3 cm) demonstrates the minimal amount of brain disruption it has caused. The craniotomy (solid line) measures 4 cm, while the dural opening (dashed line) measures 1.5 cm and the cortical defect (dotted line) measures 0.7 cm.
FIGURE 6. Postoperative digital subtraction angiogram (right internal carotid injection, right anterior oblique view) shows no residual AVM nidus and no early venous drainage.

FIGURE 7. Postoperative CT of the brain without contrast shows near complete removal of the hematoma and minimal disruption of brain tissue.

from materials commonly available in the operating room.\textsuperscript{14-19} There are now commercially available cylindrical plastic retractor systems specifically designed for intracranial use. The BrainPath\textsuperscript{TM} tubular retractor system (NICO corp) has emerged as a valuable tool for providing safe and efficient access to subcortical lesions. The system consists of a disposable clear plastic sheath and a reusable obturator. The obturator fits within the sheath and has a tapered end with an atraumatic tip. After opening the arachnoid over the sulcal entry point, the obturator and sheath are advanced as a unit through the brain tissue using stereotactic navigation. Once the target is reached, the obturator is removed, leaving the sheath in place to maintain the operative corridor. The sheath has an inner diameter of 13.5 mm and is available in lengths of 50, 60, and 75 mm.

Reported uses of the BrainPath\textsuperscript{TM} system have included primarily spontaneous ICH\textsuperscript{20-24} and brain tumors.\textsuperscript{21,25} Other applications include traumatic ICH,\textsuperscript{26} cavernomas,\textsuperscript{27-29} a ruptured periventricular aneurysm,\textsuperscript{30} brain abscess,\textsuperscript{21} and radiation necrosis.\textsuperscript{31} The case series of BrainPath\textsuperscript{TM}-mediated ICH evacuation by Labib and colleagues\textsuperscript{24} included 2 cases in which AVMs were discovered at the time of surgery after negative CT angiograms, and the authors did not recommend the use of BrainPath\textsuperscript{TM} for the routine resection of AVMs.\textsuperscript{24} While there have also been case reports of brain AVM resection using other tubular retractor systems,\textsuperscript{13,16} ours is the first reported case of planned AVM resection using BrainPath\textsuperscript{TM}.

AVM surgery follows a commonly accepted sequence of steps, beginning with exposure and identification of the main sites of arterial input and venous drainage. Resection of the nidus begins with disruption of arterial input, followed by circumferential dissection, and ligation of major draining veins allows for the ultimate disconnection and removal of the dearterialized nidus. AVM resection using BrainPath\textsuperscript{TM} follows these same principles but requires consideration of some additional principles to provide optimal results. BrainPath\textsuperscript{TM} requires a craniotomy approximately 3 cm in diameter, while the dural opening should be smaller (1.5 cm). This configuration provides a dural cuff that stabilizes the sheath, leaves the unexposed brain protected by dura, and leaves ample extradural space for manipulation of the sheath that is not restricted by bone. When using BrainPath\textsuperscript{TM}, a transulcal approach is preferable because it requires less disruption of brain tissue compared to entering the cortex through a gyrus. In our experience, the tapered end and blunt tip of the obturator function to open the sulcus in atraumatic fashion so that minimal arachnoidal dissection is required prior to introducing the device. The surgeon must determine the appropriate depth for initial introduction of the sheath. For evacuation of ICH, we find it most useful to cannulate to the deep margin of the hematoma and
work from the inside out. For an AVM, however, shallow cannulation is necessary. An ideal target for initial cannulation would be slightly superficial to the near margin of the nidus, in order to avoid violating the nidus before visualizing it. For this resection, we utilized a fine-tip suction, bipolar forceps, and bayoneted microscissors. We found that the BrainPath™ sheath allowed for ample room for bimanual operation using these instruments, while providing excellent visualization. In the event of difficult operating conditions, the BrainPath™-mediated corridor could easily be converted to a larger corridor using an alternative retractor system. For this reason, we used a 4-cm craniotomy, which is slightly larger than we would typically employ for ICH evacuation.

Trajectory planning is a core element of the BrainPath™ approach. The ideal trajectory should minimize disruption of white matter tracts. For this lesion involving the posterior frontalbasal region and anterior basal ganglia, important nearby tracts include the inferior fronto-occipital fasciculus, uncinate fasciculus, anterior limb of the internal capsule (ALIC), and superior longitudinal fasciculus (SLF). Selecting a trajectory that lies sufficiently anterior within the frontal lobe should spare the uncinate fasciculus, ALIC, and SLF. In addition to avoiding these white matter tracts, our trajectory (Figure 4) avoided eloquent cortex at the entry point, provided a relatively short operative corridor, was posterior enough to allow for a unilateral incision behind the hairline, and facilitated evacuation of the hematoma before encountering the nidus.

There are a few characteristics of this AVM that made it amenable to resection using the BrainPath™ technique. These include its small size, compact nidus shape, and arterial input from only a few small-caliber feeding arteries that were surgically accessible. Employing small angular movements of the sheath, we were easily able to reach all surfaces of the nidus and to coagulate and divide the feeding vessels. A large AVM would be more difficult to attack using BrainPath™, as it would require large angular movements of the sheath and would provide visualization of only a small portion of the nidus at a time. This is in contrast to ICH and tumors, which can be debulked from within, allowing the peripheral portions of the lesion to fall into the field. Resection of this AVM was also aided by the fact that it had ruptured. Rupture status is a favorable factor for resection because in addition to minimizing the risk of causing a postoperative neurological decline, the hematoma can dissect a plan between the nidus and functional brain tissue and create a cavity around the nidus that minimizes the need for brain retraction. In this case, evacuation of the hematoma through the BrainPath™ sheath was easily performed and provided a generous cavity at the depth of the sheath that provided immediate exposure of the anterior and lateral surface of the nidus.

**Limitations**

There are a few limitations to using BrainPath™ for AVM resection. Although BrainPath™ provided excellent access for resection of this particular AVM, it must be emphasized that this was a highly selected case that was amenable to BrainPath™-mediated resection for the reasons listed above. However, AVMs that are appropriate for this technique are likely rare, and standard microsurgical techniques should remain the treatment of choice for the majority of AVMs. The small diameter of the sheath, although sufficient for the introduction of 2 instruments while maintaining proper visualization, provides little excess space for an assistant surgeon to perform tasks such as suction or retraction. Fortunately, such assistance was not necessary in this case due to the small lesion size and minimal amount of bleeding encountered, but we would not recommend utilizing BrainPath™ for AVMs that are large or appear to have high flow. Furthermore, there is a learning curve associated with this technique, and we recommend that surgeons should refine their technique with less complex cases (eg, ICH) before using BrainPath™ to resect an AVM.

**CONCLUSION**

We have reported the successful planned resection of a ruptured subcortical AVM utilizing the BrainPath™ tubular retractor system (NICO corp). This system provided adequate visualization and surgical freedom for circumferential dissection around the AVM nidus and removal of the adjacent ICH, with minimal disruption of the overlying brain tissue. We propose that tubular retractor systems may be considered when accessing small, deep, ruptured AVMs. Their utility for unruptured lesions is uncertain, and standard cranial approaches should continue to be used for medium and large AVMs.

**Disclosure**

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

**REFERENCES**

COMMENT

This is a fascinating case report and elegant video of resection of a ruptured AVM using the BrainPath\textsuperscript{TM} tubular retractor system (NICO Corporation, Indianapolis, Indiana). The authors demonstrate that the exposure afforded by the tubular retractor was more than adequate to accomplish a comfortable resection of the AVM fulfilling the 3 essential maneuvers for AVM resection, namely early identification of the nidus, and preservation of the draining vein until the end of the resection. The angiographic and clinical results are excellent. Obviously in this particular case the authors chose to resect the AVM during the subacute period, which has its advantages and disadvantages.\textsuperscript{1} The timing of resection of a hemorrhagic AVM remains a topic of debate in the cerebrovascular neurosurgical community. In my practice, I typically prefer to postpone resection of a hemorrhagic AVM for 8 to 12 weeks. The dysautoregulation that accompanies the AVM hemorrhage may render surgery during the acute period and the postoperative management more challenging. I perform a follow-up angiogram the week before the resection to assess the full extent of the AVM once the clot has dissipated. There is typically a porencephalic cavity where the clot used to be that facilitates the resection. Nevertheless, it is difficult to argue with the outstanding surgical results achieved in this case, for which I commend the authors.

Rafael J. Tamargo
Baltimore, Maryland