Balloon-assisted transarterial embolization of intracranial dural arteriovenous fistulas

Clinical article

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Object. The authors report their preliminary experience using a balloon-assisted technique (BAT) in the transarterial embolization of intracranial dural arteriovenous fistulas (DAVFs).

Methods. The authors reviewed the prospectively collected data obtained in 7 consecutive patients with DAVFs in whom embolization was achieved using transarterially injected Onyx with either the venous or arterial BAT. Procedures were performed at the Division of Interventional Neuroradiology at the University of California at Los Angeles Medical Center between September 2005 and January 2008.

Results. Three patients presented with cortical venous reflux and 4 did not. Three patients underwent transarterial Onyx-based embolization combined with transvenous balloon protection; the balloon was inflated in the transverse sinus in 2 of these patients and in the superior sagittal sinus in the third. One of them underwent an additional transarterial Onyx embolization with arterial BAT, whereas 4 other patients were treated with arterial BAT alone. The occipital artery was temporarily occluded with the balloon in 4 of these cases, whereas in the fifth, the authors used temporary balloon occlusion of the middle meningeal artery. Angiograms obtained immediately after embolization demonstrated complete or near-complete obliteration of the fistula in 6 patients and partial occlusion in 1 patient. There were no immediate or postprocedural complications. Two patients who presented with intracranial hemorrhage never suffered a second hemorrhage, and all other patients experienced either complete resolution or significant improvement of their symptoms.

Conclusions. The BAT provides a new complementary method in the transarterial embolization of DAVFs that are not amenable to transvenous embolization. The venous BAT protects the patency of critical venous pathways, whereas the arterial BAT provides better control of the Onyx-based embolization.

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KEY WORDS • balloon • dural arteriovenous fistula • embolization • liquid embolic agent • Onyx

The intracranial DAVF usually involves the wall of a major dural sinus in the cranial fossa. The lesions with CVR and venous hypertension, retrograde sinus flow, and Galenic drainage have poor natural history, more aggressive clinical symptoms, and poor long-term clinical outcome.17,20 Although surgical approaches can cure certain types of DAVFs, endovascular occlusion of the fistulous connection has been adopted as the primary therapeutic strategy for definitive or palliative treatment in many cases of DAVF, particularly those in the presence of CVR.

A new liquid embolic agent, Onyx (ev3, Inc.), has improved characteristics that result in more thorough and controllable penetration than previous materials. It can produce more reliable occlusion than traditionally seen with coils, acrylics, and/or particles. Its potential for complete occlusion of a DAVF has been recently described in the literature.3,5,7,11,14,16,18,19 Furthermore, the treatment of DAVFs with CVR, previously limited to transvenous coil occlusion of the dural sinus or surgical disconnection of leptomeningeal veins, now includes transarterial Onyx-based embolization, recently shown to be both safe and efficacious.7

Benign cranial DAVFs without CVR or retrograde venous flow should be conservatively managed. Palliative transarterial embolization is offered when patients experience bothersome symptoms. However, transarterial,
particulate embolic agent–based embolization of DAVFs risks incomplete treatment with subsequent recanalization, and using transarterial acrylic-based embolization can risk migration of embolic agent into the venous, systemic, or pulmonary circulation.

In July 2005, the US FDA approved Onyx for presurgical embolization of cerebral arteriovenous malformations. Since then, it has been used at our institution for treatment of DAVFs as well. In complex intracranial DAVFs not amenable to transvenous sinus occlusion, we reasoned that transarterial Onyx-based embolization with either the arterial or venous BAT would be a safe and more effective method of treatment. We describe our initial experience in using this novel endovascular technique to treat 7 consecutive patients with intracranial DAVFs.

Methods

Patient Population

A prospectively maintained database of information collected in patients with DAVFs was retrospectively reviewed. Thirty-nine consecutive patients with intracranial DAVFs were treated endovascularly with Onyx between September 2005 and January 2008. The fistulous connections, proximal draining veins, and appropriate distal segment of the arterial supply of these DAVFs were transarterially occluded using Onyx as a palliative strategy, whereas definitive treatment was accomplished by transvenous Onyx injection in combination with coil embolization. During this period, 7 patients with DAVFs underwent transarterial Onyx-based embolization utilizing the arterial or venous BAT.

There were 3 women and 4 men ranging from 20 to 65 years of age. Three patients presented with pulsatile tinnitus, 2 with progressive headache and papilledema, and 2 with intracranial hemorrhage. Of the 7 DAVFs, 4 involved the transverse sinuses, 1 the sigmoid sinus, 1 the superior sagittal sinus, and 1 the tentorium. Based on the presence of cortical or retrograde venous sinus drainage, 1 venous sinus was classified as Borden Type I or II/Cognard Type I, IIa, or IIa + IIb, and 2 lesions as Borden Type III/Cognard Type III.

Endovascular Technique

In this series, the larger feeding arteries from the ECA, mainly the transosseous branch of the OA and posterior branch of the MMA, were catheterized distally in preparation for transarterial Onyx injection. The reflux-hold-reinjection technique was used after the tip of an Onyx-compatible Marathon or Echelon-10 microcatheter (ev3, Inc.) was navigated to a position believed by the operator to be wedged or as close to the fistula site as obtainable. We used over-the-wire, single-lumen occlusion catheters with varying sizes of Onyx-compatible balloons (ev3, Inc.) for 2 differing methods of arterial or venous BAT during transarterial Onyx embolization.

In the venous BAT, the balloon catheter was navigated transvenously and positioned in the recipient venous structure adjacent to the fistula, and the balloon was temporarily inflated during transarterial Onyx injection. Balloon occlusion was used to prevent untoward distal Onyx migration and to simultaneously achieve better penetration of the liquid into the fistulous connections in and around the sinus wall. We used such a venous BAT to treat 3 patients with DAVFs when a patent venous sinus and adjacent key cortical veins required preservation to maintain functional cortical venous outflow.

In the arterial BAT, the balloon catheter was positioned in the ECA feeding artery proximal to the tip of another microcatheter used for transarterial Onyx embolization. During transarterial injection of the liquid agent, the balloon was temporarily inflated to increase proximal resistance and aid plug formation, resulting in better control of reflux and enhanced distal penetration. Alternatively, the arterial BAT was used in high-flow fistulas to prevent distal Onyx migration. We used the arterial BAT with a transarterial embolization approach in 5 patients with either high-grade DAVFs with an isolated venous sinus or more benign but high-flow DAVFs without CVR. The clinical presentation and angiographic results are summarized in Table 1.

Results

Three patients (Cases 1–3) underwent transarterial Onyx injection combined with the venous balloon occlusion. The balloon was inflated within the transverse sinus in 2 patients and in the superior sagittal sinus in 1 patient. There were 2 sessions in which we used the venous BAT during transarterial embolization in 1 patient (Case 1). However, the fistula was incompletely occluded because of early termination due to distal Onyx migration. Follow-up cerebral angiography demonstrated some tiny but persistent feeding arteries not amenable to catheterization. Because there was no evidence of sinus thrombosis, high-flow stenotic venopathy, or CVR, stereotactic radiosurgery was offered, but the patient was lost to further follow-up (Fig. 1). In the remaining 2 patients, an anatomical cure was achieved; in 1 of these patients an additional transarterial Onyx embolization session was undertaken utilizing the adjunctive arterial BAT.

Four other patients (Cases 4–7) were treated using transarterial Onyx embolization with the arterial BAT, in a total of 4 treatment sessions. There were 3 sessions of balloon inflation in the OA and 1 in the MMA (Fig. 2). Immediately following embolization, there was complete or near-complete obliteration of the fistula in 2 patients. Of the remaining 2 patients, 1 with a Borden Type I DAVF was nearly completely occluded after the second transarterial embolization at 9-month follow-up. The other patient with a Borden Type III tentorial DAVF was partially treated in a staged fashion prior to planned surgical treatment in combination with stereotactic radiosurgery; outcome is pending angiographic follow-up.

In this series, a total of 9 sessions using the arterial or venous BAT was performed and better fistula penetration of the transarterially injected Onyx was achieved. There were no difficulties or complications involving balloon inflation, deflation, or retrieval. No untoward embolization into the cerebral circulation occurred. There were no immediate or postprocedural complications. In a short-
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Illustrative Cases

Case 2

This 52-year-old man presented with progressive headache, papilledema, and minor cognitive difficulties. Cerebral angiography revealed an extensive DAVF involving the left transverse sinus (Fig. 3A). Because of the elevated intracranial pressure, a balloon was used in the recipient venous pouch along the left transverse sinus to preserve left transverse sinus patency. We navigated a 7 × 7-mm HyperForm balloon occlusion catheter (ev3, Inc.) into the left transverse sinus and inflated it to occlude the greater part of this venous pouch (Fig. 3B). We then catheterized 2 feeding MMA branches and injected the embolic agent, which achieved excellent penetration into the fistulous connections and venous pouch itself (Fig. 3C). One month later, complete obliteration was achieved after repeat transarterial Onyx 34–based embolization through a transosseous branch of the left OA in combination with the arterial BAT in the proximal OA, followed by injection of Onyx 18 through an MMA feeding branch (Fig. 3D and E). The patient’s symptoms improved after the procedure and were completely resolved at 22-month follow-up.

Case 3

This 56-year-old woman developed a progressive and bothersome pulsatile tinnitus 6 months following resection of a cerebellar meningioma. Cerebral angiography revealed a DAVF involving the right transverse sinus (Fig.

TABLE 1: Clinical and angiographic characterization in 7 patients with DAVFs*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Location</th>
<th>Clinical Presentation</th>
<th>Arterial Supply</th>
<th>Venous Drainage</th>
<th>Borden Type</th>
<th>Cognard Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20, F</td>
<td>SSS</td>
<td>headache</td>
<td>Lt recurrent meningeval artery, bilat MMA, bilat STA, rt OA</td>
<td>antegrade</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>2</td>
<td>52, M</td>
<td>Lt TS</td>
<td>headache, papilledema</td>
<td>Lt MHT, bilat OA, Lt PAA, Lt MMA, Lt STA</td>
<td>antegrade &amp; retrograde, &amp; perimesencephalic vein</td>
<td>II</td>
<td>IIa + IIb</td>
</tr>
<tr>
<td>3</td>
<td>56, F</td>
<td>rt TS</td>
<td>pulsatile tinnitus</td>
<td>Lt OA, rt MMA, rt PAA</td>
<td>retrograde</td>
<td>I</td>
<td>IIa</td>
</tr>
<tr>
<td>4</td>
<td>49, M</td>
<td>Lt tentorial region</td>
<td>intracranial hemorrhage</td>
<td>Lt MHT, Lt MMA, Lt IMA, Lt PAA</td>
<td>perimesencephalic vein</td>
<td>III</td>
<td>III</td>
</tr>
<tr>
<td>5</td>
<td>65, F</td>
<td>Lt TS</td>
<td>bruit</td>
<td>Lt MHT, bilat OA, Lt MMA, Lt PAA</td>
<td>antegrade &amp; retrograde</td>
<td>I</td>
<td>III</td>
</tr>
<tr>
<td>6</td>
<td>60, M</td>
<td>Lt SS</td>
<td>bruit</td>
<td>Lt MHT, Lt OA, Lt MMA, Lt APA</td>
<td>antegrade &amp; retrograde</td>
<td>I</td>
<td>IIa</td>
</tr>
<tr>
<td>7</td>
<td>61, M</td>
<td>Lt TS</td>
<td>intracranial hemorrhage</td>
<td>Lt OA</td>
<td>cortical veins</td>
<td>III</td>
<td>III</td>
</tr>
</tbody>
</table>

* APA = ascending pharyngeal artery; IMA = internal maxillary artery; MHT = meningohypophyseal trunk; PAA = posterior auricular artery; SS = sigmoid sinus; SSS = superior sagittal sinus; STA = superficial temporal artery; TS = transverse sinus.

Fig. 1. Case 1. This patient presented with a residual DAVF involving the superior sagittal sinus (SSS) in the parietal region after an unsuccessful resection. Left: Unsubtracted angiogram obtained during embolization revealing near-complete occlusion of the lesion with Onyx (arrowheads) when a temporary balloon (arrow) is inflated to protect the midposterior portion of the SSS. Right: Postembolization angiogram demonstrating that the SSS and large cortical veins adjacent to the fistula remain patent.
Because the right transverse sinus was the dominant venous outlet of the brain, we treated this fistula using transarterial embolization with balloon protection of the right transverse sinus. A 7 × 7-mm HyperForm balloon occlusion catheter was advanced through the left transverse sinus and across the midline into the right transverse sinus. Complete occlusion of the fistula and preservation of the right transverse sinus were achieved after Onyx injection into a transosseous branch of the right OA, done with balloon protection of the right transverse sinus (Fig. 4B). The pulsatile tinnitus disappeared immediately following the procedure. At 4 months, follow-up cerebral angiography demonstrated persistent obliteration of the fistula and normal flow in the right transverse and sigmoid sinuses (Fig. 4C and D). The patient remained asymptomatic at 22-month follow-up.

**Case 7**

This 61-year-old man with a 3-year history of superior sagittal sinus thrombosis presented with intracranial hemorrhage. Cerebral angiography revealed an aggressive left transverse sinus DAVF fed by multiple transosseous branches from the left OA with only CVR (Fig. 5A). There was complete occlusion of the sagittal sinus, torcular herophili, and left sigmoid sinus as well as portions of the right sigmoid sinus. The major cerebral venous drainage was through the cavernous sinuses and pterygoid plexus. We navigated a microcatheter into a large transosseous branch of the left OA into a position optimal for Onyx injection. A 4 × 7-mm HyperForm balloon occlusion catheter (ev3, Inc.) was advanced into the main pedicle of the left OA adjacent to the origin of the transosseous branch for Onyx injection (Fig. 5B). Transarterial proximal balloon occlusion produced good Onyx penetration into the fistula with reflux into the feeding arteries arising from the distal branch of the left OA, resulting in complete occlusion of the DAVF and preservation of the isolated sinus (Fig. 5C).

**Discussion**

Transarterial embolization with liquid embolic agents, such as low-concentration acrylics or Onyx, is a particularly useful treatment option in selected patients with DAVFs that have direct CVR or are unsuitable for transvenous coil embolization due to limited venous access. The fistulas can be definitively cured using low-concentration acrylics administered with a wedged microcatheter position and/or in flow-controlled conditions. The nonadhesive, superior penetration, and long injection working-time properties of Onyx have broadened its utility in the transarterial treatment of brain arteriovenous malformations and DAVFs. The advantage of Onyx over N-butyl cyanoacrylate for the embolization of DAVFs has been recently

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Transarterial Embolization Route</th>
<th>BAT Route</th>
<th>Balloon Type</th>
<th>Onyx</th>
<th>Anatomical Results</th>
<th>Clinical Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rt MMA &amp; lt STA</td>
<td>VBAT, SSS</td>
<td>HyperGlide 4 × 30 mm</td>
<td>4.5 ml Onyx 18</td>
<td>near-complete occlusion; unchanged at 2 mos</td>
<td>improved, 4 mos</td>
</tr>
<tr>
<td>2</td>
<td>lt MMA</td>
<td>VBAT, TS</td>
<td>HyperForm 7 × 7 mm</td>
<td>5.0 ml Onyx 34</td>
<td>anatomical cure</td>
<td>complete cure, 22 mos</td>
</tr>
<tr>
<td></td>
<td>lt OA</td>
<td>ABAT, lt OA</td>
<td>HyperForm 4 × 7 mm</td>
<td>5.0 ml Onyx 34 &amp; 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>rt OA</td>
<td>VBAT, TS</td>
<td>HyperForm 7 × 7 mm</td>
<td>2.5 ml Onyx 18</td>
<td>anatomical cure; no recurrence at 4 mos</td>
<td>complete cure, 22 mos</td>
</tr>
<tr>
<td>4</td>
<td>lt MMA</td>
<td>ABAT, lt MMA</td>
<td>HyperForm 4 × 7 mm</td>
<td>2.0 ml Onyx 34</td>
<td>partial occlusion</td>
<td>improved, 22 mos</td>
</tr>
<tr>
<td>5</td>
<td>lt OA</td>
<td>ABAT, lt OA</td>
<td>HyperForm 4 × 7 mm</td>
<td>4.0 ml Onyx 18</td>
<td>partial occlusion; near-complete occlusion after 2nd embolization</td>
<td>improved, 9 mos</td>
</tr>
<tr>
<td>6</td>
<td>lt OA</td>
<td>ABAT, lt OA</td>
<td>HyperForm 4 × 7 mm</td>
<td>6.0 ml Onyx 34</td>
<td>near-complete occlusion</td>
<td>improved, 3 mos</td>
</tr>
<tr>
<td>7</td>
<td>lt OA</td>
<td>ABAT, lt OA</td>
<td>HyperForm 4 × 7 mm</td>
<td>2.5 ml Onyx 34</td>
<td></td>
<td>improved, 3 mos</td>
</tr>
</tbody>
</table>

*ABAT = arterial BAT; VBAT = venous BAT.*
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addressed. Transarterial Onyx-based embolization is a promising technique option as a definitive treatment for DAVFs.\textsuperscript{7,11,14,18}

In our opinion, the arterial or venous BAT provides a new adjunctive method in the transarterial Onyx-based embolization treatment of complex DAVFs. We believe that the arterial BAT serves 3 unique purposes during transarterial injection. First, it can decrease the rapid flow within the fistulous connections, thus minimizing the risk of distal migration of the embolic material into the systemic venous or pulmonary circulation caused by high-flow shunting. This migration is seen in rare, symptomatic pulmonary complications of transarterial acrylic embolization of brain arteriovenous malformations.\textsuperscript{10,15} Second, it can play an important protective role in the normal cerebral vasculature. The balloon can be inflated in the ICA or vertebral arteries at the site of the meningeal feeding arteries, which have anastomotic connections with the target vessel being embolized. It can thus prevent the embolic material from occluding the intracranial artery and/or causing distal embolism via those anastomotic channels. Third, balloon inflation in the feeding artery proximal to the Onyx injection position produces better control of the material’s reflux and more distal penetration into the fistula by simulating a “wedged” effect. Because liquid embolic agents such as Onyx preferentially flow down the pressure gradient, progressive occlusion of the fistulous connections decreases the gradient, resulting in reflux. With either an Onyx plug proximal to the injection catheter or with proximal balloon inflation, the proximal resistance increases, producing a gradient that allows forward Onyx penetration. This technique is especially useful in DAVFs because of the rapid tapering, small-diameter feeding arteries resulting in early reflux during Onyx injection. Also, the balloon allows an earlier and more effective “plug” that reduces procedure time and therefore radiation exposure.

In addition, the venous BAT can prevent Onyx from inadvertently occluding the lumen of a functioning venous sinus and migrating into adjacent key cortical or deep veins when the balloon occludes the recipient venous structure. This in turn avoids the potential sequelae of venous infarction or hemorrhage. In our series, 2 types of Onyx liquid material, Onyx 34 and Onyx 18, were used for transarterial embolization of the DAVFs. Onyx 34 has a higher viscosity than Onyx 18 (34 and 18 cSt, respectively), and this results in greater cohesion of the injected material and less mixing and fragmentation in the flow stream. Therefore, Onyx 34 may be used for high-flow fistulas to minimize the likelihood of distal Onyx migration to the outflow veins or pulmonary system. Because Onyx 18 may allow better penetration due to its lower viscosity, it can be used when distal migration is thought to be less likely. With arterial balloon-assisted Onyx embolization, although flow is controlled in that pedicle (where the balloon is inflated), when the agent penetrates the other arterial pedicles, the possibility of venous migration can still occur. Also, in our experience when there was tenuous and critical pial venous outflow, we also selected Onyx 34 to ensure that those veins (such as the perimesenceph-
alic veins) were protected. Therefore, we used Onyx 34 in those cases in which there were other large arterial feeders (high flow) and/or critical pial venous outflow.

Our preliminary clinical experience with balloon-assisted transarterial Onyx embolization in selected patients with DAVFs has been encouraging. We used the venous BAT for protective purposes and the arterial BAT in the ECA feeding artery for better penetration and control of proximal Onyx reflux. Because most of the DAVFs in this series did not have CVR, transarterial Onyx embolization was chosen to decrease the arterial input enough to reduce the symptoms while secondarily avoiding progressive venopathy and subsequent transformation into a more malignant angioarchitecture. This technique may decrease the number of embolization sessions and improve the chance of anatomical cure.

Balloon-assisted transarterial Onyx embolization of craniofacial vascular malformations or DAVFs has been recently described in only 2 other small series.\textsuperscript{2,16} Rezende et al.\textsuperscript{16} reported use of a temporary balloon in the ophthalmic segment of the ICA during transarterial Onyx embolization via the MMA to treat a sphenoparietal DAVF. This technique prevented the untoward passage of Onyx into the ICA via the recurrent meningeal branch of the OA, and complete occlusion of the fistula was achieved with a single injection. Arat et al.\textsuperscript{2} used the arterial BAT through the ECA approach in 4 patients with high-flow craniofacial vascular malformations during transarterial Onyx embolization. They reported difficulty with balloon deflation and retrieval in 1 patient due to extensive Onyx reflux. Andreou et al.\textsuperscript{1} used the arterial BAT during N-butyl cyanoacrylate embolization in 5 patients harboring high-flow pial AVFs or DAVFs. Although 1 DAVF in this series was completely occluded, they used a balloon as flow control only because of incompatibility of N-butyl cyanoacrylate with the balloon material and the likelihood of catheter retention ("gluing") with long injection of glue. Our arterial BAT with Onyx differs significantly in that we not only perform flow control but also allow creation of a plug without the concomitant risk of catheter retention (gluing).

It should be noted, however, that the balloon-assisted
approach should be reserved for complicated cases such as the ones described in our cohort. In most cases, this novel technique cannot substitute for proper use of the reflux-hold-reinjection technique. Additionally, the potential concerns of this technique need to be considered. Increased proximal resistance may allow Onyx reflux into all artery-to-artery or artery-to-vein connections, some of which may be dangerous anastomoses. Meticulosus fluoroscopic monitoring of Onyx deposition and a good understanding of cerebrovascular and the DAVF’s unique angioarchitectural anatomy are critical to minimize the likelihood of this occurrence. Although only short-term follow-up results are available, the durable and long-term occlusive effect of Onyx has been confirmed in our previous swine experiment.  

Conclusions

The balloon-assisted approach provides a new complementary method in the transarterial use of Onyx to treat DAVFs not amenable to transvenous embolization. It is anticipated that with more experience, this technique will result in more anatomical cures and improved safety during transarterial Onyx embolization of selected DAVFs. Long-term angiographic follow-up and larger series will be necessary to further assess the efficacy and durability of this novel technique.

Disclosure

Dr. Duckwiler is a paid consultant for ev3, Inc. The authors report no other conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References


Fig. 5. Case 7. A: Preembolization left CCA angiogram showing a DAVF with CVR (arrowhead). Multiple occipital feeding arteries originate from proximal points of origin along the OA (arrow), where the arterial BAT can significantly reduce flow into the fistula. B: Superselective angiogram obtained during the arterial BAT in the proximal OA (arrowhead), demonstrating decreased washout in the fistula from the other feeding arteries. C: Postembolization left ECA angiogram revealing complete occlusion of the fistula.


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