CASE REPORT

Direct access to the middle meningeal artery for embolization of complex dural arteriovenous fistula: a hybrid treatment approach

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SUMMARY

Endovascular embolization has become increasingly favored over microsurgical resection for treatment of complex dural arteriovenous fistulas (DAVFs). However, endovascular treatment can be restricted by tortuous transarterial access and a transvenous approach is not always feasible. We present a Borden III DAVF treated by direct access to the middle meningeal artery (MMA) and Onyx embolization performed in a hybrid operating room—angiography suite. A middle-aged patient with pulsatile headaches was found to have left transverse sinus occlusion and DAVF with retrograde cortical venous drainage fed by multiple external carotid artery (ECA) feeders. Endovascular attempts via conventional transvenous and transarterial routes were unsuccessful, and the major MMA feeder was accessed directly after temporal craniotomy was performed under neuronavigation. Onyx embolization was performed; complete occlusion of the fistula was achieved. Three-month follow-up angiography showed no residual filling; the patient remains complication-free. A combined surgical—endovascular technique in a hybrid operating room—angiography suite can be an effective treatment for DAVFs complicated by inaccessible arterial and transvenous approaches.

BACKGROUND

Dural arteriovenous fistulas (DAVFs) are vascular abnormalities consisting of direct connections between meningeal arteries and dural venous sinuses or cortical veins. The Borden classification system is often used to categorize DAVF according to venous drainage characteristics,¹ and classes II and III are thought to have a more aggressive clinical course and a higher risk of neurological deficits. The etiology of DAVF development is not completely understood, but its formation may follow a precipitating event such as trauma, infection, or venous thrombosis of the affected venous channel, which is frequently a dural venous sinus.^{2 3}

Several treatment options exist for symptomatic DAVFs. Microsurgical resection usually consists of ligation of the dural draining vein and skeletonization and isolation of the involved dural sinus. Although considered more definitive treatment, these operations can be challenging due to the presence of venous hypertension, multiple transosseous and dural feeders, and the need for extensive bony work. More contemporary endovascular techniques

using liquid embolic agents including Onyx (ev3-Covidien, Irvine, California, USA) and n-butyl cyanoacrylate (NBCA) (Trufill; Codman, Raynham, Massachusetts, USA) have become increasingly favored and are now considered first-line treatment in these cases.⁴ DAVFs can be accessed by transvenous or transarterial approaches, based on lesion morphology. Onyx is often used to embolize the fistula and, compared with other agents, its use has the advantage of allowing a larger volume of embolic agent to be injected over a longer duration, thereby reducing the number of staged treatments needed.⁵ However, protracted NBCA injections can also be achieved with ancillary approaches using NBCA dilution and co-injection of dextrose water to prevent polymerization of cast in the vicinity of the microcatheter being used to deliver the NBCA. Additionally, transvenous occlusion of the affected sinus using coils can be an effective treatment. Nevertheless, endovascular treatment can be limited by difficult access to target vessels, as dural feeders for a transarterial approach are usually tortuous and a transvenous route is not always possible because the fistulous venous pouch is isolated from adjacent venous sinuses. Here we present a case of Borden III DAVF of the transverse sinus treated by direct access of the middle meningeal artery (MMA) and Onyx embolization performed in a hybrid operating room—angiography suite.

CASE PRESENTATION

A middle-aged patient presented with progressively worsening pulsatile headaches and an episode of dizziness. Neurological examination revealed no focal findings; however, a bruit was audible over the left mastoid region.

INVESTIGATIONS

Brain MRI and angiography showed prominent cortical veins in the left hemisphere, suggesting a vascular abnormality. Diagnostic cerebral angiography demonstrated a complex DAVF supplied by branches of the left external carotid artery (ECA), including the left MMA and left occipital artery (figure 1A, B) as well as bilateral posterior meningeal arteries (figure 1C, D), and drained retrogradely by multiple dilated cortical veins into the superior sagittal sinus (figure 1B). The left transverse sinus was occluded; the direct connection between the feeding arteries and cortical veins suggested the lesion was a Borden type III DAVF.

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Figure 1 Diagnostic cerebral angiogram showing a Borden III dural arteriovenous fistula (DAVF). (A) Injection from the left external carotid artery, arterial phase, shows feeders from the left middle meningeal artery and left occipital artery. (B) The venous phase shows occlusion of the left transverse sinus and cortical venous drainage via multiple enlarged veins into the superior sagittal sinus. The DAVF was also supplied by bilateral posterior meningeal arteries (C), left vertebral artery injection and (D) right vertebral artery injection.

TREATMENT

An attempt was made to access the major left ECA pedicles endovascularly under conscious sedation; however, the severe arterial tortuosity at the level of the foramen spinosum and calvarial sections precluded our ability to get close enough to the

fistula to provide effective transarterial embolization. The transvenous approach was also ineffective because of the complete isolation of the left transverse sinus.

Due to the failure of the endovascular approach, we considered direct vascular access distal to the transcalvarial sections

Figure 2 Intraoperative photographs. (A) Direct craniotomy access to the left middle meningeal artery (MMA), which is significantly hypertrophied. (B) Advancement of an Echelon-10 microcatheter into a left MMA branch for endovascular access.

where the critical tortuous segments were encountered. We planned a small left temporal craniotomy using CT angiography-guided stereotactic navigation (Stryker Navigation, Kalamazoo, Michigan, USA) to obtain direct access to the major left MMA hypertrophied branch for subsequent endovascular Onyx embolization in the hybrid operating room–surgical angiography suite (Siemens Healthcare, Malvern, Pennsylvania, USA).

Under general anesthesia, the patient was positioned laterally with Mayfield pin fixation and a 6 Fr femoral sheath was inserted. Stereotactic navigation was registered with head CT angiography data and achieved <2 mm accuracy. A curvilinear incision was made to expose the temporal bone (figure 2A).

An angled diagnostic catheter was advanced into the left ECA and an angiographic run was performed. With the assistance of neuronavigation, the location of the main left MMA feeder was identified and further verified using intraoperative fluoroscopic co-localization during intraoperative angiography (figure 3A). Using a polishing drill, the elongated relatively straight segment of the MMA feeder was skeletonized and remaining bone peeled off to directly expose the feeder. After confirming the optimal insertion point that bypassed the proximal tortuosity of the left MMA, an arteriotomy was created with a 25 gauge needle single puncture and an Echelon-10 microcatheter (ev3-Covidien) was advanced over a Syncho2 microcatheter (Boston Scientific, Natick, Massachusetts, USA) directly into the left MMA (figure 2B). Under roadmap guidance from the diagnostic catheter in the left ECA, the microcatheter was advanced to the distal left MMA, close to the fistula location (figure 3B). After confirmation with microangiography, embolization was performed with Onyx-34 through the Echelon-10 microcatheter. The Onyx was allowed to reflux proximally in the MMA, and ultimately 2 mL was injected. A control angiogram from the left ECA demonstrated complete obliteration of the DAVF (figure 3C). The bony opening was covered with titanium plates and the incision closed in multiple layers.

OUTCOME AND FOLLOW-UP

The patient tolerated the procedure well, was discharged 1 day after surgery, and had an uneventful postoperative course. At 3 months after the procedure the headaches had completely resolved and the patient remained free of clinical symptoms. Follow-up angiography showed no residual filling of the fistula (figure 4A–C).

DISCUSSION

Treatment options for complex DAVFs include endovascular embolization (transarterial or transvenous approach), microsurgical ligation and, controversially, radiosurgery.⁶ Endovascular embolization is frequently considered first-line treatment for DAVF. Successful clinical and angiographic outcomes are routinely reported following embolization.^{4 5 7 8} However, uncertainty exists with respect to treatment via a transarterial or a transvenous embolization technique. Our experience, as exemplified by this case, demonstrates that transarterial embolization can be highly effective and curative if one can obtain access close enough to the fistulous connection. Others have noted that transvenous embolization is also highly effective, as would be expected because access is made to the same venous pouch fistulous connection.^{3 7} It should be recognized that, before the availability of protracted arterial embolization with liquid embolic agents such as Onyx or specifically-configured NBCA, the short duration of injection prevented complete obliteration of fistulous segments so a higher cure rate was achieved using a transvenous route. This

Figure 3 Intraoperative angiogram. (A) Left external carotid artery (ECA) injection to create a roadmap with the use of suction to indicate the location of the middle meningeal artery. (B) Position of the Echelon microcatheter before Onyx injection into the feeders. (C) Left ECA injection shows no residual filling of the dural arteriovenous fistulae after Onyx embolization of the fistula.

is no longer an impediment because protracted injections are routine. Moreover, the transarterial route is frequently more attractive because part of the pathology that results in high-risk DAVFs with retrograde cortical venous drainage is the isolation of the venous sinus and fistulous pouch, which makes endovascular transvenous access difficult and sometimes impossible.

Several innovative techniques combining microsurgical and endovascular methods have been devised to treat complex

Figure 4 Three-month follow-up angiogram. Injection of the left external carotid artery (A), left vertebral artery (B), and right vertebral artery (C) shows no residual filling of the dural arteriovenous fistula.

DAVFs. Multiple investigators have attempted direct cut-down to the venous side of the DAVF and successfully performed transvenous embolization after obtaining open surgical access.^{9–12} Weber *et al*¹³ described an effective approach to treating DAVFs when venous access is limited in which the occluded transverse sinus is recanalized by balloon angioplasty and soft coronary stent deployment to re-establish antegrade flow and ameliorate venous hypertension. Crowley *et al*¹⁴ reported a surgical technique to access the ECA (exposed and cannulated) for subsequent transarterial embolization in a patient with tortuous arch and proximal vessel anatomy. An approach through the ECA is a potentially beneficial alternative in unusual cases where the limitation of vascular access is more proximal. On the basis of the success of these cases and others, we have developed a novel approach to accommodate the particular circumstances dictated by our case.

In this report we describe combined surgical and transarterial embolization for treatment of a Borden III DAVF. Although the tortuosity of the feeders could make a transarterial endovascular approach a technical challenge, stereotactic navigation and direct exposure of the intracranial MMA enabled access to the fistula. By using a direct access technique, we were able to bypass the proximal tortuosity and inject Onyx. The chance of cure in our patient was significantly improved by the large-volume injection, and complications associated with Onyx reflux were avoided by this approach. Our patient benefited from the use of a hybrid operating room–angiography suite, which permitted the use of both surgical and endovascular techniques. Thus, we did not have to separate the case into surgical and endovascular procedures, which can increase the risk of complications. As endovascular techniques develop, combined techniques may become increasingly obsolete, yet they offer a contemporary alternative for complicated cases unamenable to conventional treatment options.

Although Onyx DAVF embolization has been associated with widespread success, the procedure is not without risk and several complications have been identified. Lv *et al*¹⁵ reported that Onyx injection caused bradycardia in 11.1% of DAVF embolization cases by stimulating the trigeminocardiac reflex intraoperatively. Intravenous atropine will effectively block the depressor response due to Onyx in the MMA at the level of the foramen spinosum. Additionally, Pei *et al*¹⁶ reported a case of hypoglossal nerve palsy that began after Onyx embolization. Onyx reflux within the hypoglossal canal may have interrupted vessels that supply the hypoglossal nerve. Despite these complications, Onyx embolization has continued to provide successful results in most patients.^{4 5}

Learning points

- ▶ Endovascular techniques using liquid embolic agents including Onyx and n-butyl cyanoacrylate have become first-line treatment for dural arteriovenous fistulas (DAVFs).
- ▶ DAVFs can be accessed transarterially or transvenously, but endovascular approaches can be limited by tortuous feeding arteries or occluded venous sinuses.
- ▶ Direct surgical access to a major arterial feeder, such as the middle meningeal artery, can be performed safely with neuronavigation guidance.
- ▶ Embolization via direct access to a major feeding artery has the advantage of avoiding proximal arterial tortuosity, close placement of the microcatheter to the fistulous point, and injection of a large volume of Onyx without concerns of reflux.

Contributors NL and AHS: conception and design. NL and AMB: drafting the manuscript. All authors were involved in acquisition of the data, analysis and interpretation of the data, critically revising the manuscript and final approval of the manuscript.

Competing interests EL: shareholder/ownership interests in Intratech Medical Ltd, Mynx/Access Closure, and Blockade Medical LLC; principal investigator for the Covidien US SWIFT PRIME trials; compensation from Abbott for carotid training for physicians. MM: educational grant from Toshiba. AHS: research grants from the National Institutes of Health (co-investigator: NINDS 1R01NS064592-01A1 and NIBIB 5R01EB002873-07, not related to present submission), and the University at Buffalo (Research Development Award); financial interests in Hotspur, Intratech Medical, StimSox, Valor Medical, Blockade Medical, and Lazarus Effect; consultant to Blockade Medical, Codman and Shurtleff, Concentric Medical, ev3/Covidien Vascular Therapies, GuidePoint Global Consulting, Lazarus Effect, MicroVention, Penumbra, Stryker Neurovascular and Pulsar Vascular; speakers' bureaus of Codman and Shurtleff and Genentech; serves on National Steering Committees for the following company-sponsored trials: 3D Separator (Penumbra), FRED (MicroVention) and SWIFT PRIME (Covidien); advisory boards of Codman and Shurtleff and Covidien Neurovascular; and honoraria from Abbott Vascular and Codman and Shurtleff for training other neurointerventionalists in carotid stenting and for training physicians in endovascular stenting for aneurysms. KVS: consultant/speakers' bureau/honoraria: Toshiba; speakers' bureau/honoraria: ev3/Covidien, The Stroke Group.

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