Endovascular Management of Anterior Cranial Fossa Dural Arteriovenous Malformations

A Technical Report and Anatomical Discussion

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Summary

Dural arteriovenous fistulas (dAVFs) of the anterior cranial fossa have traditionally been treated by open surgical disconnection. Safe navigation through the ophthalmic artery or fragile cortical veins has historically provided a barrier to effective endovascular occlusion of these lesions. Using current microcatheter technology and embolic materials, safe positioning within the distal ophthalmic artery, beyond the origin of the central retinal artery, is achievable. We describe two cases in which anterior cranial fossa dAVFs were treated by exclusively endovascular strategies, and highlight the pertinent technical and anatomic considerations. We discuss the clinical symptoms resulting from the differing venous drainage patterns.

Introduction

Dural arteriovenous fistulas (dAVFs) of the anterior cranial fossa are rare lesions that impart unique anatomical and pathophysiological considerations. While the cerebral sinuses serve as the direct venous outlet in the majority of dAVFs, these fistulae drain almost exclusively into pial veins^{1,2}. Cortical venous drainage portends poor outcome secondary to an increased risk of hemorrhage and venous infarction³. An-

terior cranial fossa dAVFs, therefore, necessitate complete obliteration and cure^{4,5,6,7}.

Currently, most dAVFs are treated optimally by endovascular modalities. A notable exception has been anterior cranial fossa lesions. Cribiform plate fistulae usually derive primary arterial supply from the distal ophthalmic artery and the anterior and posterior ethmoidal arteries. As no dural sinus exists at this location, venous drainage most often occurs into frontal cortical veins, often resulting in dangerous venous ectasias and varices⁸. Due to the small caliber of tortuous ophthalmic and ethmoidal arteries, coupled with a risk of inadvertent central retinal artery occlusion, endovascular techniques have not historically been the first line of treatment^{9,10}.

Rapid advances in technology have greatly increased the scope of endovascular approaches to these difficult lesions.

Evolving microcatheter design, embolic agents and imaging equipment have rendered previously inaccessible lesions manageable by endovascular strategies.

We describe two patients harboring anterior cranial fossa, cribiform plate dAVFs successfully treated through an exclusively endovascular approach. In each of these cases, Onyx non-adhesive liquid embolic agent was used (in conjunction with n-butyl cyanoacrylate in one of the cases) to obliterate the fistulous connection. The report contrasts the venous drainage pattern of the two anterior cranial fossa dAVFs. The first fistula drains classically, ultimately in-

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Figure 1 AP (A) and lateral (B) right internal carotid artery angiogram and AP left internal carotid artery angiogram (C) demonstrating an anterior cranial fossa dAVF fed by the bilateral ophthalmic/ethmoidal arteries with drainage through inferior frontal pial veins (with an associated varix) and ultimately into the superior sagittal sinus. AP (D) and lateral (E) right external carotid angiograms illustrate filling of the dAVF through the ethmoidal arteries.

Figure 2 Superselective angiogram (oblique) of the right ophthalmic artery distal to the origin of the central retinal artery. Note the absence of a retinal choroidal blush and prominent opacification of the dAVF.

to the superior sagittal sinus, while the second fistula assumes egress into the deep venous system. These anatomical differences result in distinct clinical manifestations

Clinical Presentation/ Technique

The collection and publication of material in this study was approved by the University of

California Los Angeles Medical Center Institutional Review Board.

Case 1

The patient is a 57-year-old man with history of Hunt Hess grade I, Fisher Grade II subarachnoid hemorrhage who presented with an anterior cranial fossa dAVF evident on angi-

Figure 3 Post Onyx embolization lateral (A) and AP (B) angiogram of the right common carotid artery demonstrates complete closure of the fistula. Note the Onyx cast in the region of the distal right ophthalmic artery.

Figure 4 Lateral oblique left (A) and right (B) internal carotid angiograms demonstrating the cribriform plate dAVF supplied by the bilateral distal ophthalmic/ethmoidal arteries. Note the inferior frontal venous varix seen on both projections.

ogram from an outside hospital. The procedure was performed under general anesthesia, and an intravenous bolus of heparin was given at the beginning of the intervention and anticoagulation was maintained throughout. A diagnostic angiogram demonstrated a right cribriform plate dAVF supplied by ethmoidal branches of the distal bilateral ophthalmic arteries, and the ethmoidal branches of the bilateral internal maxillary arteries. Venous drain-

age occurred through a dilated venous pouch and into right frontal cortical veins that ultimately drained into the anterior portion of the superior sagittal sinus (Figure 1). Following the diagnostic cerebral angiogram, a 6 French shuttle sheath (Cook Inc., Bloomington, IN, USA) was placed in the right internal carotid artery. A 4.3F 115 cm Outreach distal access catheter (Concentric Medical, Mountain View, CA, USA) was advanced through the shuttle sheath

Figure 5 AP angiogram of the left internal carotid artery in the arterial (A,B), capillary (C) and venous (D) phases, demonstrating cortical venous drainage and ultimate egress into the deep venous system. See text for anatomical discussion.

into the cavernous segment of the right internal carotid artery. Next, under roadmapping technique, a Marathon microcatheter (ev3, Irvine, CA, USA) was navigated through the distal access catheter and into the right ophthalmic artery, distal to the origin of the central retinal artery and proximal to the origin of the ethmoidal arteries. Super-selection angiography confirmed the position of the microcatheter tip with no evidence of choroidal blush (Figure 2). The microcatheter was then pre-

pared with the dimethyl sulfoxide (DMSO) in the standard manner. Under subtraction fluoroscopy, Onyx 34 (ev3, Irvine, CA, USA), followed by Onyx 18 (ev3, Irvine, CA, USA), was then slowly infused into the fistula. This was continued until adequate penetration of the fistula and some subtle reflux of the Onyx was noted. The microcatheter was removed, and an angiogram was performed. There was no filling of the fistula. A small amount of Onyx penetration was noted in the collaterals from the

Figure 6 Lateral (A) and AP (B) superselective angiograms of the ophthalmic artery distal to the origin of the central retinal artery. Note the absence of a retinal choroidal blush and prominent opacification of the dAVF.

Figure 7 Post nBCA embolization, lateral (A) and AP (B) angiograms of the left common carotid artery with no early venous drainage evident in the region of the cribriform plate. Adequate contrast opacification is evident distal to the angiographic origin of the central retinal artery.

left ophthalmic artery (Figure 3). A diagnostic angiogram of the left common carotid artery was then performed. There was no angiographic evidence of residual fistula.

The patient experienced an uneventful perioperative course and was discharged home from the hospital on postoperative day 3, neurologically intact. At one month follow-up, he remained without clinical deficit. Eight month follow-up angiogram demonstrated no evidence of residual fistula.

Case 2

The patient is a 54-year-old woman who presented with a two-year history of severe headaches, lethargy, diplopia and anosmia. She was referred with an MRI suspicious for a right inferior frontal lobe vascular malformation. She refused open surgical intervention but was amenable to angiography and endovascular treatment.

The procedure was performed under general

Figure 8 Lateral angiogram of the left internal carotid (A) and vertebral (B) arteries. The unaffected thalamic vasculature fills the internal cerebral veins in a normal temporal fashion. Drainage occurs through the right lateral mesencephalic vein. There is filling of the posterior portion of the straight sinus via precentral cerebellar veins, but no filling of the vein of Galen or anterior segment of the straight sinus.

Figure 9 AP (A-C) and lateral (D-F) angiograms of the right internal carotid artery in the arterial (A,D), capillary (B,E) and venous (C,F) phases. Residual filling of the dAVF occurs via the right ophthalmic/ethmoidal arteries. An nBCA glue cast is evident in the posterior aspect of the left BVR and alters the venous drainage of the fistula. Blood flow into the right BVR (by way of the anastomosis with the left BVR anterior to the location of the persistently thrombosed Galenic vein) is obstructed by the glue cast, establishing the left petrosal vein and ipsilateral transverse/ sigmoid sinus as the primary venous outlet for the fistula.

Figure 10 Post Onyx embolization AP (A) and lateral (B) angiograms of the right common carotid artery demonstrate complete closure of the fistula.

Figure 11 Three-dimensional reconstruction of pre-operative left internal carotid artery angiogram (oblique views). A) Left ophthalmic artery. B) Fistulous connection. C) Venous ectasia. D) Peduncular vein. E) Left BVR. F) Right BVR.

anesthesia, and an intravenous bolus of heparin was given prior to the intervention and anticoagulation was maintained throughout. A diagnostic cerebral angiogram revealed a Cognard type IV anterior cranial fossa dAVF at the cribiform plate, supplied by anterior and posterior ethmoidal branches of the bilateral ophthalmic arteries (Figure 4). Drainage of this fistula occurred through an inferior frontal vein with an

associated venous varix. This drained into the right deep middle sylvian vein and through a peduncular vein that crossed the anterior aspect of the brainstem, to anastomose with the left basal vein of Rosenthal (BVR). There was flow through the left BVR, into the right BVR at the junction with the previously thrombosed vein of Galen. Venous outlet occurred through the bilateral BVRs and into the petrosal veins

(predominately right) and ultimately the transverse and sigmoid sinuses (Figure 5). There was no posterior drainage out the BVR into the vein of Galen or the straight sinus.

Following the diagnostic cerebral angiogram, a 6 French angled guide catheter (Cordis Neurovascular, Miami, FL, USA) was placed in the left internal carotid artery. Next, under roadmapping technique, a Marathon microcatheter was navigated into the left ophthalmic artery, distal to the origin of the central retinal artery and proximal to the origin of the ethmoidal arteries. Super-selection angiography confirmed the position of the microcatheter tip with no evidence of choroidal blush (Figure 6). Under subtraction fluoroscopy, a 1:1 mixture of n-butyl cyanoacrylate (nBCA) glue diluted in lipiodol (Cordis Neurovascular, Miami, FL, USA) was then infused into the fistula. The microcatheter was then quickly removed. Immediate post-injection angiogram demonstrated no filling of the fistula through the left internal carotid artery (Figure 7). Distal nBCA material was noted in the left BVR. The unaffected vasculature filled the internal cerebral veins with no evidence of contrast stagnation. Drainage occurred through the right lateral mesencephalic vein (Figure 8).

The 6F guide catheter was then inserted into the right internal carotid artery. An intracranial biplane angiogram was performed. Persistent filling of the above-described arteriovenous fistula remained through the distal right ophthalmic artery via ethmoidal collaterals at the cribriform plate. This fistula was again drained by an inferior frontal vein with a venous pouch that drained into the right deep middle sylvian vein and then to a peduncular vein that crossed the anterior aspect of the brainstem and anastomosed with the BVR on the left side. There was sluggish flow through the left BVR secondary to nBCA glue material and no apparent flow into the right BVR. The venous outlet occurred via the left petrosal vein and into the left transverse and sigmoid sinus (Figure 9).

Next, under roadmapping technique, a Marathon microcatheter (ev3, Irvine, CA, USA) was navigated into the right ophthalmic artery, distal to the origin of the central retinal artery and proximal to the origin of the ethmoidal arteries. Super-selection angiography confirmed the position of the microcatheter tip with no evidence of choroidal blush. The microcatheter was then prepared with the dimethyl sulfoxide (DMSO) in the standard manner. Under subtraction

fluoroscopy, Onyx 18 (ev3, Irvine, CA, USA) was then slowly infused into the fistula. This was continued until adequate penetration of the fistula and some subtle reflux of the Onyx was noted. The microcatheter was removed, and an angiogram was performed. There was no filling of the fistula and no distal embolization of the Onyx material (Figure 10).

Postoperative carotid and vertebral artery angiograms demonstrated unaffected thalamic drainage via the internal cerebral veins with no contrast stagnation. Drainage occurred through the right lateral mesencephalic vein. There was filling of the posterior portion of the straight sinus via precentral cerebellar veins but no filling of the vein of Galen (as in previous angiograms).

The patient experienced postoperative confusion and lethargy with transient MRI evidence of edema in the left thalamus/ midbrain. She recovered fully and was discharged home two weeks after the procedure, with resolution of her diplopia and headaches. She returned for her one month follow-up appointment without complaint and neurologically intact, aside from her pre-existing anosmia. Six month follow-up angiogram demonstrated no evidence of residual fistula.

Discussion

These cases illustrate important anatomical considerations and technical concepts in the endovascular management of anterior cranial fossa dAVFs.

The fistula in *case 1* represents a typical anatomic pattern of anterior cranial fossa dAVFs. Arterial supply occurred via the bilateral ophthalmic and ethmoidal arteries. Inferior frontal cortical venous drainage ultimately fed into the anterior portion of the superior sagittal sinus. Venous ectasias and varices with associated hemorrhage (as in this case) are common, and increase treatment urgency. Obliteration of the fistulous connection was achieved with Onyx through a robust right ophthalmic artery. Penetration of the fistulous connection and the contralateral feeding vessels was achieved with minimal reflux.

The fistula in *case 2* was supplied by the bilateral ophthalmic/ ethmoidal arteries as they traversed the cribriform plate. The venous outlet pattern of this lesion is not characteristic of most anterior cranial fossa dAVFs (Figure 11). Initial drainage into cortical veins and associ-

ated varices is typical. However, outlet occurred via the middle cerebral vein and the deep venous system rather than into the anterior segment of the superior sagittal sinus.

Veins from the basal surface of the frontal lobes typically drain in two directions. Most commonly, anterior orbitofrontal branches drain into the superior sagittal sinus. Posteriorly directed veins (posterior orbitofrontal and olfactory veins) can join the venous confluence beneath the anterior perforated substance and drain into the superficial middle cerebral veins, cavernous sinus or sphenoparietal sinus. The patterns of egress do not typically involve the deep venous drainage system.

In the second case, the right deep middle sylvian vein drained into a peduncular vein, crossed the anterior aspect of the brainstem and anastomosed with the BVR on the left side. As the Galenic vein was persistently thrombosed, flow occurred through the left BVR, into the posterior segment of the right BVR. A high volume of venous flow, unable to reach the vein of Galen, straight sinus and torcular, was accommodated by the BVRs and cortical veins. This drainage pattern threatens the venous outflow from critical thalamic and mid-brain structures. This likely resulted in clinical manifestations of headaches, lethargy and diplopia. Venous outlet occurred through the bilateral BVRs and into the petrosal veins (predominately right) and ultimately the transverse and sigmoid sinuses (sagittal sinus⁵). There was no posterior drainage out the BVR into the vein of Galen or the straight sinus. As demonstrated in this case, this altered drainage pattern, coupled with venous congestion secondary to thrombosis, can lead to clinical symptoms referable to the thalamus and midbrain.

Following embolization with nBCA through the left ophthalmic artery, a distal glue cast resulted in stagnation of flow through the posterior aspect of the left BVR (Figure 9). As residual filling of the dAVF occurred via the right ophthalmic/ ethmoidal arteries, the nBCA fragment altered the flow pattern of the fistulous venous drainage. Blood flow into the right BVR (by way of the anastomosis with the left BVR anterior to the location of the persistently thrombosed Galenic vein) was completely obstructed by the glue cast, establishing the left petrosal vein and ipsilateral transverse/sigmoid sinus as the primary venous outlet. This represented a dangerous temporary alteration in flow dynamics as the available routes of venous egress were

diminished, but arterialized fistulous flow into the venous system was not eliminated.

Obliteration of the fistulous connection was ultimately achieved with Onyx through a robust right ophthalmic artery. Following embolization, thalamic drainage via the internal cerebral veins occurred in normal temporal fashion, with no contrast stagnation. As the vein of Galen was thrombosed, drainage occurred through the right lateral mesencephalic vein. There was filling of the posterior portion of the straight sinus via precentral cerebellar veins but no filling of the vein of Galen (as in previous angiograms). Congestion in the left BVR likely resulted in the transient thalamic and brainstem edema evident on postoperative MRI and the associated lethargy and confusion. These above examples highlight two different venous drainage patterns for anterior cranial fossa dAVFs (one typical and one atypical). The report also demonstrates the safety and efficacy of endovascular treatment for anterior cranial fossa dAVFs in patients with suitable vascular anatomy. Although the anatomical configurations and embolization materials utilized varies, the technical principals of such cases remain constant.

Achievement of safe endovascular closure of anterior cranial fossa dAVFs depends on angioarchitecture of the lesion and regional anatomical pathophysiology. Different routes of vascular access and a variety of embolic materials are available. Transvenous fistula access requires catheter navigation from the puncture site to the anterior superior sagittal sinus and through tortuous and fragile cortical veins, often with associated varices⁴. Therefore, the shorter, transarterial access route is usually preferable^{11,12}. If present, external carotid artery supply is most often of secondary significance, and thus, the most effective access is usually through the distal ophthalmic and ethmoidal arteries¹³.

Using current microcatheter technology, safe positioning within the distal ophthalmic artery, well beyond the origin of the central retinal artery, is often achievable. This was the case in both of our patients.

Historically, transarterial embolization of anterior fossa dAVFs has been performed with nBCA through the distal ophthalmic artery. This technique requires high levels of operator expertise and remains somewhat unpredictable secondary to polymerization properties, viscosity and variable binding rates, requiring manipulation according to flow velocity and distance from the arteriovenous shunt². Proximal po-

lymerization fails to occlude the fistula while distal venous migration may result in infarction or hemorrhage.

The advent of Onyx non-adhesive liquid embolic agent provides a valuable alternative¹⁴. Onyx does not polymerize. As the DMSO solvent diffuses, Onyx material precipitates; allowing for a prolonged injection and resultant shunt penetration and exit vein occlusion¹⁵. Positioning of the microcatheter a significant distance distal to the central retinal artery is of paramount importance during Onyx infusion, as this technique affords a higher risk of serious complications secondary to reflux. The reflux of Onyx along the microcatheter, when attempting to obtain more distal penetration, could produce visual impairment through retinal artery ischemia or penetration of normal anastomoses. By contrast, nBCA may simply fail to penetrate deeply enough to achieve a cure, but is far less likely to reflux along the catheter and cause retrograde filling of regional anastomoses.

In each of our cases, embolic agents were injected without detrimental reflux, and the fistula was completely obliterated. One dAVF had bilateral ophthalmic and ethmoidal supply, and was treated with Onyx alone while the other was supplied by the bilateral ophthalmic/ethmoidal arteries and was treated with combined nBCA and Onyx embolization.

The alternative to endovascular occlusion is surgical coagulation and fistula disconnection. Surgery is performed in a non-eloquent area of the brain, provides a large exposure, and allows for evacuation of an accompanying hematoma, if present^{9,16,11}. As open surgical approaches to

anterior cranial fossa dAVFs are relatively straightforward and safe, endovascular treatment strategies are acceptable only if they can meet these standards. The two patients in this series were discharged from the hospital, neurologically intact and remained so at one month follow-up. In such cases, endovascular treatment affords patients the opportunity to avoid the small risks and inconvenience inherent to frontal craniotomy.

Conclusions

This report illustrates the feasibility, safety and efficacy of an endovascular treatment approach for anterior cranial fossa dAVFs. The two cases demonstrate different patterns of venous egress. The more typical first case depicts the classic venous drainage pattern of inferior frontal lobe dAVFs, into the superior sagittal sinus. The second case is an anatomical illustration of an unusual drainage pattern. Venous egress occurs through the deep venous system and correlates with the associated clinical symptoms. As surgical disconnection is a proven, curative management strategy for anterior cranial fossa dAVFs, patient selection is of paramount importance in determining the most appropriate candidates for endovascular fistula occlusion.

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