Endovascular Treatment of Tentorial Dural Arteriovenous Fistulae

E. WAJNBERG¹, G. SPILBERG¹, M.T. REZENDE², D.G. ABUD³, I. KESSLER⁴, C. MOUNAYER⁵.

Association of Rothschild Foundation Alumni (ARFA)

¹ Hospital Universitário Clementino Fraga Filho, Federal University of Rio de Janeiro; Rio de Janeiro, Brazil

² Hospital Felício Rocho; Belo Horizonte, Minas Gerais, Brazil

³ Hospital das Clínicas, Medical School of Ribeirão Preto, University of São Paulo; São Paulo, Brazil

⁴ Hospital Universitário de Brasília, University of Brasília; Brasília, Brazil

⁵ University Hospital Dupuytren; Limoges, France

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Summary

Tentorial dural arteriovenous fistula (DAVF) is a rare vascular disease, which accounts for less than 4% of all cases of intracranial DAVF. Because of the high risk of intracranial hemorrhage, patients with tentorial DAVF need aggressive treatment. Management approaches are still controversial, and endovascular treatment has emerged as an effective alternative. In the current work, we describe our experience with the endovascular approach in the treatment of these deep and complex DAVF of the tentorium.

Eight patients were treated between January 2006 and July 2009. Six patients (75%) presented with intracranial hemorrhage related to the DAVF rupture. Four patients (50%) had subarachnoid bleeding and two had intraparenchymal hematoma. Endovascular treatment was performed via the transarterial route alone in five cases (62.5%), by the transvenous approach in two cases (25.0%) and in a combined procedure using both arterial and venous routes in one patient (12.5%). Complete obliteration of the fistula was achieved in all cases. The outcome at 15 months was favorable (modified Rankin scale 0-3) in seven (87.5%) patients. Complete cure of the lesion was confirmed in these cases.

This paper reports on the effectiveness of endovascular treatment in tentorial DAVF management. The choice of the venous versus the arterial approach is determined by regarding different anatomical dispositions.

Introduction

Dural arteriovenous fistulae (DAVF) account for 10-15% of intracranial arteriovenous shunts¹⁻³, and tentorial DAVF account for nearly 4% of total intracranial DAVF. The natural history of DAVF depends to a great extent on their venous drainage patterns^{1,4}. Intracranial DAVF that drain into a major dural sinus, without reflux into cortical veins, usually have a benign clinical course^{1,5,6}. However, if sinus drainage occurs with retrograde flow into arterialized leptomeningeal veins, or if the fistula drains solely into cortical leptomeningeal veins, a more aggressive natural history is observed^{1,3,7-9}.

Tentorial DAVF almost always drain into leptomeningeal veins (Cognard types III and IV), and thus carry a high risk for hemorrhage. The reported occurrence of intracranial hemorrhage ranges from 60% to 74%^{1,10-12}. In some cases, the hemorrhage can include a fatal bleed in the posterior fossa^{7,13}. Therapeutic options for treating DAVF include transarterial and/or transvenous embolization, surgical excision of the dural nidus, ligation of the draining vein, and stereotactic radiosurgery^{2,9,14,15}. The aim of the treatment is complete and permanent obliteration of the fistula.

Since the initial descriptions of therapeutic embolization of DAVF in the early 1970s⁹, various embolic agents have been used with the arterial approach, including particles, liquid silicone, ethyl alcohol, platinum microcoils, and n-butyl cyanoacrylate (NBCA)^{16,17}. Ethyl vinyl

Table 1 Patient presentation, angiographic characteristics, and treatment approach.

Patient number	Age/sex	Presentation	Feeding artery	Venous drainage	Grade	Treatment/approach vessel
1	47/F	Subarachnoid hemorrhage	MMA	Perimesencephalic	III	Transarterial w/Onyx® - MMA
2	70/M	Occipital hemorrhage	MMA PMA	Vermian veins (cerebellar)	IV	Transarterial w/Onyx® - MMA
3	65/M	Subarachnoid hemorrhage	MMA MHT OA PA	Perimesencephalic vein of Galen (Varix), tentorial, cerebellar	III	Transvenous w/coils
4	52/M	Pulsatile tinnitus, hemiparesthesia	MMA MHT PMA	Lateral Pontomesencephalic vein	IV	Transarterial w/Onyx® - MMA
5	42/F	Occipital hemorrhage	MMA OA PMA	Occipital vein	IV	Transarterial w/Onyx® - MMA
6	49/M	Subarachnoid hemorrhage	MMA OA MHT	Perimesencephalic vein of Galen, cerebellar	III	Transarterial w/Onyx® -MMA
7	42/M	Incidental	MMA OA MHT	Perimesencephalic vein of Galen, cerebellar	III	Transarterial w/Onyx® - MMA Transvenous w/ coils
8	61/F	Subarachnoid hemorrhage	MMA MHT	Tentorial, cerebellar	III	Transvenous with Onyx®

OA, occipital artery; PMA, posterior meningeal artery; MHT, meningohypophyseal trunk; MMA, middle meningeal artery; APA, ascending pharyngeal artery

alcohol (EVAL, or Onyx®) is a biocompatible polymer that is dissolved in dimethyl sulfoxide (DMSO). In comparison with NBCA, Onyx® is not an adhesive, as it does not polymerize but rather precipitates as the DMSO diffuses in aqueous conditions, resulting in vessel occlusion. Due to the lack of polymerization, the use of Onyx® allows a prolonged injection time and is more predictable than NBCA.

We believe that it is possible to safely and effectively treat tentorial DAVF with direct cortical drainage of the vein by endovascular techniques. Due to its capacity to penetrate the shunt and occlude the exit vein, Onyx® has been extremely effective in achieving complete occlusion of fistulae in our patients without the need for complementary surgical treatment. Because the embolic material reaches the draining vein, accomplishing total occlusion, complete cure of the fistulae were guaranteed. Despite recent advances in endovascular technology, many researchers^{7,18-20} advocate open surgery for the treatment of tentorial DAVF. This report reviews the management of tentorial DAVF, presenting eight cases of tentorial

DAVF with pure leptomeningeal venous drainage that were successfully treated by interruption of the draining vein, and examining the rationale for endovascular therapy.

Patients and Methods

All patients initially underwent computed tomographic (CT) scanning or magnetic resonance imaging (MRI) of the brain. Patients all underwent six-vessel cerebral angiographic evaluations before treatment. The clinical findings, angiographic characteristics of the eight patients treated with the endovascular technique were retrospectively reviewed, and neurological outcomes assessed by the modified Rankin Scale (mRS) (Table 1).

Patient Population

We reviewed the files of eight consecutive patients suffering from intracranial tentorial DAVF and treated by endovascular techniques between January 2005 and July 2009 in three

different departments. The patients harboring tentorial DAVFs were identified in the Database of each institution. Patient records, neuroimaging, and follow-up data were retrospectively reviewed. There were 5 men and three women with ages ranging from 42 to 70 years (mean age, 53.5 yrs). Table 1 presents a complete profile of the patients in this series. All of the patients were treated by the endovascular approach. The transarterial route alone was used in five patients, the transvenous route alone in two and a combined procedure using both arterial and venous routes in one patient.

Clinical Presentation

The features of these patients are summarized in Table 1. The majority of patients (75%) in this series presented with sudden headache and intracranial hemorrhage, including four with subarachnoid hemorrhage (SAH) (Fisher grades II-IV) and two with intraparenchymal hematoma. Nonhemorrhagic presentation was observed in two patients, one of whom was discovered after the appearance of left-sided tinnitus and, in another patient, the DAVF was considered an incidental finding. Non-focal neurological deficits were not observed. No etiological factors, including brain trauma, surgery, or sinus thrombosis, were identified in any of the patients.

Angiographic Features

All patients underwent complete cerebral angiography, including both internal and external carotid arteries and both vertebral arteries. All angiograms were reviewed by an interventional neuroradiologist at the time of treatment and were independently reviewed in our retrospective analysis. Lesions were graded according to the Cognard classification scheme. Lesion location, arterial supply, retrograde leptomeningeal venous drainage, venous varices or stenosis, and associated vascular pathological features were noted (Table 1). All patients presented with direct leptomeningeal venous drainage (type III or IV). According to the Cognard classification, 62.5% of the fistulae were type III, and the remaining 37.5% were type IV.

Treatment

The procedure was performed under general anesthesia in all cases, and an intravenous bolus of 5000 IU of heparin was given at the be-

ginning of the procedure. A 6F femoral access was carried out, and the tip of a 6F guiding catheter was placed inside the right external carotid artery when the transarterial route was chosen. When a venous approach was taken, a bilateral 5F and 6F femoral access was employed, one for road-mapping and the other for internal jugular access. In most cases in this series, the lesions exhibited tortuous retrograde leptomeningeal venous drainage without direct connection to a sinus, making arterial approaches technically easier than a transvenous approach. When a catheter could be navigated transarterially to a position just proximal to the nidus, this approach was chosen to push embolic material across to the fistulous zone. For patients with a safe venous pathway to the nidus, a transvenous endovascular approach was used as a first-line therapy. Using fluoroscopic guidance and road-mapping, a 1.5 Fr microcatheter (Ultraflow, Micro Therapeutics, Irvine, CA, USA) was advanced over a 0.010 inch micro guidewire (Silverspeed, Micro Therapeutics, CA, USA) into the largest caliber afferent pedicle up to the fistulous zone. The microcatheter lumen was flushed with DMSO, and the dead space was slowly filled with Onyx®18. Next, 0.2 mL of Onyx® was injected within the DAVF simultaneously with subtracted fluoroscopy, with special attention given to arterial reflux. After the microcatheters were wedged, Onyx® was injected using the “plug-and-push” injection technique. When unwanted reflux of Onyx® or flow into undesirable vessels was observed, we paused in the injection for one to ten minutes to solidify the Onyx®, and then restarted the injection. The immediate control angiogram showed complete DAVF obliteration without reflux in every case. When embolization with micro-coils was necessary, bare platinum coils and standard techniques previously described were used^{2,15,17,21}.

Results

Analysis of the angiographic findings revealed that all patients presented with direct venous drainage. According to the Cognard classification¹⁰, 62.5% of the fistulae were type III, and the remaining 37.5% were type IV. Venous varix of the vein of Galen was demonstrated in one case and treated with coils that completely occluded the varix. Total occlusion of the shunt was observed in all eight patients.

Figure 1 A) Vertebral artery angiogram (lateral view) revealing a tentorial dural arteriovenous fistula, with feeding arteries arising from the posterior meningeal artery. B) Venous phase, showing retrograde venous pial drainage to the Vermian veins. C) Transarterial embolization (anteroposterior view): a microcatheter was positioned through the middle meningeal artery to the fistulous zone. A total of 1.8 ml of Onyx® was injected across the shunt to the venous side, leading to total occlusion of the shunt. D) Left vertebral artery injection (anteroposterior view, post-procedure), demonstrating complete obliteration of the fistula.

Six of the eight patients (75%) initially underwent transarterial embolization. Five of these patients (83%) experienced complete radiological cures after a single session. Patient 3 underwent transvenous embolization, and patient 8 received combined, staged treatment by both transarterial and transvenous procedures that provided radiological obliteration of his lesion. Three patients (37.5%) underwent transvenous embolization: two with micro-coils and one with Onyx®. Only one patient required combined treatment, both transarterial and transvenous, to obtain a cure. No patients underwent radiosur-

gery or subsequent surgical resection of their lesions. Table 1 presents a detailed analysis of data for each patient in this series.

Immediate post-embolization angiography revealed complete obliteration of all tentorial DAVF. All patients underwent angiographic follow-up. There was no evidence of recurrence in any of these cases. All presenting symptoms not related to the hemorrhage resolved after DAVF obliteration. No seizures were reported.

The clinical follow-up periods averaged 15.5 months, with a range of one to 35 months, for the seven surviving patients. Patient 2 died

Figure 2 A) Brain MRI (axial FLAIR) depicting abnormal flow voids, which represent dilated veins in the cerebello-pontine angle and along the medial border of the temporal lobe. B) Right internal carotid artery angiogram (lateral view) revealing a tentorial dural arteriovenous fistula, with feeding arteries arising from the internal carotid artery (marginal tentorial artery), and drainage into the leptomeningeal veins. C) Transvenous embolization: the microcatheter was positioned through the superior petrous sinus into the venous pouch, and coil occlusion was achieved. D) Right internal carotid artery angiogram, post-procedure, demonstrating obliteration of the fistula.

from consequences of pulmonary fibrosis. The angiographic follow-up periods averaged 9.2 months, with a range of 0 to 20 months. Three patients underwent a single post-treatment angiographic examination, performed immediately after endovascular treatment. Five patients underwent two or more angiographic assessments. All patients in this study achieved angiographically-documented obliteration of their

lesions before discharge. No recurrent lesions were discovered in follow-up angiographic assessments. No patient experienced episodes of re-bleeding, and there were no cases of decline in neurological status during follow-up clinical monitoring. Table 2 presents the clinical and radiological follow-up data for this patient population. Of the seven surviving patients, all exhibited neurological improvement; there were

Table 2 **Angiographic and post-treatment clinical evaluations.**

Patient no.	Clinical follow-up results	mRS	Follow-up angiograms
1	Normal neurological examination	0	Post-procedure only
2	Died	6	Post-procedure only
3	Normal neurological examination	0	8 mo
4	Normal neurological examination	0	20 mo
5	Residual quadrantanopsia	1	6 mo
6	Normal neurological examination	0	6 mo
7	Normal neurological examination	0	6 mo
8	Normal neurological examination	0	Post-procedure only

mRS: modified Rankin Scale

no episodes of re-bleeding or other nonhemorrhagic neurological deficits. The outcome at 15 months was favorable (modified Rankin scale 0-3) in seven (87.5%) patients. There was one death unrelated to the procedure.

Illustrative Cases

Patient 2 (Figure 1A-D): A 60-year-old man with idiopathic pulmonary fibrosis and severe polycythemia, had an episode of sudden headache associated with homonymous hemianopsia. The non-enhanced CT scans of his brain showed occipital intraparenchymal hemorrhage and vascular serpiginous images in the right occipital region. A cerebral arteriogram demonstrated early arteriovenous shunting to a DAVF fed by distal branches of the middle and posterior meningeal arteries with retrograde venous pial drainage to the superior vermian vein. His treatment consisted of transarterial embolization, after navigating a 1.5 Fr flow-guided microcatheter through the middle meningeal artery to the fistulous zone, with 1.8 mL of Onyx® injected across the nidus to the venous side, leading to total occlusion of the shunt.

Patient 3 (Figure 2A-D): A 65-year-old man was admitted to the neurosurgical department with a Fisher III subarachnoid hemorrhage. MRI and angiography revealed a left tentorial DAVF with arterial supply from the external and internal circulation. Feeding vessels were identified arising from the marginal tentorial artery, the middle meningeal artery and the accessory meningeal artery. Drainage occurred through the leptomeningeal veins to a large venous varix and an enlarged perimesencephalic vein, the straight sinus, superior petrous sinus, and pial veins to the transverse-sigmoid junc-

tion. Treatment consisted of transvenous embolization with Guglielmi detachable coils. Transvenous embolization of the venous pouch was performed through the superior petrous sinus, via the right femoral-right jugular vein. Complete occlusion of the shunt was reached and follow-up angiography eight months later revealed persistent obliteration of the fistula.

Discussion

A tentorial DAVF is an abnormal arteriovenous shunt located in the tentorial dura mater. The arterial supply arises from the dural branches of the cerebral arteries⁵. An extensive fistula may empty itself directly into a dural sinus causing retrograde flow in the arterialized leptomeningeal veins or may drain solely via the leptomeningeal veins, causing venous tortuosity, variceal aneurysmal dilatation of pial veins, local venous congestion and sometimes bleeding^{2,18-20,22}.

Picard et al.¹² divided the venous tributaries in the tentorium into the following three regions. The lateral tentorial sinus group lies adjacent to the lateral sinus and receives supratentorial drainage from the lateral and inferior surfaces of the temporal and occipital lobes. The medial tentorial sinus group is situated adjacent to the torcula and drains into it or the lateral or straight sinus. These sinuses primarily receive infratentorial venous drainage from the cerebellar hemispheres and vermis. Finally, lesions along the free edge of the tentorium receive venous drainage from the basilar and lateral mesencephalic veins and may have infra- or supratentorial drainage, or even drain into spinal veins (Cognard Type V).

DAVF have a variable natural history with regard to the risk of bleeding. This natural history is related to the type of venous drainage. Cognard et al.¹⁰ defined the groups of venous drainage patterns: type I, located in the main sinus, with antegrade flow; type II, in the main sinus, with reflux into the sinus (IIa), cortical veins (IIb), or both (IIa + b); type III, with direct cortical venous drainage without venous ectasia; type IV, with direct cortical venous drainage with venous ectasia; and type V, with spinal venous drainage. DAVF with leptomeningeal drainage have a much more aggressive natural course. Patients with this drainage pattern are about 20 times more likely to have progressive neurological deterioration^{9,13}.

In 2002, Kim et al.¹³ studied the drainage of DAVF and found that tentorial DAVF have an almost constant cortical drainage. Spontaneous subarachnoid hemorrhage, intraventricular hemorrhage, intracranial hematoma, visual symptoms, and bruit may result from tentorial DAVF^{13,23}. Awad et al.¹ reviewed 337 cases of DAVF and found that 97% of patients with tentorial DAVF showed aggressive behavior associated with hemorrhagic or nonhemorrhagic stroke, possibly because most cases of tentorial DAVF drained only into the pial vessels.

In a review of 86 cases of tentorial DAVF from the English language literature¹⁸ only 5.8% of the cases of tentorial DAVF emptied into dural sinuses, including the transverse sinus, superior petrosal sinus, and straight sinus. Of the 86 cases, 94.2% of tentorial DAVF were drained solely by the leptomeningeal veins for the thrombotic dural sinus. In these lesions, venous outflow obstruction precipitated leptomeningeal venous drainage, resulting in the arterIALIZATION of pial veins and the formation of venous aneurysms, both of which are prone to hemorrhage.

The goal of treatment should be the complete and permanent occlusion of the arteriovenous shunt. Several options are available for the treatment of DAVF, including arterial embolization, transvenous occlusion, stereotactic radiosurgery, and direct surgical obliteration^{9,12,14,21,24-27}. Interventional and surgical procedures are both used to disconnect the venous drainage system. Management options for the treatment of DAVF include surgical procedures (venous drainage clipping, surgical excision, arterial feeder ligation) as well as transvenous or transarterial endovascular treatment. The choice of an endovascular strategy

depends on the clinical presentation, anatomical location, arterial supply, and venous drainage pattern. Several advances in endovascular technique allow for a successful obliteration of the majority of these lesions. Treatment selection depends on the skills of the neurosurgeon and interventional neuroradiologist, and on lesion accessibility.

Endovascular Treatment

It is our view that endovascular treatment should be considered the first choice in the treatment of tentorial DAVF. Either an arterial or a transvenous approach can be used. In cases with easy venous access to the fistula, a transvenous approach is preferred. Most transverse/sigmoid sinus fistulae can be treated via transvenous access. Klisch et al.¹⁵ reported an 86% cure rate using transvenous coil embolization of transverse/sigmoid sinus fistulae. In more difficult lesions, where no easy venous access is identified, arterial wedging has been used as a feasible option^{9,17}. Houdart et al.²⁸ employed a local craniotomy for exposure of the sinus and subsequent direct puncture, using coils and/or NBCA to obliterate the fistula.

Two routes of venous drainage are observed for tentorial DAVF: the dural sinus and leptomeningeal veins. Transvenous embolization has been effective in the treatment of tentorial DAVF draining into the dural sinus^{9,12,15}. The transvenous endovascular approach, which is highly effective in curing other types of DAVF¹⁵, has historically been avoided in tentorial DAVF, as this method would require difficult catheter navigation through tortuous leptomeningeal veins to reach the point where the fistula is located.

Polyvinyl alcohol particles (PVA) are easy to handle, causing palliative reduction of the shunting flow, but the recurrence rate is usually lower with liquid adhesives such as NBCA, and the possibility of reaching the site of fistulous communication is greater^{9,16-18}. The use of NBCA necessitates substantial handling experience. Because of NBCA's physico-chemical properties, namely its polymerization rate and viscosity, its effects are not always predictable. In some cases, it may not reach the shunt itself, producing proximal feeder occlusion. Transarterial embolization with Onyx® has been suggested as an initial treatment for tentorial DAVF when a good vascular route is present. The cure does not depend on the liquid agent

used, but rather in its ability to reach the venous outlet of the fistula. The option of using particles should be considered a palliative treatment.

The trigeminal reflex has been recently described²⁹ as a complication of the embolization of DAVFs using Onyx®. It can be caused by mechanical stimulation of the middle meningeal artery in the spinosum foramen during embolization. Although it is a potential complication of this method, it was not seen in our series.

Tomak et al.³⁰, in their series of 22 patients with tentorial DAVF, included 18 patients treated with transarterial embolization, only six of them being cured. The successful complete obliteration of a fistula through arterial access was only 33%, possibly due to the materials used to treat these patients. Using Polyvinyl alcohol particles, the transarterial route was rarely curative and latter in the series, NBCA allowed a better cure rate (45%).

Stereotactic radiosurgery has been described as a treatment modality for DAVF^{22,25,26,31}. Lewis et al.²² treated nine patients with fistulae involving the tentorium. Seven patients were treated through a combination of embolization and radiosurgery. Four patients had residual DAVF on follow-up. Pan et al.³¹ reported a complete obliteration rate of 58% for tentorial fistulae treated with either radiosurgery exclusively, or with radiosurgery after surgery/embolization had failed to produce complete obliteration. Symptoms were completely resolved in 71% of the patients. Radiosurgery represents an adjunct to the treatment of DAVF and should be reserved for benign DAVF for which other treatments have failed. DAVF with pial drainage requires immediate and complete obliteration, which cannot be provided by radiosurgery^{9,20,30}. Microneurosurgery also plays a role in the management of patients with DAVF, its primary objective being the disconnection of the venous outlet. A simple DAVF on the cortical surface can be treated by disrupting the draining vein^{7,9,19}. As with transvenous endovascular occlusion, redirection of the flow may result in post-procedure hemorrhage⁷. More complex DAVF that require extensive exposure are best treated with the assistance of cra-

nia base techniques^{8,11,16,32}. Before the development of endovascular or skull base techniques, technical difficulties in deep or complex DAVF usually resulted in a suboptimal outcome³².

Cranial base techniques have only recently been described in the treatment of DAVF^{8,11,32}. Lewis et al.¹¹ described four patients who were treated through cranial base techniques. Three tentorial and one inferior petrosal DAVF were treated through anterior, posterior, or combined petrosectomy. De Jesus³² utilized an anterior petrosectomy to treat a tentorial DAVF. This approach allows access to the temporal and posterior fossae. Resection of the sinus may not be necessary, and the fistula can be treated by disconnecting the draining vein.

The interruption of the draining vein by open surgery as the vein enters the subarachnoid space is thought to be an optimal treatment for tentorial DAVF with pure leptomeningeal venous drainage. Grisoli et al.¹⁹ first applied this method, and it proved to be safe and effective. Other studies^{7,20} also supported this strategy based on the findings of venous drainage patterns during the treatment of tentorial DAVF. Fujita et al.²⁴ suggested that intraoperative microvascular Doppler monitoring is useful not only in evaluating arterialized leptomeningeal drainage veins but also in confirming the complete obliteration of these vessels.

Conclusion

Dural arteriovenous fistulae have a highly variable clinical history. Recent developments in catheter interventions now allow most patients to be cured with transcatheter embolization, although surgery is still the preferred option in some situations. Familiarity with drainage patterns, aggressive symptoms, recent technical advances, and current treatment strategies are essential for the treatment of intracranial dural tentorial DAVF. The choice of the venous versus the arterial approach is determined by regarding different anatomical dispositions. Longer follow-up is mandatory to determine the stability of the treatment, especially in the cases treated with Onyx®.

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Eduardo Wajnberg, MD
 Rua Nina Rodrigues, 72/102
 Jardim Botânico
 Rio de Janeiro, RJ
 22461-100 – Brazil
 Tel.: +55 21 99995451
 Fax: +55 21 25125147
 E-mail: eduardowj@gmail.com