The treatment of complex dural arteriovenous fistulae through cranial base techniques

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Introduction: The endovascular modality of treatment is the preferred treatment modality for DAVF. In some circumstances, successful obliteration may not be possible by endovascular means, and such cases may require a direct surgical treatment. The authors report on their experience with the use of cranial base approaches in the treatment of deep and complex DAVF.

Materials and Methods: Nine patients were treated between 1992 and 2003. There were six females and three males. Four patients presented with intracerebral hemorrhage, two with progressive myelopathy, two with tinnitus, and one with incapacitating chronic seizures. Four DAVF were tentorial, two transverse sigmoid, one craniocervical, one straight sinus, and one sphenoparietal. Endovascular embolization was attempted and unsuccessful in four cases, and was successful only as an adjunct to surgery in four others. All patients required the use of cranial base approaches to disconnect the fistula or resect the nidus.

Results: Complete obliteration of the fistula was possible in all cases. Six-month follow-up results were obtained on seven patients where there was no evidence of recurrence. One postoperative temporal-lobe hematoma required surgical evacuation. One patient died two years postoperatively from an unrelated cause.

Conclusion: This retrospective study demonstrates that complex DAVF can be successfully treated with the assistance of cranial base techniques.

Key Words: Arteriovenous fistula, dural, skull base
**Table 1: Patient Characteristics**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/Sex</th>
<th>Presenting Symptoms</th>
<th>Anatomical Location</th>
<th>Arterial Supply</th>
<th>Venous Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68/F</td>
<td>Quadriaparesis</td>
<td>Cranio cervical</td>
<td>Rt VMA</td>
<td>Leptomeningeal perimedullary</td>
</tr>
<tr>
<td>2</td>
<td>57/F</td>
<td>Incapacitating seizures</td>
<td>Tentorial (Isolated SPS)</td>
<td>Rt MHPA, Rt MMA, Rt AICA</td>
<td>Leptomeningeal Rosenthal</td>
</tr>
<tr>
<td>3</td>
<td>42/M</td>
<td>Cerebellar hemorrhage</td>
<td>Tentorial (Isolated SPS)</td>
<td>Rt MHPA, Rt MMA</td>
<td>Leptomeningeal petrosal vein</td>
</tr>
<tr>
<td>4</td>
<td>22/M</td>
<td>Temporal hemorrhage</td>
<td>Tentorial (Isolated SPS)</td>
<td>Rt MHPA, SPS</td>
<td>Leptomeningeal perimedullary</td>
</tr>
<tr>
<td>5</td>
<td>58/M</td>
<td>Ataxia</td>
<td>Transverse/sigmoid</td>
<td>Lt OA, Lt VA, Lt MHPA, Lt MAMA</td>
<td>Transverse/sigmoid sinus</td>
</tr>
<tr>
<td>6</td>
<td>42/F</td>
<td>Intracranial bruit</td>
<td>Transverse/sigmoid</td>
<td>Lt MHPA, Lt MAMA, Lt STA, Lt OA, Lt PICA, Lt PMA</td>
<td>Transverse/sigmoid sinus</td>
</tr>
<tr>
<td>7</td>
<td>60/F</td>
<td>Intracranial bruit</td>
<td>Straight sinus (Isolated)</td>
<td>Lt MHPA</td>
<td>Leptomeningeal superior cerebellar surface veins</td>
</tr>
<tr>
<td>8</td>
<td>45/F</td>
<td>Cerebellar hemorrhage</td>
<td>Sphenoparietal sinus</td>
<td>Lt OphthA</td>
<td>Lt sphenoparietal sinus</td>
</tr>
<tr>
<td>9</td>
<td>20/F</td>
<td>Temporal hemorrhage</td>
<td>Sphenoparietal sinus</td>
<td>Lt MHPA</td>
<td>Leptomeningeal superior cerebellar surface veins</td>
</tr>
</tbody>
</table>

AMA = accessory meningeal artery; MHPA = meningohypophyseal artery; MMA = middle meningeal artery; OA = occipital artery; OphthA = ophthalmic artery; PICA = posterior inferior cerebellar artery; PMA = posterior meningeal artery; SPS = superior petrosal sinus; TSS = transverse sigmoid sinus; VA = vertebral artery; VMA = vertebral meningeal artery. (Full form of AICA = anterior inferior cerebellar artery; STA = superficial temporal artery)

### Presenting Symptoms

Seven patients presented with rapid neurological deterioration. Four patients had intracerebral hemorrhages; two in the temporal lobe and two in the cerebellum. Three patients presented with progressive neurological symptoms from ischemia. Two patients experienced rapidly progressive myelopathy, and one patient experienced 13 years of incapacitating seizures. Two patients presented with unilateral tinnitus. In both patients, bruits were auscultated on the mastoid process.

All nine patients underwent six-vessel cerebral angiography. Four tentorial, two transverse/sigmoid, one cranio cervical, one straight sinus, and one sphenoparietal DAVF were identified. Both transverse/sigmoid fistulae had antegrade flow with no retrograde or leptomeningeal drainage. The vein of Labbé had antegrade flow in both cases. All other DAVF had either pure leptomeningeal drainage or retrograde reflux from the involved sinus.

### Treatment

The cranial base DAVF was treated through a transcondyilar craniotomy. The angiogram showed a single feeding vessel arising from the meningeal branch of the vertebral artery. Attempted embolization was unsuccessful as cannulation of the VMA was not possible. The patient was surgically treated employing a far lateral approach with removal of one-third of the right condyle. The dura was opened with a linear incision posterior to the vertebral artery. The dural sheath of Meckel’s cave was opened to expose the trigeminal nerve. The greater superficial petrosal nerve (GSPN) was cut to avoid facial nerve damage from retraction. Removal of the bone posterior to the trigeminal nerve in Glasscock’s triangle exposed the petrous portion of the carotid artery. The bone in the Kawase’s triangle, posterior to the carotid artery, was removed up to the SPS. The dural tela of Meckel’s cave was opened to expose the trigeminal nerve. The dura was then opened in a linear fashion from the inferior lateral temporal lobe to the SPS. Feeding arteries arising from the cavernous sinus were coagulated and cut. Once the SPS was encountered, it was clipped and cut, exposing the posterior fossa. The draining vein was then identified and cut.

The cranial base procedures for Patients 3 and 4 were performed in the same fashion. Patient #3 had draining directly into the petrosal vein. After the SPS was cut, the petrosal vein was coagulated and cut. Patient #4 had direct drainage into the SPS with reflux into superficial temporal veins. In this case, the entire medial half of the SPS was removed.

Patient #5, who also had a tentorial DAVF with an isolated SPS, required an orbitozygomatic osteotomy. After the sectioning of the SPS, the draining veins were identified in the posterior fossa. They were then coagulated and cut.

Two cases had transverse sigmoid sinus fistula. Patient #6 had...
multiple feeding vessels, including the left OA, VA, MMA, MHPA, and AMA. N-butyl cyanoacrylate (NBCA) embolization was used to treat the OA, MMA, and AMA. Tinnitus resolved following treatment; however, her symptoms of tinnitus returned 6 months later. The patient refused further endovascular treatment. Surgery was then offered as an option for the patient. Extensive removal of bone was necessary to skeletonize the TSS. This was accomplished through combined retrosigmoid and retrolabyrinthine bony removal. The jugular bulb was exposed by transcondylar removal of bone, including the jugular tubercle. Complete removal of the TSS from the vein of Labbé to the jugular bulb was achieved. Five mm of the lateral SPS was also removed with the TSS.

Patient #7 also presented with a TSS-DAVF. Multiple ipsilateral feeding vessels were noted on the left MHPA, MMA, AMA, STA, OA, PICA, PMA, and VMA. Antegrade flow was also noted from the vein of Labbé. Embolization of the TSS was not attempted. This could not be performed safely because of the proximity of the feeding vessels to the antegrade draining vein of Labbé. Bone removal also was used to skeletonize the TSS. This included a large retrosigmoid craniotomy with a combined petrosectomy. Jugular bulb exposure was not required in this case; therefore, a transcondylar approach was not necessary. The sinuses were resected from the vein of Labbé to the lower portion of the sigmoid sinuses. The SPS was also cut in the medial portion.

One case of an isolated straight sinus was treated. Multiple right meningeal feeding vessels arose from the VMA on the right side. They traveled through the dura onto the roof of the tentorium towards the straight sinus. Instead of draining into the straight sinus, a large vein drained the fistula onto the superior surface of the right cerebellar hemisphere. Right VMA embolization with PVA was attempted but was unsuccessful. A right combined suboccipital and transcondylar craniotomy was performed. Transcondylar removal of bone allowed access to the origin of the multiple VMA feeders. The VMA was cut at its origin from the VA. This reduced hemorrhage during exposure of the draining vein. The draining vein was accessed through inferior retraction of the right cerebellar hemisphere. The vein was coagulated and cut where it bridged from the tentorium to the superior surface of the cerebellum.

Patient #9 presented with a rare sphenoparietal DAVF. A single feeding vessel arose from the ophthalmic artery and drained directly into the sphenoparietal sinus. Retrograde flow occurred into the temporal bridging veins. Attempted arterial embolization was unsuccessful. The feeding artery could not be safely cannulated. The fistula was surgically approached via a standard pterional craniotomy. The sphenoid bone was removed, exposing the artery as it entered the sphenoparietal sinus. This vessel was coagulated and cut as it entered the sinuses. The sphenoparietal sinus was not resected.

Surgical procedures and outcomes are summarized in Table 2.

Results

Immediate postoperative angiography revealed complete obliteration of all DAVF. Seven patients underwent follow-up angiography at six months. There was no evidence of recurrence in any of these cases.

All presenting symptoms not related to presenting hemorrhage resolved after surgical obliteration. The two patients with transverse/sigmoid fistulae had complete resolution of their tinnitus after resection of the sigmoid sinuses. No seizures have been reported in the one patient who presented with intractable chronic epilepsy secondary to a tentorial dural fistula. The two patients presenting with rapidly progressive brainstem dysfunction from venous hypertension had complete reversal of their symptoms after surgery. One patient had immediate improvement of her myelopathy.

One patient with a tentorial dural fistula developed a temporal lobe hematoma. The temporal lobe hematoma was evacuated without consequence. One patient died two years after surgery from an unrelated glioblastoma. One patient had a slight ataxia, and another patient has persistent seizure activity. Both of these were probably a result of presenting intracranial hemorrhage.

Table 2: Patient Outcomes

<table>
<thead>
<tr>
<th>Patient</th>
<th>Embolization</th>
<th>Surgical Procedure</th>
<th>Angiographic Outcome</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Attempted; unable to cannulate VMA</td>
<td>Transcondylar; cut draining vein Anterior petrosectomy; bisect SPS; cut draining vein</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 40 months</td>
</tr>
<tr>
<td>2</td>
<td>Partial MMA; PVA 150-250 microns and fibered microcoils; unable to cannulate MPHA</td>
<td>Anterior petrosectomy; cut draining vein</td>
<td>Obliterated immediate postoperative</td>
<td>Asymptomatic 24 months</td>
</tr>
<tr>
<td>3*</td>
<td>Partial MMA; PVA 500-700 microns</td>
<td>Anterior petrosectomy; cut draining vein</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 12 months</td>
</tr>
<tr>
<td>4</td>
<td>Attempted; unable to cannulate MPHA</td>
<td>Anterior petrosectomy; resect SPS Orbitalzygomatic anterior petrosectomy; cut draining vein</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 12 months</td>
</tr>
<tr>
<td>5</td>
<td>Partial MMA; PVA 150-250 microns and fibered microcoils; MPHA not attempted</td>
<td>Retrolabyrinthine/retromastoid; resect TSS</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 30 months</td>
</tr>
<tr>
<td>6</td>
<td>Initial treatment with NBCA of MMA, OA, and AMA. No re-treatment after recurrence</td>
<td>Combined petrosal/retrosigmoid; resect TSS</td>
<td>Obliterated immediate postoperative</td>
<td>Asymptomatic 48 months</td>
</tr>
<tr>
<td>7*</td>
<td>Partial (l) AMA, (l) MMA, (l) STA, (l) OA; PVA 500-700 microns and fibered microcoils</td>
<td>Transcondylar; cut draining vein External sphenoid bone removal; cut feeding artery</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 16 months</td>
</tr>
<tr>
<td>8</td>
<td>Not attempted</td>
<td>Combined petrosal/retrosigmoid; resect TSS</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 6 months</td>
</tr>
<tr>
<td>9</td>
<td>Attempted OphthalmA; unable to cannulate</td>
<td>Combined petrosal/retrosigmoid; resect TSS</td>
<td>Obliterated 6 months</td>
<td>Asymptomatic 6 months</td>
</tr>
</tbody>
</table>

*Only immediate postoperative angiography was obtained. All other cases had 6-month follow-up angiography.
Case presentation: Patient #5:

A 58-year-old white male was admitted to the neurosurgical service with myelopathy. MRI revealed significant lower brainstem changes (Figures 1a and 1b). Angiography showed a right tentorial DAVF with arterial supply from both the external and the internal circulation (Figures 2a, 2b, 2c). Feeding vessels were identified arising from the meningohypophyseal trunk. Drainage occurred through the perimedullary veins. A right orbitozygomatic osteotomy with anterior petrosectomy was performed for exposure of the arterial feeding vessels as well as the posterior draining vein. Access to the posterior fossa was obtained, allowing removal of the medial section of the superior petrosal sinus with the nidus and draining vein. Follow-up angiography revealed complete obliteration of the fistula (Figures 3a, 3b).

Discussion

Dural arteriovenous fistulae have a variable natural history that ranges from benign to aggressively life-threatening. This is related to the type of venous drainage. Awad et al observed that a DAVF with leptomeningeal drainage had a much more aggressive natural course. Patients with this drainage pattern were 20 times more likely to have progressive neurological deterioration. Borden et al defined the venous drainage pattern into three groups. Type I fistulae involve antegrade
Figure 3a: Lateral right internal carotid angiography shows complete obliteration of DAVF.

Figure 3b: AP right external carotid angiography shows no residual DAVF.

drainage into a major draining sinus. In these cases no venous hypertension occurs and the clinical course is benign. Type II fistulae drain into a major sinus but create a retrograde flow into other veins that also drain into the same sinus. In these cases neurological deterioration and hemorrhage results from the venous retrograde hypertension occurring within these veins. Type III fistulae do not have any communication with a sinus and drain only into the leptomeningeal vein. Many Type III DAVF are in close anatomical proximity to a large draining sinus but do not communicate with it.

The goal of treatment should be complete and permanent elimination of the arteriovenous shunt. Several options are available for the treatment of DAVF, including arterial embolization, transvenous occlusion, stereotactic radiosurgery, and direct surgical obliteration. 1,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22,23,24

Endovascular Treatment

Endovascular treatment should be considered as the first choice in the treatment of DAVF. This can be accomplished through either an arterial or a transvenous approach. In cases that have easy venous access to the fistula, a transvenous approach is preferred. Most transverse/sigmoid fistulae can be treated through transvenous access. Klisch et al22 reported an 86% cure rate using coil embolization of transverse/sigmoid fistulae. Complete occlusion of the sinus was achieved in 43%. In more difficult lesions where no easy venous access is identified, arterial wedging has been promoted.21,23 A more aggressive approach was advocated by Houdart et al.25 They employed a cranietomy for exposure of the sinus. This was followed by a second procedure with direct cannulization of the sinus. Glue, coils, or a combination of glue and coils were used to obliterate the fistula. The ten patients treated had complete obliteration and there was no permanent morbidity.

Transarterial embolization has been suggested as an initial treatment. Tonak et al21 presented their series of 22 patients with tentorial DAVF. Eleven patients were treated between 1996 and 2000 with transarterial embolization. Five patients were cured. However, only one patient underwent an angiogram after six months; therefore, long-term recurrence cannot be assessed. Successful complete obliteration of a fistula through arterial access is less than 50%.22 In cases with small diameter internal circulation feeding vessels, there is also an increased risk of stroke.4,13,16,18,21

Stereotactic Radiosurgery

Stereotactic radiosurgery has been previously described as a treatment modality for DAVF.19,20,24 Lewis et al19 treated nine patients with aggressive fistulae involving the tentorium. Seven patients were treated through a combination of embolization and radiosurgery (800-2000 eGy). Four patients had residual DAVF on follow-up. Link et al20 also reported 29 patients treated with radiosurgery (1800-2000 eGy) followed by particulate embolization. A variety of fistulae were presented, with the majority being transverse or cavernous sinus (18 patients). Angiography obtained at one to three years following treatment showed complete obliteration in 72% of the fistulae treated. Pan et al24 reported a complete obliteration rate of 58% of transverse/sigmoid fistulae treated with only radiosurgery (1650-1900 eGy) or with radiosurgery after surgery/embolization had failed to produce complete obliteration. 71% of the patients were cured of their symptoms.

Radiosurgery represents an important adjunct to the treatment of DAVF. However, it should be reserved for benign DAVF that have failed other treatments. Aggressive DAVF require urgent and complete obliteration that cannot be provided by radiosurgery.9,21,23

Surgical Treatment

Simple DAVF on the cortical surface can be treated by disrupting the draining vein.8,9,14 As with transvenous endovascular occlusion, redirection of flow may result in post-procedure hemorrhage.8 More complex DAVF that require extensive exposures are best treated with the assistance of cranial base techniques.10,13,18,26 Prior to the development of endovascular or skull base techniques, technical difficulties in deep or complex DAVF resulted in a suboptimal outcome. Sundt and Piepgras25 reported their results on 27 patients
with transverse/sigmoid DAVF in 1983. Skeletalization of the transverse-sigmoid junction was performed, followed by resection of the involved sinuses with its arteriovenous malformation. Twenty-two patients had excellent results. Two patients died and two others had poor outcomes.

Cranial base techniques have only recently been described in treating DAVF. Lewis et al described four patients who were treated through cranial base techniques. Three tentorial and one inferior petrosal DAVF were treated through either anterior, posterior, or combined petrosectomy. De Jesus reported an anterior petrosectomy to treat a tentorial DAVF. This approach allows access to both the temporal and posterior fossa. Multiple transosseous feeding arteries are treated by using a diamond drill. If the craniotomy is supplemented with an orbitozygomatic osteotomy, less temporal lobe retraction is required. Resection of the sinuses may not be necessary and the fistula can be treated by disconnecting the draining vein. However, if the sinuses must be resected or posterior fossa access is necessary, the removal of the petrous apex allows 360° exposure of the petrosal sinuses.

Dural arteriovenous fistulae that occur at the craniocervical junction can be exposed through transcondylar bone removal. Access to the vertebral artery as it penetrates the dura is necessary to expose a fistula in this location. The authors utilized this approach in a straight sinus fistula to reduce bleeding before the suboccipital craniotomy was performed.

Disconnection of the sphenoparietal fistula required exposure by extensive removal of the lesser sphenoid wing. The resection of the extradural bone to the meningo-orbital band exposed the abnormal vessel. This was an example of disconnecting a fistula extradurally, which could not have been accomplished through an intradural exposure.

Transverse/sigmoid fistulae are exposed through skeletalization of the transverse-sigmoid junction. The proximal exposure of the superior petrosal sinuses can be achieved through a partial posterior petrosectomy. The craniotomy can be extended down to the jugular bulb by transcondylar removal of bone. The entire sigmoid sinuses can be resected if necessary.

Most transverse/sigmoid fistulae are successfully treated through transvenous coil embolization. In some cases, surgical exposure of the sinuses is required because the sinuses is either isolated or obstructed. Endo et al successfully obliterated eight cases of TSS-fistulae through direct packing of the isolated sinuses. Houdart et al also had successful obliteration of five cases of TSS-fistulae utilizing direct packing through a small craniectomy. However, in completely obliterated TSS-fistulae, direct packing is not always successful. Goto et al reported that surgical resection of the TSS was necessary in 4 of 17 cases treated with direct packing. Based on these reports, it is relevant to include sinuses resection as a form of treatment.

**Conclusion**

Dural arteriovenous fistulae have a variable clinical history. Most DAVF can be treated successfully by endovascular techniques. However, in some circumstances this may not be the optimal treatment for complete and permanent obliteration. Standard surgical techniques may not be successful in gaining good exposure to the arteriovenous fistula or nidus. By utilizing cranial base techniques, DAVF can be successfully treated with minimal morbidity and mortality.

**References**

Kattner KA, et al: Cranial base techniques for DAVF


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