Dural arteriovenous fistulas draining into the petrosal vein or bridging vein of the medulla: possible homologs of spinal dural arteriovenous fistulas

Clinical article

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Object. Dural arteriovenous fistulas (DAVFs) with leptomeningeal venous reflux generally pose a high risk of aggressive manifestations including hemorrhage. Among DAVFs, there is a peculiar type that demonstrates direct drainage into the bridging vein rather than the dural venous sinus. The purpose of this study was to investigate the characteristics of DAVFs that drain directly into the petrosal vein or the bridging vein of the medulla oblongata.

Methods. Eleven consecutive cases of DAVFs that drained directly into the petrosal vein and 6 that drained directly into the bridging vein of the medulla were retrospectively reviewed. These cases were evaluated and/or treated at Hospital de Bicêtre in Paris, France, over a 27-year period. A review of previously reported cases was also performed.

Results. Both of these “extrasinusus”-type DAVFs demonstrated very similar characteristics. There was a significant male predominance (p < 0.001) for this lesion, and a significantly higher incidence of aggressive neurological manifestations including hemorrhage or venous hypertension than in DAVFs of the transverse-sigmoid or cavernous sinus (p < 0.001). This finding was considered to be attributable to leptomeningeal venous reflux. Regarding treatment, endovascular embolization (either transarterial or transvenous) is frequently difficult, and surgery may be an effective therapeutic choice in many instances.

Conclusions. Embryologically, both the petrosal vein and the bridging vein of the medulla are cranial homologs of the spinal cord emissary bridging veins that drain the pial venous network. The authors believe that DAVFs in these locations may be included in a single category with spinal DAVFs because of their similar clinical characteristics. (DOI: 10.3171/2009.1.JNS08840)

KEY WORDS • dural arteriovenous fistula • petrosal vein • posterior fossa • spinal cord vein • medulla

Apart from classifications based on anatomy, the presence of subarachnoid venous reflux has prognostic value. In particular, the type of DAVF that drains directly into the subarachnoid veins (previously described as “extrasinusus type”) commonly poses a high risk of hemorrhage or venous congestion because of its tendency to cause leptomeningeal venous reflux.2,3,6,10,27,28 We report on 17 cases of DAVFs that drained directly into the petrosal vein (petrosal vein–draining DAVFs) or the bridging vein in the vicinity of the medulla (medulla bridging vein–draining DAVFs). We believe that these DAVFs clinically resemble one another in many ways and should therefore be grouped and

Abbreviations used in this paper: DAVF = dural arteriovenous fistula; ICA = internal carotid artery; MMA = middle meningeal artery; NBCA = N-butyl cyanoacrylate; SAH = subarachnoid hemorrhage; SRS = stereotactic radiosurgery; TAE = transarterial embolization; VA = vertebral artery.
studied together. In the present study, we discuss the characteristics of these lesions from embryological and angio-architectural viewpoints, and explore their similarities to spinal DAVFs. 

**Methods**

Between November 1980 and October 2007, 359 consecutive patients with DAVFs in any location were referred to the Department of Diagnostic and Therapeutic Neuroradiology of Bicêtre Hospital. Among these patients we identified 11 cases (3.1%) of DAVF draining into the petrosal vein, and 6 (1.7%) draining into the medulla bridging vein. The clinical data and angiographic findings in these 17 cases were reviewed retrospectively. We excluded DAVFs located in remote regions that drained into posterior fossa veins secondary to thrombosis of their “natural” outlets, in particular cavernous sinus or transverse-sigmoid lesions with venous occlusions. In the previously published literature, we found 30 cases of petrosal vein DAVFs, and 35 cases of medulla bridging vein DAVFs, all of which were well described with clinical and angiographic information. These previously reported cases were analyzed together, with special attention to their clinical characteristics. Aggressive manifestations of these DAVFs (hemorrhage or nonhemorrhagic focal neurological deficits) were evaluated in comparison with DAVFs that developed in neighboring epidural venous structures, namely cavernous sinus or transverse-sigmoid sinus DAVFs, using the incidence of aggressive manifestations as reported by Awad et al. in 1990. Awad and colleagues analyzed their experience in 17 cases and reviewed 360 cases from the literature. Statistical significance was determined by the chi-square test.

**Results**

**Petrosal Vein–Draining DAVFs**

The clinical data and angiographic findings in petrosal vein–draining DAVFs are summarized in Table 1. The patients included 8 men and 3 women, with an age range of 39–69 years (average 51.5 years). The initial manifestations were SAH in 4, venous congestion in 3 (supratentorial region in 2 and spinal in 1), cerebellar hemorrhage in 1, trigeminal neuralgia in 1, and mass effect caused by a large partially thrombosed venous varix in 1 case. One patient (Case 10) had a sudden episode of severe headache 1 month before the medical examination, and SAH was strongly suspected.

Dural arteriovenous fistulas that drained into the petrosal vein were mainly fed by the petrous branch of the MMA and the basal tentorial branch from the cavernous portion of the ICA. Contributions from petrous ridge branches of the petromastoid branch of the occipital artery; dural branches of the superior, anteroinferior, or posteroinferior cerebellar arteries; and the marginal tentorial artery regardless of its origin (MMA, ICA, or ophthalmic artery) were also identified. In all 11 cases, the feeding arteries seemed to converge at the termination of the petrosal vein into the superior petrosal sinus. In 10 cases, venous drainage of DAVFs was exclusively into the petrosal vein. In only 1 case (Case 10), we identified faint antegrade flow through the narrow superior petrosal sinus in addition to reflux into the petrosal vein. Regarding the pattern of the venous drainage, an ipsilateral ascending course through the lateral mesencephalic vein, basal vein, and the vein of Galen to the straight sinus was observed in 8 cases. In 3 cases (Cases 1, 4, and 11) venous drainage to the contralateral side through the transverse pontine vein, the vein of the pontomedullary sulcus, or the anastomotic vein of the lateral recess of the fourth ventricle was identified. In 2 of these, Cases 1 and 11, there was reflux into the spinal cord vein. In all 11 cases, ectatic changes of the draining vein were identified. Varices in the draining vein were found in 10 cases. In all cases with demonstrated SAH, varices were identified.

Excluding 1 patient (Case 7) who declined treatment, the remaining 10 patients underwent initial treatment with TAE using glue (NBCA). Complete occlusion of the fistula was obtained in 5 patients (Cases 3, 4, 6, 8, and 9) by TAE alone. In the remaining 5 cases, a significant flow reduction was obtained in 3 patients (Cases 5, 7, and 11). These patients remained clinically stable during the follow-up period (averaging 40 months). In 2 patients (Cases 1 and 10), satisfactory flow reduction could not be obtained by TAE, and surgery was recommended. Surgical interruption of the draining petrosal vein was performed in the patient in Case 10, and postoperative angiography showed complete cure of the DAVF. Before surgery, transvenous embolization was attempted in the patient in Case 10, but catheterization into the affected petrosal vein could not be achieved.

**Medulla Bridging Vein–Draining DAVFs**

The cases of medulla bridging vein–draining DAVFs are summarized in Table 2. All 6 patients were men, with an age range of 37–71 years (average 53.6 years). The clinical manifestations in these patients included myelopathy caused by spinal cord venous hypertension in 2, SAH in 3, and headache in the 1 remaining patient.

Medulla bridging vein–draining DAVFs were commonly fed by dural branches of the VA and/or branches of the neuromeningeal trunk of the ascending pharyngeal artery. The fistula was located at the level of the occipit–C1 space in 3 cases, at the level of the foramen magnum in 2, and above the foramen magnum in the remaining case. An ascending pharyngeal arteriogram was useful in determining the exact level of the fistula, with its relation to the hypoglossal branch indicating the position of the hypoglossal canal. These DAVFs drained into the medullary vein and/or the spinal vein. Four cases (Cases 12–14, and 17) showed ascending venous drainage into the cortical vein of the cerebellum or supratentorially through the lateral pontine and lateral mesencephalic veins. Descending drainage through the anterior and/or posterior spinal vein was shown in 3 cases (Cases 15–17). In all 6 cases, ectasia of the draining vein was identified, and in all 3 patients who presented with SAH, varices were identified in the draining veins.

Transarterial embolization was initially attempted in
Extrasinus DAVFs in the posterior fossa

### TABLE 1: Clinical and angiographic characteristics in 11 cases with petrosal vein–draining DAVFs*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Side</th>
<th>Manifestations</th>
<th>Feeding Artery</th>
<th>Venous Drainage</th>
<th>Ec-tasia</th>
<th>Varix</th>
<th>Treatment</th>
<th>Angio Result</th>
<th>Outcome</th>
<th>FU Period (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69, M</td>
<td>lt</td>
<td>VH of spinal cord (tetraparesis)</td>
<td>lt MMA, lt MHT, lt ILT, lt AICA dural branch</td>
<td>lt PV, transverse pontine vein, rt vein of great horizontal fissure, lt lat medullary fissure, ant &amp; pst spinal vein</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue</td>
<td>partial</td>
<td>worsened again</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>53, M</td>
<td>rt</td>
<td>SAH</td>
<td>rt MHT</td>
<td>rt PV, lt LMV, lt BV, VG, rt vein of great horizontal fissure, sup hemispheric vein, &amp; rt inf vermician vein</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue</td>
<td>partial</td>
<td>no symptoms</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>46, M</td>
<td>rt</td>
<td>cerebellar hemorrhage</td>
<td>rt MMA, rt MHT, rt ILT</td>
<td>rt PV, cerebellar hemispheric vein</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue</td>
<td>complete</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>42, M</td>
<td>rt</td>
<td>SAH</td>
<td>rt MMA, rt AMA, rt AphA</td>
<td>rt PV, transverse pontine vein, lt LMV, lt BV, &amp; VG</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue; 2 sessions in 5 yrs</td>
<td>complete</td>
<td>no symptoms</td>
<td>68</td>
</tr>
<tr>
<td>5</td>
<td>50, M</td>
<td>lt</td>
<td>VH of lt temporal lobe (memory disturbance)</td>
<td>lt MMA, lt AMA, lt OA, lt MHT, lt ILT, rt PICA dural branch, rt MHT</td>
<td>lt PV, lt LMV, lt BV, VG, &amp; lt deep sylvian vein</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue; 3 sessions in 5 yrs</td>
<td>partial</td>
<td>no symptoms</td>
<td>97</td>
</tr>
<tr>
<td>6</td>
<td>45, M</td>
<td>rt</td>
<td>mass effect by varix (lt hemiparesis)</td>
<td>rt MMA, rt OA, rt MHT, rt ILT, rt SCA dural branch, &amp; lt MHT</td>
<td>rt PV, rt LMV, rt BV, VG, &amp; lt BV</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue; 3 sessions in 6 wks</td>
<td>complete</td>
<td>improved</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>66, M</td>
<td>lt</td>
<td>It trigeminal neuralgia</td>
<td>It MMA</td>
<td>rt PV, rt LMV, rt BV, &amp; VG</td>
<td>yes</td>
<td>no</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>45, F</td>
<td>rt</td>
<td>SAH</td>
<td>rt MMA, rt AMA, rt MHT, &amp; rt OphA recurrent tentorial branch</td>
<td>rt PV, transverse pontine vein, &amp; lt PV</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue</td>
<td>complete</td>
<td>no symptoms</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>58, M</td>
<td>rt</td>
<td>VH of rt temporal lobe (lt hemianopsia)</td>
<td>rt MMA, rt AphA, rt OA, &amp; rt MHT</td>
<td>rt PV, rt LMV, rt BV, &amp; VG</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue</td>
<td>complete</td>
<td>no symptoms</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>55, F</td>
<td>rt</td>
<td>headache</td>
<td>rt MMA, rt OA, &amp; rt MHT</td>
<td>rt PV, rt LMV, rt BV, VG, &amp; rt deep sylvian vein</td>
<td>yes</td>
<td>no</td>
<td>TAE w/ glue &amp; op</td>
<td>complete</td>
<td>no symptoms</td>
<td>82</td>
</tr>
<tr>
<td>11</td>
<td>39, F</td>
<td>rt</td>
<td>SAH</td>
<td>rt MMA, rt OA, &amp; rt MHT</td>
<td>rt PV, rt LMV, rt BV, VG, rt vein of lat recess of 4th ventricle, ant spinal vein</td>
<td>yes</td>
<td>yes</td>
<td>TAE w/ glue; 2 sessions in 3 wks</td>
<td>partial</td>
<td>no symptoms</td>
<td>11</td>
</tr>
</tbody>
</table>

*AICA = anteroinferior cerebellar artery; AMA = accessory meningeal artery; Angio = angiographical; ant = anterior; AphA = ascending pharyngeal artery; BV = basal vein; FU = follow-up; ILT = inferior lateral trunk; inf = inferior; IPH = intraparenchymal hemorrhage; LMV = lateral mesencephalic vein; MHT = meningohiphysial trunk; NA = not available; OA = occipital artery; OphA = ophthalmic artery; PICA = posteroinferior cerebellar artery; pst = posterior; PV = petrosal vein; SCA = superior cerebellar artery; sup = superior; TVE = transvenous embolization; VG = Vein of Galen; VH = venous hypertension.

3 cases. In the patients in Cases 12 and 13, glue injected into the dilated hypoglossal branch of the ascending pharyngeal artery reached the venous side of the fistula, and complete occlusion of the fistula was obtained. In another patient (Case 16), transarterial embolization resulted in partial obliteration of the fistula. Except for the patients in Cases 12 and 13, in whom the fistulas were eliminated by TAE alone, direct surgery was recommended in the remaining 4 patients. Two patients (Cases 14 and 16) underwent surgical interruption of the draining vein, and postoperative angiography revealed complete obliteration of these fistulas without neurological sequelae.

**Illustrative Cases**

**Case 6**

This 45-year-old man had a progressive motor and
sensory disturbance in his left extremities over the course of 4 months. Magnetic resonance imaging revealed a large, partially thrombosed varix compressing the right midbrain and thalamus with prominent perifocal edema (Fig. 1A). Cerebral angiography demonstrated a DAVF at the termination of the right petrosal vein, which was supplied by the right middle meningeal artery, occipital artery, meningohypophysial trunk, inferolateral trunk, and dural branch of the anterosuperior cerebellar artery. The fistula drained directly into the dilated right petrosal vein with filling of the right lateral mesencephalic and basal veins. Significant venous ectasia and aneurysmal dilation of the basal vein were identified (Fig. 1B). Over a period of 6 weeks, 3 sessions of TAE with glue were performed. The last injection from the petrosquamous branch of the MMA penetrated to the petrosal vein (Fig. 1C and D), and complete obliteration of the fistula was obtained (Fig. 1E). A postprocedural CT scan demonstrated a cluster of glue in the right petrosal vein and reduced perifocal edema (Fig. 1F).

**Case 8**

This 45-year-old woman presented with SAH 4 months before admission to our institute. At the previous hospital, an intracranial DAVF had been identified. Angiography showed the DAVF to be located at the termination of the right petrosal vein and supplied by the right MMA, accessory meningeal artery, meningoypophysial trunk, and recurrent tentorial branch of the right ophthalmic artery. The venous reflux drained totally into the right petrosal vein, joining the transverse pontine vein and the left petrosal vein. At the junction of the right petrosal vein and transverse pontine vein, a large varix was identified that was considered to be the cause of the hemorrhage (Fig. 2A–C). Transarterial embolizations with glue (50% mixture of NBCA and lipiodol) from the recurrent tentorial branch of the right ophthalmic artery and accessory meningeal artery were performed. At the last injection, the glue penetrated to the venous side of the DAVF (Fig. 2D and E). Three months later, complete disappearance of the DAVF was demonstrated on angiography (Fig. 2F).

**Case 14**

This 66-year-old man experienced sudden onset of severe headache. On admission, a CT scan showed SAH localized mainly around the medulla oblongata (Fig. 3A). Angiography revealed a DAVF at the level of the foramen magnum. The feeding arteries were dural branches of the right VA and the branches of the neurorhinegeal trunk of the right ascending pharyngeal artery (Fig. 3B and C). The DAVF drained caudally into the spinal vein and cranially into the petrosal vein through the ectatic lateral medullary vein, with associated varices. The feeding arteries were considered too small to catheterize. Surgical interruption of the draining vein was performed via a suboccipital craniotomy. Postoperative angiography showed the complete disappearance of the DAVF (Fig. 3D). The patient returned to normal life without any neurological deficits.

**Case 16**

This 71-year-old man presented with progressive motor and sensory disturbances affecting his arms and legs over a period of 3 months. Magnetic resonance imaging demonstrated a flow signal void of tortuous dilated vessels around the cervical spinal cord and a hyperintense intramedullary signal on T2-weighted images in the swollen cervical spinal cord (Fig. 4A and B). Angiography showed...
Fig. 1. Case 6. A: Axial T2-weighted MR image demonstrating a large, partially thrombosed varix (arrow) at the right thalamus. Prominent perifocal edema is identified. B: Selective angiogram of the right ICA showing a DAVF supplied by cavernous internal carotid branches, draining directly into the petrosal vein (arrowhead). Note the ectasia and varix (crossed arrow) of the draining vein. C: Superselective angiogram of the petrosquamous branch from the right MMA. The convergence of the small feeding arteries into the petrosal vein is well demonstrated. D: Angiogram showing the injection of 40% diluted NBCA reaching the diseased petrosal vein (asterisk). E: Postembolization angiogram confirming complete obliteration of the fistula. F: Post-treatment CT scan shows decreased perifocal edema.

Fig. 2. Case 8. Angiograms. A and B: Selective angiography of the right ICA, anteroposterior (A) and lateral (B) projections. A DAVF at the termination of the right petrosal vein (arrow) is shown supplied by the meningohypophysial trunk. Note the varix (arrowhead) in the draining cortical vein. C: Selective angiogram of the right external carotid artery (lateral projection) showing the blood supply to the fistula from the MMA and accessory meningeal artery. D: Superselective angiogram of the right accessory meningeal artery. E: Injection of 50% NBCA is shown penetrating to the affected petrosal vein (crossed arrow). F: Follow-up image obtained 3 months after TAE injection confirms complete obliteration of the fistula.
plete cure of the fistula.

eral spinal vein with varix formation reveals a DAVF at the craniocervical junction, which drains into the lat-

romeningeal branch of the right ascending pharyngeal artery, 50% diluted NBCA was injected, but resulted in in-

plete cure of the fistula. We also identified a concurrent anterior and posterior spinal veins. From the dilated neu-

omeningeal branch of the right ascending pharyngeal artery (arrow-head). D: Follow-up angiogram obtained after surgery demonstrating complete cure of the fistula.

phy revealed a DAVF above the foramen magnum. This DAVF was fed by dural branches of the right VA (Fig. 4C and D) and the neuromeningeal branch of the right ascending pharyngeal artery (Fig. 4E), and drained into the anterior and posterior spinal veins. From the dilated neu-

omeningeal branch of the right ascending pharyngeal artery, 50% diluted NBCA was injected, but resulted in in-

omeningeal branch of the ascending pharyngeal artery (arrow-

omeningeal branch of the right ascending pharyngeal artery, 50% diluted NBCA was injected, but resulted in in-

complete obliteration of the fistula. Surgical interruption of the bridging vein draining the DAVF was performed 1 month later, and postoperative angiography revealed complete cure. We also identified a concurrent anterior cranial fossa DAVF in this patient that was not considered to directly contribute to his presenting symptoms. Surgery was also recommended for this second lesion.

Review of Previously Reported Cases

In Table 3 we summarize the clinical characteristics in 41 cases of petrosal vein–draining DAVFs and 41 cases of medulla bridging vein–draining DAVFs comprising the cases from our series and previously reported cases in the literature. In both types of DAVF, we found a signifi-

cant male predominance (p < 0.001). The age of patients with petrosal vein–draining DAVFs ranged from 30 to 72 years (average ± SD, 51.9 ± 11.5 years), and 36–76 years (58.0 ± 10.7 years) in patients with medulla bridg-

vein–draining DAVFs. Leptomeningeal venous reflux was demonstrated in all cases. The ratio of aggressive to nonaggressive manifestation was 4.1:1 in petrosal vein–draining DAVFs, and 19.5:1 in medulla bridging vein–draining DAVFs. The incidence of aggressive manifesta-

tions in these DAVFs was significantly higher (p < 0.001) than in cavernous sinus DAVFs or transverse-sigmoid si-

nus DAVFs as reported by Awad et al.2 (Table 4). Of the 41 petrosal vein–draining DAVFs, 21 (51.2%) were treated with direct surgery with or without TAE, 14 (34.1%) were treated with TAE alone, 3 (7.3%) were treated with trans-

venous embolization, and 2 (4.9%) were treated with SRS. Of the 41 medulla bridging vein–draining DAVFs, 27 (65.9%) were treated with direct surgery with or without TAE, 10 (24.4%) were treated with TAE alone, and SRS was the treatment in 1 case (2.4%). No case was treated by transvenous embolization. We could not specify which treatment was performed in the remaining 1 case of pet-

rosal vein–draining DAVF and 3 cases of medulla bridg-

ing vein–draining DAVFs.

Discussion

Petrosal Vein–Draining DAVFs

In our opinion, petrosal vein–draining DAVFs were localized to the dural zone around the termination of the petrosal vein as it penetrates the dura mater into the supe-

rior petrosal sinus. In the literature, this lesion type is also known as superior petrosal sinus or tentorial DAVF. The high incidence of aggressive manifestations, including intracranial hemorrhage may be attributable to the character-

istic venous drainage pattern of these DAVFs. The shunted flow that directly refluxes into the petrosal vein exposes the subarachnoid veins to high arterial pressure and results in the development of venous ectasia and varices. The anatomical location of the petrosal vein close to the trigeminal nerve may contribute to trigeminal neuralgia as a manifesta-

tion of these DAVFs. Regarding the treatment of these DAVFs, it seems difficult to achieve complete cure by TAE alone. The multiple feeding arteries are usually fine and tortuous, and most of these fistulas are supplied by short meningeal branches arising from highly eloquent arteries. When glue penetration to the venous side of the fistula is achieved through a sufficiently dilated feeding artery, complete obliteration may be expected, as was achieved in 5 of our cases and in the cases reported by Nakahara et al.36 and van Rooij and colleagues.55 Transvenous embolization of petrosal vein–draining DAVFs may be another option for endovascular treatment,44 but it is also technically difficult. Transvenous catheterization through the superior petrosal sinus, which is often occluded or narrowed, is not usually feasible. A transvenous approach through the supratento-

rrial draining veins, which are tortuous, ectatic, and often complicated with varices, carries a high risk of venous perforation. Selective surgical interruption of the draining bridging vein has become established as the treatment of choice in DAVFs that drain directly into the leptomeningeal vein.5,16,59 This technique is considered to carry less risk than the more extensive surgery required for excision of the nidus. In our review of the previous literature, we found that more than half of cases were treated by direct surgery, a finding that confirms that surgery is an effective
therapeutic choice for petrosal vein–draining DAVFs. We also found 2 cases in which SRS was used. Although SRS has the advantage of being less invasive, it takes > 1 year to obliterate the lesion. We consider SRS to be inappropriate in most cases of petrosal vein–draining DAVFs because these lesions usually demonstrate aggressive and life-threatening manifestations that require urgent reduction of the leptomeningeal venous reflux.

**Medulla Bridging Vein–Draining DAVFs**

Medulla bridging vein–draining DAVFs were previously described using a variety of terms, such as craniocervical junction, foramen magnum, or spinomedullary junction DAVFs. We prefer the term “medulla bridging vein–draining DAVF” because it expresses the characteristics of the lesion’s vascular anatomy well. Previously some confusion existed in distinguishing between these DAVFs and DAVFs situated in the neighboring epidural or osteoepidural region, such as the anterior part of the marginal sinus or the anterior condyloid vein. These 2 types of DAVFs must be differentiated because the venous drainage and clinical manifestations of each are considered to be very different. Aggressive manifestations of medulla bridging vein DAVFs may be attributed to the presence of significant cortical venous reflux.

Although 2 of our cases and 8 in the literature were cured with TAE alone, safe and effective TAE in this type of DAVF is not considered easy to achieve, similar to the difficulties previously discussed with respect to petrosal vein DAVFs. The feeding arteries are usually small and tortuous, and arise directly from the VA or neuromeningeal trunk of the ascending pharyngeal artery, presenting a high risk of embolic complications. For transvenous embolization, there is no feasible venous access route to the small draining veins of these DAVFs. Generally, surgical interruption of the bridging vein is the most effective treatment for medulla bridging vein DAVFs. The authors of 1 previously reported case used SRS; however, we do not consider that SRS is an adequate modality to treat the majority of these DAVFs, as discussed above in the section on management of petrosal vein–draining DAVFs. As previously stated, the exact level of the draining bridging vein of these DAVFs varied individually in our series. Kinouchi et al. also discussed the variability in location of draining bridging veins in these DAVFs based on intraoperative findings. Regarding the bridging vein situated near the foramen magnum and connecting the pial venous network in the vicinity of the medulla oblongata to the surrounding epidural venous system, in their examination of cadavers, Matsushima et al. described these vessels as connecting the vein of the pontomedullary sulcus or the lateral medullary vein to the sigmoid or inferior petrosal sinus near the jugular foramen, or to the marginal sinus near the hypoglossal canal. These authors mentioned that the location of the bridging veins was not constant. Although they did not provide detailed descriptions, the existence of these bridging veins has also been noted by other authors. The various locations of these bridging veins may be easily understood based on their embryological development (described be-
Embryological Considerations

Medulla bridging vein–draining DAVFs and similarities between the petrosal vein–draining and the termination of these bridging veins. Medulla bridging vein DAVFs may develop around the age (average ± SD) of 51.9 ± 11.5 years for the petrosal vein group and 58.0 ± 10.7 years for the medulla bridging vein group.

The significant leptomeningeal drainage of these DAVFs may be attributable to the original role of these pia-arachnoid veins, which drain the pial venous network of the neural structures. The difficulty in transvenous embolization of these DAVFs can be explained by their particular venous anatomy. The draining bridging vein is situated at a distance from the large epidural or osteoepidural venous structures (transverse sinus, sigmoid sinus, and jugular bulb), and only connects with them through small epidural veins such as the superior petrosal sinus or marginal sinus; these small veins usually have occlusive changes.

The embryological considerations are schematically presented in Fig. 5. The locations of these DAVFs correspond to the “lateral” epidural venous territory, serving as a basis for a new overall classification of DAVFs. The craniospinal epidural spaces can be categorized into 3 different compartments: ventral, dorsal, and lateral. Each compartment has its own specific drainage role in the embryological development of the venous system of the central nervous system and surrounding bone structures. The ventral epidural venous system drains structures derived from the notochord and adjacent sclerome. The dorsal epidural venous system is related to the venous drainage of bony structures such as the sinus processes at spinal level, and the vault and calvaria cranially. Finally, the lateral epidural group collects the emissary bridging veins of the pial venous system of the brain and spinal cord. Dural arteriovenous fistulas developing in these venous structures will drain primarily either into the subarachnoid veins or the epidural-paraspinal collecting vessels according to the compartment involved, unless there is an additional comorbidity such as epidural sinus thrombosis at its outlet or high flow characteristics that may cause secondary subarachnoid spinopetal or cranioptetal drainage. This embryologically based classification establishes similarities between the spinal and cranial epidural venous systems. The petrosal vein and the bridging vein of the medulla are considered homologs of the emissary bridging vein of the spinal re-

Some of these similarities may be attributable to their common, peculiar angioarchitecture. Both DAVF types have an embryologically similar topography. They develop at the site where the bridging veins—derived from the embryological pia-arachnoid veins—penetrate the dura. The petrosal vein is derived from the embryological menencephalic vein, and the bridging vein that drains the vicinity of the medulla is thought to be developed through the annexation of the embryological ventral myelencephalic vein, hypoglossal vein, and first cervical intersegmental vein.

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TABLE 3: Summary of clinical characteristics in petrosal vein and medulla bridging vein–draining DAVFs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Petrosal Vein-Draining DAVFs (41 lesions)</th>
<th>Medulla Bridging Vein-Draining DAVFs (41 lesions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female ratio</td>
<td>32:9</td>
<td>35:6</td>
</tr>
<tr>
<td>Significance for male predominance</td>
<td>p &lt; 0.001</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Age (average ± SD)</td>
<td>51.9 ± 11.5 yrs</td>
<td>58.0 ± 10.7 yrs</td>
</tr>
<tr>
<td>CVR</td>
<td>41 (100%)</td>
<td>41 (100%)</td>
</tr>
<tr>
<td>Manifestations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAH</td>
<td>12 (29%)</td>
<td>15 (36.6%)</td>
</tr>
<tr>
<td>IPH</td>
<td>5 (12.2%)</td>
<td>2 (4.9%)</td>
</tr>
<tr>
<td>Spinal venous htn</td>
<td>9 (22.0%)</td>
<td>21 (51.2%)</td>
</tr>
<tr>
<td>Brain venous htn</td>
<td>4 (9.8%)</td>
<td>1 (2.4%)</td>
</tr>
<tr>
<td>Parenchymal compression by venous varices</td>
<td>3 (7.3%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Trigeminal neuralgia</td>
<td>5 (12.2%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Others</td>
<td>3 (7.3%)</td>
<td>2 (4.9%)</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OP &amp; TAE</td>
<td>21 (51.2%)</td>
<td>27 (65.9%)</td>
</tr>
<tr>
<td>TAE</td>
<td>14 (34.1%)</td>
<td>10 (24.4%)</td>
</tr>
<tr>
<td>TVE</td>
<td>3 (7.3%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>SRS</td>
<td>2 (4.9%)</td>
<td>1 (2.4%)</td>
</tr>
<tr>
<td>NA</td>
<td>1 (2.4%)</td>
<td>3 (7.3%)</td>
</tr>
</tbody>
</table>

* CVR = cortical venous reflux; htn = hypertension; IPH = intraparenchymal hemorrhage; TVE = transvenous embolization.
† Determined by chi-square test.

Similarities Between the Petrosal Vein–Draining and Medulla Bridging Vein–Draining DAVFs and Embryological Considerations

There are remarkable similarities between the clinical characteristics of petrosal vein–draining and medulla bridging vein–draining DAVFs: 1) both predominantly affect elderly males; 2) both present a high risk of aggressive manifestations including hemorrhage and venous hypertension; 3) endovascular embolization is generally difficult (especially via a transvenous approach); and 4) surgical management is relatively effective.

TABLE 4: The incidence of aggressive manifestations of the various types of DAVFs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Petrosal Vein–Draining DAVF</th>
<th>Medulla Bridging Vein–Draining DAVF</th>
<th>Cavernous Sinus Sinus DAVF</th>
<th>Transverse-Sigmoid Sinus DAVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggressive manifestation†</td>
<td>33</td>
<td>39</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>Nonaggressive manifestation</td>
<td>8</td>
<td>2</td>
<td>39</td>
<td>212</td>
</tr>
<tr>
<td>Ratio (aggressive/nonaggressive)</td>
<td>4.1:1</td>
<td>19.5:1</td>
<td>1.65</td>
<td>1.88</td>
</tr>
</tbody>
</table>

* The incidence of cavernous sinus and transverse-sigmoid sinus DAVFs was defined based on the study by Awad et al., 1990.
† The incidence of aggressive manifestations in petrosal vein draining and medulla bridging vein–draining DAVFs was significantly higher than in either cavernous sinus or transverse-sigmoid sinus DAVFs (p < 0.001, chi-square test).
Extrasinusal DAVFs in the posterior fossa

Most of the characteristics of petrosal vein–draining DAVFs and medulla bridging vein–draining DAVFs are shared with spinal DAVFs except for the incidence of hemorrhage. In general, thoracolumbar spinal DAVFs seldom present with SAH. Koch et al. have suggested, however, that there is a relatively high incidence of SAH from cervical spinal DAVFs. We do not have a definite explanation for this discrepancy, but it might be attributable to a difference in the blood flow of DAVFs that develop at different levels. Dural arteriovenous fistulas that develop in the cranial or cervical region might have a higher flow than those in the thoracic or lumbar regions, leading to an increased tendency to bleed; this interesting issue requires further investigation. We also believe that some extrasinusal DAVFs situated in the supratentorial region, such as in the anterior cranial fossa, middle fossa, or on the tentorial incisura, can be categorized in the same group (DAVFs developing in the lateral epidural venous territory), considering their similar embryological and clinical characteristics. Van Dijk and associates reported a marked male predominance in the incidence of anterior cranial fossa DAVFs in their series. Although the pathogenesis of these DAVFs remains unclear, the advanced age of patients suggests that these DAVFs are acquired and not congenital.

In the present series, we found antegrade sinus drainage in a single patient (Case 10), in whom there was also stenosis in the superior petrosal sinus. The rarity of the antegrade sinus drainage in these DAVFs suggested the presence of thrombosis in a superior petrosal sinus or epidural venous collecting vessels draining the bridging vein of the medulla. Although it is unclear whether the thrombosis is primary or secondary, we speculate that preceding sinus thrombosis in the outlet of the petrosal vein or bridging vein of the medulla might trigger the development of these DAVFs. The marked male predominance and the simultaneous presence of a medulla bridging vein–draining and an anterior cranial fossa DAVF in 1 patient (Case 16), leads us to suspect the existence of common pathogenic factors in this category (lateral epidural venous group) of lesions.

Conclusions

Petrosal vein–draining and medulla bridging vein–draining DAVFs have similar characteristics including a significant male predominance, a rather elderly age at presentation, an extremely high rate of aggressive neurological manifestations from hemorrhage or venous hypertension caused by leptomeningeal venous reflux, the difficulty of endovascular treatment, and the relative efficacy of direct surgery. We believe that both types of DAVFs we have described should be included in the same category as spinal DAVFs because of their similar clinical, angioarchitectural, and embryological characteristics.
Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Please include this information when citing this paper: published online May 8, 2009; DOI: 10.3171/2009.1.JNS08840.
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