Combining endovascular and neurosurgical treatments of high-risk dural arteriovenous fistulas in the lateral sinus and the confluence of the sinuses

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Object. The authors describe the use of a systemic approach to treat dural arteriovenous fistulas (DAVFs) in the lateral sinus and the confluence of sinuses in 17 patients who presented with signs and symptoms related to intracranial hemorrhage, infarction, and diffuse brain swelling.

Methods. Angiographic examination revealed three different types of DAVFs in these high-risk patients: 1) extremely high flow DAVF not associated with sinus occlusion or leptomeningeal retrograde venous drainage (LRVD); 2) localized DAVF with exclusive LRVD and without sinus occlusion; and 3) diffuse DAVF with sinus occlusion and LRVD. Because of the complex nature of these lesions, the authors adopted a staged protocol in which they combined endovascular and surgical treatments.

Conclusions. The authors believe that by close collaboration between endovascular therapists and vascular neurosurgeons, high-risk DAVFs in the lateral sinus and the confluence of sinuses can be successfully managed without treatment-related morbidity and mortality.

Key Words • dural arteriovenous fistula • transverse sinus • sigmoid sinus • embolization • surgery • combined treatment

OVER the last two decades, there has been increased attention paid to patients with dural arteriovenous fistulas (DAVFs) who are at high risk for the occurrence of intracranial hemorrhage and neurological disturbances. High-risk or aggressive DAVFs are characterized by the following angiographic findings:1,3,5,18–20 inflow of a large amount of arterial blood from the dural branches of the external carotid artery (ECA) and often from those of the internal carotid artery (ICA) and the vertebrobasilar (VB) system; arterial blood supply to the fistula that is reconstituted via complex collateral channels in recurrent cases; and occlusive changes of the venous sinuses and prominent retrograde filling of the leptomeningeal veins, which often carry varices.

Of these angiographic findings, most attention has focused on venous drainage patterns. Several investigators have demonstrated that neurological manifestations relate to the venous territory and not to the features of arterial supply or to the location of the fistula.18,22,39 By performing a metaanalysis on 100 aggressive cases of DAVF, Awad, et al.,1 proved that leptomeningeal retrograde venous drainage (LRVD) was significantly associated with aggressive behavior of fistulas.

Using LRVD as a key element, several classifications of DAVF have been developed with the aim of predicting the risk of catastrophic neurological manifestations.4,6,11,20,32 The authors of the studies reasoned that patients in whom LRVD did not occur should be treated conservatively or symptomatically, whereas patients with LRVD should undergo urgent and aggressive treatment. However, all classifications are incomplete because of gaps in our knowledge of this disease.21 Occasionally there are cases of DAVF that demonstrate aggressive behavior without the presence of LRVD.6,8,10 Also, lesion location and extension have not been taken into consideration in these classifications. Therefore, existing classifications are not helpful in designing a treatment plan for individual cases.

Among aggressive DAVFs, the most challenging lesions to treat have been the DAVFs in the transverse and sigmoid sinuses (lateral sinus21) and in the confluence of sinuses. This is because of the strategic importance of these sinuses in intracranial venous circulation. Additionally, both endovascular and surgical approaches have limited value because of the complexity of the angioarchitecture.31 It is expected that treatment results will improve by combining endovascular and surgical approaches.
TABLE 1
Clinical and imaging findings in 17 patients with DAVFs

<table>
<thead>
<tr>
<th>Finding</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>homonymous hemianopsia</td>
<td>5</td>
</tr>
<tr>
<td>Gerstmann syndrome</td>
<td>2</td>
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<tr>
<td>aphasia</td>
<td>1</td>
</tr>
<tr>
<td>mental deterioration</td>
<td>4</td>
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<tr>
<td>disturbed consciousness</td>
<td>1</td>
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<tr>
<td>hemiplegia</td>
<td>1</td>
</tr>
<tr>
<td>seizure</td>
<td>2</td>
</tr>
<tr>
<td>headache</td>
<td>6</td>
</tr>
<tr>
<td>exophthalmos</td>
<td>2</td>
</tr>
<tr>
<td>easily fatigued</td>
<td>1</td>
</tr>
<tr>
<td>tinnitus</td>
<td>5</td>
</tr>
<tr>
<td>subcortical hemorrhage</td>
<td>7</td>
</tr>
<tr>
<td>SAH</td>
<td>4</td>
</tr>
<tr>
<td>subdural hemorrhage</td>
<td>1</td>
</tr>
<tr>
<td>ventricular hemorrhage</td>
<td>2</td>
</tr>
<tr>
<td>cerebral infarct</td>
<td>4</td>
</tr>
<tr>
<td>diffuse brain swelling</td>
<td>4</td>
</tr>
</tbody>
</table>

However, few studies have been published that deal with the combined endovascular-surgical approach in a large number of patients with complex DAVFs of the transverse and sigmoid sinuses. Moreover, treatment results in earlier reports were not always satisfactory and were occasionally associated with serious complications.

The purpose of this study is to describe the use of a systemic approach in the treatment of high-risk DAVFs of the lateral sinus and the confluence of sinuses in which we achieved angiographically confirmed clinical cure, with minimal treatment-associated complications.

Clinical Material and Methods

Of the 35 cases of aggressive DAVF of the lateral sinus and the confluence of sinuses treated at our institution during the past 15 years, the lesions that were associated with unifocal occlusion in the lateral sinus and LRVD were completely obliterated in 18 patients by embolizing the diseased segment of the sinus via a transfemoral approach. A combined endovascular-surgical approach was performed in 17 other cases. These 17 patients were placed into three groups based on the following angiographic characteristics: extremely high flow DAVFs without sinus occlusion and LRVD (Case 1); localized DAVFs with exclusive LRVD (Cases 2 and 3); and DAVFs with bifocal or diffuse sinus occlusion and LRVD (Cases 4–17). Embolization was performed in the patients by one of the authors (K.G.) at three university-affiliated hospitals in western Japan. Clinical signs, symptoms, imaging findings, and treatment are summarized in Tables 1 and 2. Clinical manifestations consisted of cortical abnormality of the occipital, parietal, and temporal lobes; generalized cerebral dysfunction; and increased intracranial pressure (ICP). Imaging findings were either one or two of the following: intracranial hemorrhage, infarction, or diffuse brain swelling.

Nine of the patients underwent a combined endovascular-surgical approach at presentation, and the other eight had recurrent DAVFs that had been treated previously with embolization or ligation of the feeding arteries or radiotherapy, or a combination of the two at other hospitals.

In view of the difficulties associated with either the endovascular or the surgical approach, we adopted the following protocol for the combined treatment of high-risk DAVFs.

Transarterial Embolization

After thorough angiographic evaluation, the arterial inflow to the lesion is reduced by transarterial embolization using polyvinyl alcohol (PVA) foam particles. As many feeding arteries as possible arising from the dural branches of the ECA are selectively cannulated, using microcatheters, and then embolized. Selective cannulation of the posterior meningeal branch of the vertebral artery (VA) and the marginal tentorial branch of the ICA is attempted if the arteries are actively involved with the blood supply to the fistula and if they are hypertrophic. These branches are embolized using a 20 to 30% concentration of liquid embolic material, N-butyl-cyanoacrylate (NBCA), which is diluted and opacified by the oily contrast material (Lipiodol; Guerbet, Paris, France). Additionally, if large fistulas are found on the ECA branches, they are embolized with high-concentration (70%) NBCA.

Transvenous Embolization

The diseased segment of the sinus is packed as tightly as possible with microcoils within a few days after transarterial embolization and before recanalization becomes prominent. If the DAVFs are associated with unifocal occlusion in the lateral sinus, placement of a microcatheter into the diseased segment of the sinus is attempted via a transfemoral approach. The diseased segment of the venous sinus is packed by placing thin, long platinum coils (0.018 in) such as Guglielmi detachable coils (GDCs) or interlocking detachable coils (IDCs), Boston Scientific Co., Natick, MA) and short, fibered coils such as Vortex coils (Boston Scientific Co.) or Tornado coils (Cook Inc., Bloomington, IN) alternatively. If the transfemoral approach to the diseased sinuses is not possible because of severe stenoses or bifocal occlusion of the sinus or if the fistula is not completely obliterated via a transfemoral approach, intraoperative embolization is performed. A craniectomy or a small burr hole enables direct access to the diseased segment of the venous sinus. The diseased segment of the dural sinus is directly packed with larger fibered occlusion coils (0.038 or 0.035 in), such as Gianturco coils (Cook Inc.), under the guidance of intraoperative digital subtraction angiography.

Complementary Surgical Procedures

Surgical isolation or resection of the diseased segment of the sinus is performed if a persistent fistula with LRVD is revealed on control angiography. These complementary surgical procedures are performed as follows: first, hypertrophic dural branches of the occipital artery are coagulated and cut off at their entry into the posterior aspect of the mastoid bone. After performing craniotomy and localized mastoidectomy, the transverse sinus and the upper part of
the sigmoid sinus are exposed. A rete of markedly hypertrophic dural arteries, observed at the transverse–sigmoid junction, is coagulated. Two dural incisions are then made parallel to the long axis of the transverse sinus. By reflecting the dura mater that overlies the cerebellar hemisphere, the posterior meningeal branch of the VA, which is entering the fistula, and a dilated marginal tentorial artery, which is seen below the tentorium cerebelli, are sought and coagulated. When the lesion is located posteriorly, multiple dural branches that penetrate the skull through the honeycomb-like perforations are noted in the external occipital protuberance. After turning back the scalp flap, blood usually pours from these holes, but this can be prevented by performing transarterial embolization beforehand. A maze of dilated dural arteries, seen at the confluence of the sinuses, is coagulated. When inspecting the tentorium cerebelli from below, retrograde filling of the vermian veins is often noted. Connected directly, or indirectly via the tentorial sinus, to the transverse sinus or the confluence of sinuses, these veins are first coagulated and then severed. The dura mater overlaying the occipital lobe is then reflected. After elevating the occipital lobe, several cortical veins, including the vein of Labbé, are recognized and are double ligated and divided. After severing the superior petrosal sinus, the diseased segment of the transverse and sigmoid sinuses is cut from the tentorium cerebelli and completely resected.

Surgical procedures are performed in patients after anesthesia is induced with isoflurane and supplemented with fentanyl. Neurophysiological monitoring is used only in patients who require test occlusion for cortical veins with ambivalent flow and in those whose venous sinuses are without occlusive changes. If prominent hyperemia and swelling of adjacent brain regions are noted during surgery or on diagnostic imaging, these complementary surgical procedures are postponed for a few weeks.

We performed control angiography intraoperatively and 1 week, 3 months, 6 months, 1 year, and 2 years posttreat-

**TABLE 2**

*Signs, symptoms, imaging findings, and treatments in 17 patients with DAVFs in the lateral sinus and the confluence of sinuses*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Site of Lesion</th>
<th>Symptoms &amp; Imaging Findings</th>
<th>1st Treatment</th>
<th>Treatment Interval</th>
<th>Final Treatment</th>
<th>Last Follow-Up Result/Duration (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28, M</td>
<td>lt TS</td>
<td>Gerstmann syndrome,</td>
<td>transart + resection</td>
<td>6 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>2†</td>
<td>34, M</td>
<td>rt TS (sinus wall)</td>
<td>headache, tinnitus,</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>3†</td>
<td>45, M</td>
<td>rt TS (sinus wall)</td>
<td>symptoms, subcort hem</td>
<td>transart + resection</td>
<td>3 yrs</td>
<td>intact/3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>62, M</td>
<td>lt TSS (S. occluded)</td>
<td>headache, tinnitus,</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>51, M</td>
<td>lt TSS (S. occluded)</td>
<td>headache, aphasia,</td>
<td>transart + resection</td>
<td>3 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>62, F</td>
<td>lt TSS (isolated)</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>64, F</td>
<td>lt TSS (isolated)</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>62, M</td>
<td>lt TSS (isolated)</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>66, M</td>
<td>lt TSS (isolated)</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>10</td>
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<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
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<td>11</td>
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<td>transart + resection</td>
<td>2 yrs</td>
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<td></td>
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<td>12</td>
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<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>61, M</td>
<td>lt TSS (isolated)</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
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<tr>
<td>14</td>
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<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
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<tr>
<td>15</td>
<td>42, M</td>
<td>bilat TSS &amp; CS</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>59, M</td>
<td>bilat TSS &amp; CS</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
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<tr>
<td>17†</td>
<td>62, F</td>
<td>bilat TSS &amp; CS</td>
<td>headache, diffuse brain</td>
<td>transart + resection</td>
<td>2 yrs</td>
<td>intact/6</td>
<td></td>
</tr>
</tbody>
</table>

* CS = confluence of sinuses; embol = embolization; OcA = occipital artery; RC = recanalization; S. subcort hem = subcortical hemorrhage; transart = transarterial; transven = transvenous; TS = transverse sinus; TSS = transverse and sigmoid sinuses.
† Patient also reported on by Tanaka, et al.
‡ Patient also reported on by Ishii, et al.

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ment. The DAVF was considered completely obliterated or eliminated when no early opacification of venous structures was demonstrated in the previous lesion site in immediate follow-up examination. When complete DAVF obliteration or elimination persisted and when regression of the feeding pedicles that come from the dural and pial arteries was observed at late follow-up examination (> 1 year), the lesion was defined as angiographically cured. Neurological evaluation was performed immediately pre- and posttreatment and at the time of follow-up angiography by a board-qualified neurologist. Clinical cure was defined as disappearance of the following: recurrent stroke, tinnitus, and signs and symptoms of focal cortical abnormality, generalized cerebral dysfunction, and increased ICP.

Results

Using this treatment protocol, angiographically demonstrated complete cure of the DAVF was achieved in all cases, although three patients refused follow-up angiography after 6 months. In some initial cases with extremely high flow and extensive lesions, the angiographic follow-up period was extended more than 2 years. Clinical cure was attained in all patients, although neurological deficits persisted in seven: visual field defect and dysphasia caused by previous subcortical hemorrhage in five and slight dementia in two (Table 2). The clinical follow-up period was extended up to several years in some cases because of the persistence of subjective symptoms and/or neurological deficits. No treatment-related neurological deficit was seen in any case.

Of 13 patients with unilateral DAVFs of the transverse and sigmoid sinuses, preoperative transfemoral transvenous embolization was possible in three; the patient in Case 1 was the only one who did not have occlusive change of the dural sinus or LRVD. This patient had extremely abundant arterial flow to the fistula from the dural and pial arteries (Fig. 1). After surgical resection of the diseased segment of the sinus, a complete cure was attained. This became possible by the regression of engorgement of pial arteries brought about by the transfemoral transvenous embolization of the sinus. In the other two patients (Cases 4 and 5), the sigmoid sinus that carried the DAVF was occluded before its junction with the jugular bulb. Therefore, a microcatheter was advanced into the diseased segment of the lateral sinus, down to the occlusion site in the sigmoid sinus via the confluence of sinuses, and into the contralateral transverse sinus via a transfemoral approach. Most of the diseased segment of the lateral sinus was embolized, but the fistula was not completely occluded and LRVD persisted. Surgical resection of the entire diseased segment was easily achieved because marked reduction of blood flow through the fistula had been attained by performing preoperative embolization.

In two patients (Cases 2 and 3), the fistula was localized on the sinus wall and drained predominantly into the cortical veins that carried varices.35 Following transarterial embolization, a small craniotomy was performed, and the arterial inflow was coagulated. The disease was cured by surgically disconnecting the cortical veins at the point of their exit from the fistula and the dural sinus, taking care not to sacrifice the patency of the dural sinus.

In eight patients (Cases 6–13), the diseased segment of the lateral sinus was completely isolated from the other venous sinuses by bifocal occlusions of this structure, and it was associated with prominent LRVD (Fig. 2). On angiography, five lesions were demonstrated to have been completely obliterated by intraoperative embolization alone. For the other three patients with a DAVF that widely involved the lateral sinuses, complementary surgical...
Combined treatment of hazardous DAVFs

**Illustrative Cases**

**Case 1**

**History and Examination.** This 28-year-old man in whom a DAVF in the left transverse–sigmoid junction was originally diagnosed when, at 4 years of age, he displayed symptoms that included left conjunctival injection and proptosis. At 19 years of age he suddenly developed severe headache, right-sided hemiplegia, and disturbance of consciousness. He was admitted to a nearby hospital and was found to have a large subcortical hematoma that involved the left temporal and parietal lobes. Evacuation of the hematoma was performed, and the DAVF was left untouched. After recovering from this acute episode, the patient suffered from recurrent episodes of seizure, syncopal attack, and transient Gerstmann syndrome. Angiography demonstrated one unique feature in this patient: there was prominent participation of numerous pial arteries with the DAVF in addition to the ECA branches (Fig. 1A and B).

**Treatment.** Initially, transarterial embolization was performed. The tip of the microcatheter was advanced deep into the ECA branches close to the fistula where three main feeding pedicles that carried relatively large fistulas resulted in angiographically demonstrated complete cure. In the patient in Case 17, after we performed an extensive transarterial embolization of the dural branches of the bilateral ECA, only the surgical isolation of the spontaneously obliterated bilateral lateral sinuses and the confluence of sinuses resulted in angiographic cure.19 There was no incidence of profuse bleeding during skin incision and bone removal because of the presurgical transarterial embolization, and blood transfusion was not necessary in any of the 17 cases.
bolized using PVA particles. Four days later, via the transfemoral approach, the diseased segment of the sinus was tightly packed with platinum coils. One day after embolization, a small subcortical hematoma, located lateral to the atrium of the left lateral ventricle, was revealed by computerized tomography scanning; however, the patient remained neurologically intact. One week after embolization, a control angiogram demonstrated a marked subsidence of the pial artery engorgement; however, the DA VF was not completely obliterated by embolization, and a fistula between the pial vessels and the tentorial sinus became prominent (Fig. 1C). The diseased segment of the dural sinus, which extended from the confluence to the superior petrosal sinus, was resected. The sinus was severely adherent to the temporal lobe in the transverse–sigmoid junction, where numerous leptomeningeal arteries converged in the fistula. There was no profuse bleeding during surgery. A control angiogram revealed complete disappearance of the DA VF (Fig. 1D). The number of seizures has dramatically decreased, and the patient has been neurologically intact for the past 6 years.

Case 11

History and Examination. This 42-year-old woman who had previously undergone embolization and ligation of the ECA for a DA VF of the left transverse and sigmoid sinuses at another hospital (Fig. 2A) suffered a subarachnoid hemorrhage (SAH) 2 years later. Preembolization angiography revealed a recurrent DA VF that was characterized by numerous feeding pedicles that were reconstituted by collateral branches, a transverse sinus isolated by bifocal occlusion, and prominent LRVD (Fig. 2B). A left occipital and suboccipital craniotomy was performed 3 days later to expose the transverse and sigmoid sinuses. After coagulating the posterior branch of the middle meningeal artery and the dural branches of the posterior cerebral artery (PCA), a microcatheter was placed directly into the isolated segment of the transverse and sigmoid sinuses. This diseased segment was packed tightly with occlusion coils (mostly Gianturco coils, supplemented by IDCs and Vortex coils) and was surgically isolated from the adjacent dura mater. It was noted, however, that a varicose vein, which was found on the vein of Labbé at its entry to the sinus, remained reddish. After inspecting the inner aspect of the varix, a small arterial twig that arose from the PCA was connected to the varix. This twig was coagulated, and finally the varix collapsed. Complete obliteration of the DA VF was confirmed by immediate (Fig. 2D) and late follow-up angiography. The patient has been neurologically intact for the past 6 years, during which time she has not experienced headache or been easily fatigued.

Case 14

Examination and Treatment. This 58-year-old man suffered from Gerstmann syndrome caused by a venous infarction of the temporal lobe. Angiographic examination revealed an extensive DA VF that extended from the left sigmoid to the confluence of sinuses (Fig. 3A and B). The bilateral ECA branches were extensively embolized using PVA particles, and the posterior meningeal branches of the left VA were embolized using NBCA. Surgery was performed the following day. The soft tissue and the bone did not bleed more than usual due to the effect of embolization. After coagulating many dural and tentorial branches, the segregated transverse sinus, the left half of the confluence of sinuses, and the straight sinus were tightly packed with microcoils. However, the transverse sinus contained a few different channels, not all of which

Fig. 3. Case 14. Angiographic studies. A: Left ECA angiogram, lateral view, showing a high-flow DAVF of the isolated lateral sinus, featuring a prominent LRVD, by bifocal occlusion. B: Right ECA angiogram, lateral view, revealing a DAVF of the confluence of sinuses with prominent reflux into the straight sinus and its tributaries. C: Control left common carotid artery angiogram, obtained 1 week postsurgery, showing complete elimination of the DAVF. Note the coils that pack the left half of the confluence of sinuses and superior petrosal and sigmoid sinuses, which were left in place. D: Venous phase of right ICA angiogram, anteroposterior view, confirming preservation of normal antegrade flow from the sagittal to the right transverse sinuses. Note the coils that pack the left half of the sinus confluence and parts of the superior petrosal and the sigmoid sinuses, which were left in place.
Combined treatment of hazardous DAVFs

**Case 16**

*History.* This 59-year-old man developed tinnitus in his right ear approximately 10 years ago and since then has had occasional episodes of SAH, headache, and vomiting. He gradually developed gait disturbance, hallucinations, and urinary incontinence approximately 1 year prior to admission to a nearby university hospital. He developed a subcortical hematoma in the right occipital lobe several hours after angiography. Transarterial embolization, performed twice at the same hospital, only transiently reduced the degree of tinnitus.

*Examination and Treatment.* The patient was referred to us, and angiography performed at our institute revealed an extensive DAVF that involved the bilateral lateral sinuses and the confluence of sinuses (Fig. 4A). The medial part of the bilateral transverse sinuses was segregated from the rest of the venous sinuses because of an extensive occlusive process. Reflux of shunted blood into the straight sinus, the superior petrosal sinus, and their tributaries was prominent (Fig. 4B). A diffuse congestion of dilated cortical veins was noted in the posterior two-thirds of the bilateral cerebral hemispheres (Fig. 4C). It was also noted that major venous runoff of cerebral venous circulation were obliterated. Control angiography revealed disappearance of reflux into most of the cortical veins and the deep venous system. However, there were several cortical veins, including the duplicated veins of Labbé, which were still draining arterialized blood. After confirming the subsidence of hyperemia of the left occipital lobe and left cerebellar hemisphere, surgery was performed. All tentorial arteries and cortical veins were disconnected, and the transverse sinus was resected. Control angiography revealed complete elimination of the DAVF (Fig. 3C). The flow from the superior sagittal sinus to the right transverse sinus was completely preserved (Fig. 3D). The patient has been neurologically intact for the past 5 years.

*Fig. 4.* Case 16. Angiographic studies. Right ECA angiograms, anteroposterior (A) and lateral (B) views, showing an extensive DAVF that involves the bilateral lateral sinuses and the confluence of the sinuses. The medial part of bilateral transverse sinus is segregated from the other venous sinuses due to occlusion of the left transverse and sigmoid sinuses and the posterior part of the superior sagittal sinus. The lateral half of the right transverse sinus is severely stenotic. Reflux into the straight sinus, superior petrosal sinus, and their tributaries is prominent. A right ECA angiogram (C), lateral view, in the venous phase, showing prominent retrograde filling of the dilated cortical veins in the posterior half of the right cerebral hemisphere. A right ICA angiogram (D), lateral view, in the venous phase, showing congestion of the cortical veins in the posterior two-thirds of the cerebral hemisphere. Major runoff of the superior sagittal sinus was established through the hypertrophic bilateral sphenoparietal sinuses, which were faintly opacified (arrows). These sinuses further enlarged postsurgery and later densely opacified (see Fig. 4G). Control arterial phase VA angiogram (E), lateral view, 1 month after surgical devascularization of the bilateral transverse sinuses and the confluence of sinuses. Note prominent filling of the straight sinus via leptomeningeal arteries of the bilateral PCA and superior cerebellar artery. Control venous phase left common carotid artery angiogram (F), lateral view, obtained at the same time as the image in Fig. 4G. Note persistent filling of the sigmoid, superior petrosal, and the straight sinuses. Control venous-phase left common carotid artery angiogram (G) obtained 3 months after resection of the sinuses. Note disappearance of the cortical venous congestion and reconstitution of the venous outflow via bilaterally hypertrophic sphenoparietal sinuses (arrows).
with dementia over the years. The pathways of the bilateral transverse sinuses and the confluence of sinuses was performed. Localized mastoidectomies were then performed bilaterally to expose the transverse–sigmoid junction. The rete of dilated dural branches, which was most prominent in the transverse–sigmoid junction and the confluence of sinuses, was thoroughly coagulated. After severing the dura mater above and below the transverse sinus, the tentorial arteries were coagulated extensively from below and above the tentorium cerebelli. The occipital and the superior sagittal sinuses were clipped and severed. However, cortical veins connected to both supra- and infratentorial structures and the straight sinus were left untouched so as not to compromise the venous circulation further. The dura mater on both sides of the sinus was resected (width 1 cm) and replaced with artificial dura to prevent revascularization of the fistula. The postoperative course was uneventful. However, control vertebral angiography, performed 1 month after the procedure, showed prominent filling of the straight sinus via the leptomeningeal arteries of the bilateral PCA and the superior cerebellar artery, which was not seen preoperatively (Fig. 4E). Also, control left common carotid artery angiography revealed persistent filling of the sigmoid, superior petrosal, and the straight sinuses via the remaining tentorial branches (Fig. 4F).

Second Operation. At second surgery, no area with cerebral infarct was observed. Every cortical vein connected to the bilateral transverse sinuses and the confluence of sinuses was resected infra- and supratentorially. The straight sinus was then clipped and severed, and the medial halves of the bilateral transverse sinuses were resected, including the confluence of sinuses. No brain swelling was noted postprocedure. The residual DAVF at the transverse–sigmoid junction was embolized via a transfemoral–transvenous approach. Control angiography showed complete obliteration of the DAVF, disappearance of the cortical venous congestion, and reconstitution of the venous outflow via bilaterally hypertrophic sphenoparietal sinuses (Fig. 4G). Signs and symptoms of increased ICP quickly disappeared, and the patient has slowly recovered from dementia over the years.

Discussion

Angiographic and Clinical Cure

The procedures in this systemic approach, which allowed us to cure, clinically and angiographically, 18 lesions in our 17 patients were as follows: intraoperative venous sinus embolization in five patients, surgical disconnection of LRVD in two, surgical isolation in four, and surgical resection in seven patients. In the past, before catheterization techniques and embolic materials were readily available, the only way to attain complete cure of a DAVF had been surgical removal of the lesion. Recently, however, it was demonstrated that complete obliteration of the lesion became possible by tightly packing the diseased segment of the dural sinus with coils.15,23,33 Because few histopathological studies of DAVFs have been reported,16,27 we have examined resected specimens obtained in nine of these cases.17 We found an abnormal connection between the dural arteries and the dural veins within the venous sinus wall, through small vessels averaging approximately 30 µm in diameter. Therefore, it seems possible that by densely packing the diseased segment of the sinus, a firm thrombus is formed and that organized thrombus will then lead to permanent occlusion of the DAVF. Since the advent of long platinum coils such as GDCs and IDCs, dense packing of the sinus through microcatheters has become easy; however, use of only these platinum coils often leads to early recanalization of the lesion, despite dense packing, because these bare platinum coils are less thrombogenic. By weaving fibered coils into the mesh of the long platinum coils, formation of a firm thrombus is facilitated. In our experience treating 85 patients with DAVFs in various sites, who underwent embolization of the diseased segment of venous sinuses, three of eight patients who underwent embolization with only IDCs experienced recanalization within 6 months. No angiogram demonstrated recurrence in later follow up when a complete angiographic obliteration had been observed at 6 months postprocedure.

Angiographic Subtypes of High-Risk DAVFs

The treatment strategy for DAVFs should be decided mainly based on its angioarchitecture. Angiographically, the DAVFs in the 17 cases presented here are grouped into the following three types.

Extremely High Flow DAVF Without Sinus Occlusion and LRVD. Functional obstruction of the sinus was postulated as a pathomechanism of focal cortical abnormality and SAH in Case 1.5 Resection of the diseased sinus segment completely cured this patient. Cure was achieved after the subsidence of hyperemia of the adjacent brain region, which was effected by transvenous embolization of the fistulous portion of the dural sinus, but there was formation of a small asymptomatic subcortical hematoma after the procedure. Although several investigators find the sinus occlusion test helpful in patients with DAVFs with ambivalent flow,13,17 its reliability and value are controversial. Temporary occlusion is not predictive of the long-term effect, and additionally, no balloon is long enough to cover extensive lesions entirely. Furthermore, abrupt elevation of venous sinus pressure generated by the occlusion test may induce intracranial hemorrhage and cerebral venous infarct. A combination of surgically isolating the diseased sinus segment followed by radiotherapy, as was performed after transarterial embolization in Case 15, is the treatment of choice for DAVFs located in sinuses that function as major runoff from cerebral venous circulation.

Localized DAVF With Exclusive LRVD. The fistulas were easily cured by a simple surgical disconnection of cortical veins from the sinus wall, with preservation of dural sinus patency in Cases 2 and 3; these results were similar to cases reported by Barnwell, et al.3 Recently, Davies and coworkers’ claimed that all cases that showed retrograde
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leptomeningeal drainage could be cured safely and effectively or converted to a benign type by eliminating only the retrograde leptomeningeal drainage, either by embolization or surgical disconnection, rather than surgical resection. The authors validated the classification and the treatment method of DAVFs proposed by Borden, et al., that dealt with arteriovenous shunts that were fed by the cranial and spinal dural arteries under the same category. However, this classification is unacceptable from the anatomical point of view. Furthermore, we concur with Collice, et al., who claimed that only DAVFs with pure leptomeningeal drainage, which are confined to the wall of the dural sinus (as in our Cases 2 and 3), can be treated by the simple surgical interruption of a draining vein at its exit from the sinus wall; this has been performed successfully in DAVFs of tentorial sinus. In the literature, DAVFs with pure leptomeningeal drainage are most commonly seen outside the major venous sinus, such as in the anterior fossa, the tentorial sinus, and the superior petrosal sinus. Most of the DAVFs that are occasionally seen in the transverse and superior longitudinal sinuses seem to be “extrasinusal dural lesions,” which develop in the transdural portion of the cerebral vein. In fact, not a single case of DAVF with pure leptomeningeal drainage that arose from the lateral sinus was found in the series by Borden, et al., but curiously, they used an illustration of DAVF of the transverse sinus to explain their new classification system of DAVFs. In addition, with regard to the general concept of DAVFs of the transverse sinus, their illustration was misleading for two reasons: 1) it gave the impression that all DAVFs with pure leptomeningeal drainage are generated under the process of recanalization of sinus thrombosis and 2) it oversimplified the angioarchitecture of the transverse sinus. Anatomical studies have been undertaken that demonstrate that the transverse sinus receives many cortical veins from the supra- and infratentorial structures, via capacious tentorial sinuses or directly, and often separately, into the sinus, as well as being connected to the emissary veins and the superior petrosal sinus. Therefore, the possibility must be kept in mind that clipping a leptomeningeal vein that drains the fistula after insufficient embolization may result in rerouting the fistulous output and overloading other leptomeningeal veins. Furthermore, from a technical point of view, it is important to recognize that even the clipping of a draining vein can be hazardous and might be responsible for a venous infarct and a fatal hemorrhage. Therefore, some adjuvant measures should be undertaken to decrease the arteriovenous shunt progressively, the degree of venous engorgement, and the size of the venous bed recruited by the fistula.

Dural AVF With Bifocal or Diffuse Sinus Occlusion and LRVD. All of the remaining 14 patients had LRVD-associated DAVFs, which extensively involved the lateral sinuses. They were associated with monofocal occlusion in the sigmoid sinus (Cases 4 and 5), bifocal occlusion in the sigmoid and the transverse sinuses (Cases 6–13; Fig. 2), and culminated in the most complex and hazardous situation, that which involved the confluence of sinuses and/or bilateral lateral sinuses (Cases 14–17; Figs. 3 and 4). The complex angioarchitecture of many of these lesions often makes both surgical and endovascular approaches problematic.

Surgical Approach

Surgical obliteration of the arterial supply and excision of the diseased segment of the dural sinus may be curative, but they are not acceptable as a standard treatment. The extremely abundant vascularity in the surrounding dura mater, skull, and overlying soft tissues causes tremendous intraoperative blood loss and leads to a high incidence of complications. Moreover, preexisting brain swelling and hyperemia are occasionally aggravated by surgery, with consequent hemorrhagic complications. Some authors have stressed the need to take great precautions and make necessary preparations to protect against the possibility of potentially catastrophic hemorrhage during scalp-flap reflection, soft-tissue dissection, and craniotomy.

Endovascular Approach

Standard endovascular approaches for this high-risk lesion are usually difficult and marked by failure. Transarterial embolization using particulate embolic agents usually does not completely close the fistula because of the multitude of small arterial pedicles that supply the lesion. There is also a high incidence of recanalization with particulate emboli. Although liquid embolic materials provide more stable results, they are associated with a higher risk of embolic penetration into the cortical veins or nutrient vessels of the cranial nerves, with a resultant focal neurological deficit and cranial nerve palsy, respectively.

Transvenous embolization plays a key role in the curative treatment of DAVF. The diseased segment of the venous sinus can be accessed with a microcatheter via transfemoral approach in cases with unifocal occlusion such as in Cases 4 and 5. This was not an option in Cases 6 to 15 and 17, however, because the bifocal occlusion of the venous sinuses caused complete segregation of the diseased segment from the rest of the sinuses.

Combined Endovascular–Surgical Approach

According to a metaanalysis of the literature relevant to DAVFs, combined endovascular–surgical treatment has proved significantly more effective than either therapy alone in treating DAVFs of the transverse and sigmoid sinuses. Our protocol for the combined treatment of high-risk DAVFs with occlusive change in the lateral sinus and confluence of sinuses consisted of 1) embolization of the feeding pedicles; 2) embolization of the diseased segment of the venous sinus; and 3) complementary surgical procedures (see Clinical Material and Methods).

Transarterial Embolization. The value of transarterial embolization in the treatment of DAVF is controversial, and in recent years much emphasis has been placed on the embolization of the diseased segment of the venous sinus. However, as was shown in our cases, preoperative transarterial embolization using PVA particles is a simple and useful adjunct that effectively reduced arterial inflow and facilitated operative exposure of the involved segment of the dural sinuses. Particularly in the treatment of high-flow DAVFs, shunted blood should be reduced by transarterial embolization as an initial step. The reason is that when faced with abundant inflow through the fistula,
packing the venous sinuses with occlusion coils may sometimes result in coil migration, incomplete obliteration, or even increased risk of venous infarction and intracranial hemorrhage resulting from the inadvertent diversion of arterialized blood into the cortical veins.\textsuperscript{6,17,35} In performing extensive transarterial embolization via the venous approach, there is no fear of losing sight of the entire abnormal segment. The reason for this is that the DAVFs are kept opacified from the arterial branches that are inaccessible by catheter techniques because of the many feeding arteries. Devascularization of DAVFs by the transarterial approach is especially difficult when treating recurrent lesions, because feeding pedicles often reconstitute through complex collateral channels from extracranial arteries. Additional participation of the tentorial and dural branches arising from the ICA and VB systems is common (Fig. 2). Embolization of these branches markedly reduces shunted blood in some cases; however, this is a risky procedure due to the possibility of reflux of the embolic material into the intracranial circulation. The only viable way to perform this safely is for an experienced technician to inject, under the guidance of high-resolution digital subtraction angiography, a small amount of NBCA diluted with oily contrast material or PVA particles suspended in water-soluble contrast material. In cases improperly treated by surgical or endovascular ligation of the ECA, abundant collateral branches are established to the feeding pedicles from the muscular branches of the VA (Fig. 2). In this situation, intracranial VB branches are usually fed by the contralateral VA, and muscular branches are embolized by PVA particles following occlusion of the VA by using detachable balloons below the origin of the posterior inferior cerebellar artery. If the patient cannot tolerate test occlusion of the VA, the branches can be embolized with PVA particles, under temporary balloon occlusion of the VA above, followed by copious washing out of the dead space prior to balloon deflation to alleviate the possibility of scattering PVA particles into intracranial circulation.

\textbf{Intraoperative Embolization.} In intraoperative embolization procedures, one of the major advantages is that large threaded fibered coils, which are much less expensive and more thrombogenic than thin platinum coils, can be used for effective packing of the diseased segment of the sinus. The second advantage is that the sigmoid sinus may be easily embolized, which obviates the need for its extensive surgical exposure, which is otherwise necessary to obliterate numerous small feeding vessels coming to the fistula directly through the mastoid and petrous bones.\textsuperscript{28} Injection of liquid adhesive directly into the dural sinus should be avoided because of the strong possibility of causing an infarct related to migration of the embolic material into the cortical vein or artery.\textsuperscript{5,14} As a result of transvenous embolization, regression of the inaccessible arterial supply of arteries, such as the numerous leptomeningeal arteries and tentorial branches of the ICA and VB systems, takes place (Figs. 1 and 2). Concomitantly, there is also a marked diminution of preexisting brain hyperemia.

\textbf{Complementary Surgical Procedures.} In many cases DAVFs tend to persist or recur despite surgical interven-

\textbf{Conclusions}

It is believed that the treatment goal of potentially hazardous, complex DAVFs of the lateral sinus and confluence of sinuses should be the complete obliteration of the lesion at the initial stage. These lesions are grouped by type into three angiographic categories: 1) extremely high flow DAVF without sinus occlusion and LRVD, which is the best treated by transarterial embolization combined with transvenous occlusion, followed by resection of the diseased segment of the sinus or surgical isolation of the segment and radiation; 2) localized DAVF with exclusive LRVD, which is the best treated by transarterial embolization combined with surgical disconnection of LRVD; and 3) DAVF with bifocal or diffuse sinus occlusion and LRVD, which is the best treated by transarterial embolization combined with tight packing of the segmented sinus with or without complementary surgical isolation or resection of the lesion. Of course, the less intrusive course is the most desirable, but usually that option is not totally successful. Incomplete embolization and surgical devascularization reduce the risk factors only temporarily, fail to halt progression, and make subsequent treatment difficult.\textsuperscript{34,38}

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