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Treatment of Dural Arteriovenous Malformations Involving the Superior Sagittal Sinus

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We report the diagnosis and treatment of seven dural arteriovenous malformations involving the superior sagittal sinus. The most common presenting symptom was headache, although two patients presented with hemorrhage. Embolization alone effected a complete cure in four patients, while a combination of embolization and surgery was used in the remaining three patients. The first of these had intraoperative exposure and embolization of multiple feeding branches of both middle meningeal arteries, which resulted in a complete cure without deficits. The second patient had multiple embolizations and surgeries with eventual resection of the involved sagittal sinus to effect a complete cure, which was complicated postoperatively by paraparesis. The third patient had preoperative embolization and subsequent surgical resection of the superior sagittal sinus, resulting in a complete cure without deficits.

Because of their unique midline location, multiplicity of arterial feeders, and critical venous drainage, dural malformations involving the superior sagittal sinus often require unusual and aggressive forms of therapy.

Dural arteriovenous malformations (DAVMs) are infrequent, constituting 10–15% of all intracranial arteriovenous malformations [1]. They most often occur in the region of the transverse, sigmoid, and cavernous sinuses, but they can occur in any dural structure. Chaudhary et al. [2] and Houser et al. [3] presented evidence that some DAVMs are acquired lesions caused by dural sinus thrombosis.

In the past 8 years we have treated 65 DAVMs with a variety of treatment methods, including compression therapy, intravascular embolization, and embolization in conjunction with surgery. Of these 65 DAVMs, seven (11%) involved the superior sagittal sinus. Because of their midline location, essential venous drainage, and multiplicity of potential arterial inputs, DAVMs in this region present unique problems in their diagnosis and treatment. Generally, surgical extirpation of the involved dura and dural sinus is recommended for definitive cure of DAVMs in the posterior fossa [4]. However, because the superior sagittal sinus drains the majority of venous outflow of the cerebral hemispheres, surgical resection may not be tolerated [5]. Intravascular embolization has emerged as an effective treatment for DAVMs in other locations; however, technical factors may limit the success rate in the superior sagittal sinus region. We report the result of embolization therapy, sometimes in conjunction with surgery, in the treatment of DAVMs in this unusual location.

Subjects and Methods

The radiographic and clinical findings of seven patients who were treated over the past 6 years for DAVMs involving the superior sagittal sinus were reviewed. Patients' ages ranged from 35 to 55 years (mean, 44 years). The causes, presenting symptoms, arterial feeders, venous drainage, treatments, and outcomes are summarized in Table 1.

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TABLE 1: Summary of Superior Sagittal Sinus Malformations

Patient No.	Causes	Presenting Symptoms	Arterial Feeders	Venous Drainage	Treatment	Outcome (Follow-up)
1	Trauma: skull fracture	Weakness, cortical blindness, dementia	Bilateral MMA, left anterior falx artery	Cortical vein to deep medullary veins	Embolized with PVA	100% closure (4 yrs), weakness improved, blindness unchanged
2	Unknown	Chronic headache	Bilateral MMA, OA, STA	SSS	Preoperative spheres and balloons, surgical resection	100% closure (3 yrs)
3	Trauma: skull fracture	Headache and bruit	Bilateral MMA, STA, OA, parietooccipital branches, vertebral artery	SSS	Multiple surgeries, SSS surgery, SSS resection	100% closure (3 yrs), residual hemiparesis
4	Trauma: scalp laceration and skull fracture	Headache and pulsatile mass	Bilateral MMA and STA	Cortical vein to SSS	Percutaneous puncture of STA with IBCA	100% closure (2 yrs)
5	Unknown	Aphasia (parietal lobe hemorrhage)	Bilateral MMA and vertebral artery	Cortical vein to SSS	Embolized with PVA and IBCA	100% closure (1 yr)
6	Unknown	Weakness (right subdural hematoma)	Bilateral MMA	SSS	Surgical exposure of MMA, embolized with IBCA	100% closure (8 months)
7	Unknown	Headache	Bilateral MMA	SSS	Embolized with PVA	100% closure (2 yrs)

Note.—MMA = middle meningeal artery; PVA = polyvinyl alcohol; OA = occipital artery; STA = superficial temporal artery; SSS = superior sagittal sinus; IBCA = isobutyl-2-cyanoacrylate.

Results

Causes

In three patients trauma was the inciting factor associated with the development of the fistula. One of these patients had a depressed skull fracture in the parietal region, which was surgically debrided. Three months later he noted a bruit in both ears and a DAVM involving the superior sagittal sinus was diagnosed. The second patient suffered a scalp laceration with a nondepressed skull fracture, and a pulsatile mass was noted beneath the laceration site several months after the trauma. An angiogram performed 2 years later revealed a dural malformation involving the superior sagittal sinus with venous drainage to a dilated cortical vein. The third patient had skull trauma, and 6 months later developed a bruit and headache. The presumed mechanism by which a DAVM develops after trauma is by direct laceration of the wall of the dural sinus or sinus thrombosis with subsequent recanalization.

In the other four patients, no underlying cause could be found. In one 44-year-old patient with symptoms of severe unilateral headaches dating back to age 12, the long-standing DAVM presumably resulted in the extensive thickening of the calvarium, which was caused by hyperemia of the underlying dura.

Gender

Unlike the strong female predominance among patients with DAVMs located in other dural sinuses, especially in the cavernous sinus region [6], there was nearly equal gender distribution in this study of four men and three women. Three of the men had traumatic origin of their dural fistula, which accounted for their high representation in our patient population.

Presenting Symptoms

In four of the seven patients, severe headache was the initial symptom. One of these (patient 2) had severe headaches for 32 years ascribed to migraines before angiographic confirmation of a dural fistula. Another (patient 3) presented with a bruit in both ears and headache. The other two patients presented with hemorrhage as the initial symptom: the first had a subdural hematoma and the second presented with an intraparenchymal parietal lobe hematoma.

Location

In all seven patients, the dural fistula involved the middle third of the superior sagittal sinus. One patient also had a second DAVM involving the cavernous sinus with proptosis.

Headaches, which were this patient's major complaint, were localized in the vertex and attributed to the superior sagittal sinus involvement. In none of the cases was the superior sagittal sinus occluded or narrowed. None of the patients had previous symptoms to suggest complete sinus occlusion, although subtotal occlusion could not be excluded.

Arterial Supply

All seven patients had arterial supply from both middle meningeal arteries. The remaining supply to the fistula was as follows: two patients with transosseous branches of the superficial temporal artery, two patients with occipital artery, one patient with anterior falx artery, one patient with posterior meningeal branch of the vertebral artery, and one patient with cortical supply. In the single patient with cortical supply from the parietooccipital branches of the posterior cerebral artery (patient 3) (Fig. 1), the previous surgical débridement of a depressed skull fracture possibly caused the formation of adhesions and resulted in the bridging supply.

Venous Drainage

Six of the seven patients had venous drainage to the superior sagittal sinus. The remaining patient (patient 1) (Fig. 2) had arterial supply from both middle meningeal arteries with venous drainage to a cortical vein paralleling the course of the superior sagittal sinus. Although the superior sagittal sinus was patent, the connection with the draining vein was occluded. The venous drainage was through deep medullary veins to the deep venous system. This circuitous drainage pathway resulted in venous hypertension. There was low density in the parietal and occipital lobes on CT scan in the region of the venous drainage, which was presumed to be cerebral edema or infarction. The patient had symptoms of cortical blindness, dementia, and fluctuating motor weakness. After embolization with polyvinyl alcohol (PVA) particles there was complete closure of the DAVM, resolution of dementia, and improvement of motor strength, but no change in visual function.

In two patients there was bilateral arterial supply from both middle meningeal arteries and venous drainage to a dilated cortical vein, which eventually drained to the superior sagittal

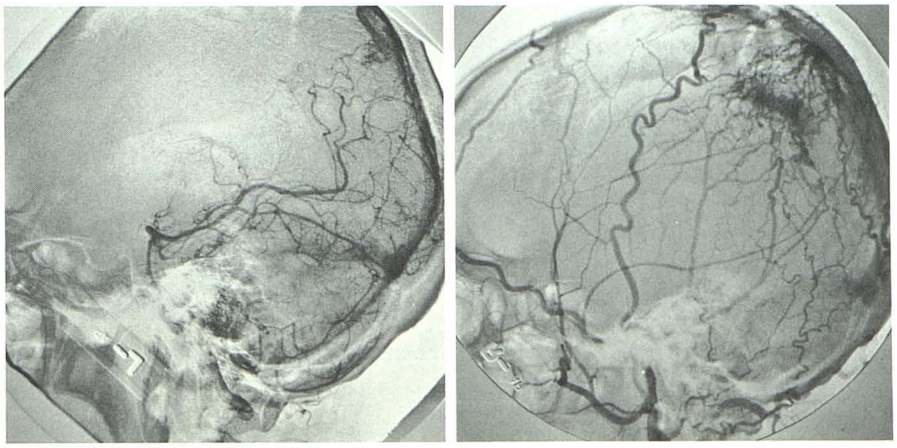

Fig. 1.—Patient 3.
***A*, Vertebral artery angiogram, lateral projection. Cortical supply to dural arteriovenous malformation supplied from parietooccipital branches of posterior cerebral arteries.**
***B*, External carotid angiogram demonstrates dural fistula at site of parietal skull fracture.**

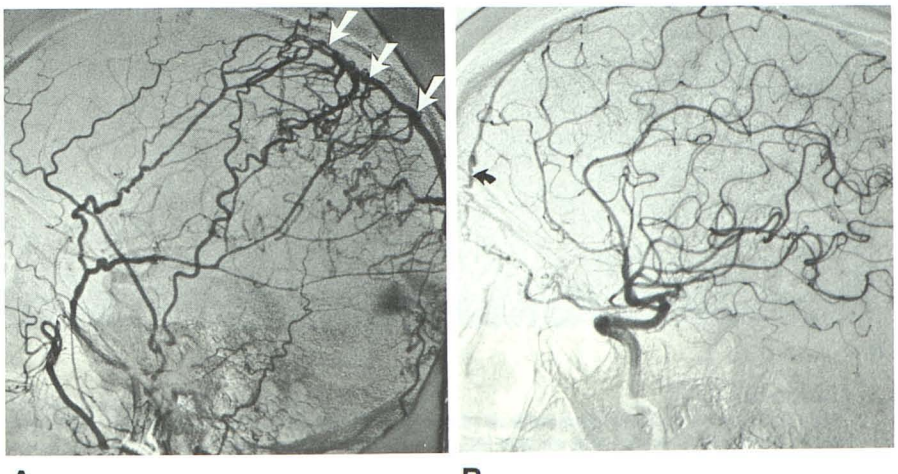

Fig. 2.—Patient 1.
***A*, External carotid artery angiogram, lateral view, demonstrates hypertrophied middle meningeal artery supplying a dural arteriovenous malformation with venous drainage to a cortical vein (*arrows*), which drained to deep medullary veins.**
***B*, Internal carotid angiogram, lateral view, with supply to same dural arteriovenous malformation from anterior falx artery (*arrow*).**

sinus. The first (patient 5) (Fig. 3) demonstrated hypertrophied middle meningeal arteries draining into a dilated parietal cortical vein. The patient presented with an intraparenchymal parietal lobe hemorrhage in the region of the draining vein resulting in dysphasia, weakness, and sensory symptoms that improved over the subsequent several weeks. One month later a second intraparenchymal hemorrhage occurred in the same location, and was associated with subarachnoid hemorrhage. Embolization of both middle meningeal arteries resulted in 90% closure of the fistula with a small amount of supply persisting from the posterior meningeal branch of the vertebral artery. A follow-up angiogram 1 year later demonstrated complete obliteration of the fistula.

The second patient (patient 4) (Fig. 4) suffered a skull fracture and scalp laceration leading to the development of a pulsatile mass and headache localized in the region of the scalp laceration. Angiography revealed a DAVM supplied by bilateral middle meningeal and superficial temporal arteries, which drained to a dilated cortical vein with varicies. This vein eventually drained to the superior sagittal sinus. The venous varicies were thought to be caused by venous outflow obstruction at the junction of the draining vein with the superior sagittal sinus. Severe carotid bifurcation atherosclerosis and narrowing precluded transfemoral embolization, but percutaneous puncture of both superficial temporal arteries and injection of isobutyl-2-cyanoacrylate (IBCA) resulted in a complete cure.

Treatment Techniques

Embolization

Four patients were treated by embolization alone. One patient's DAVM (patient 7), involving both the cavernous sinus

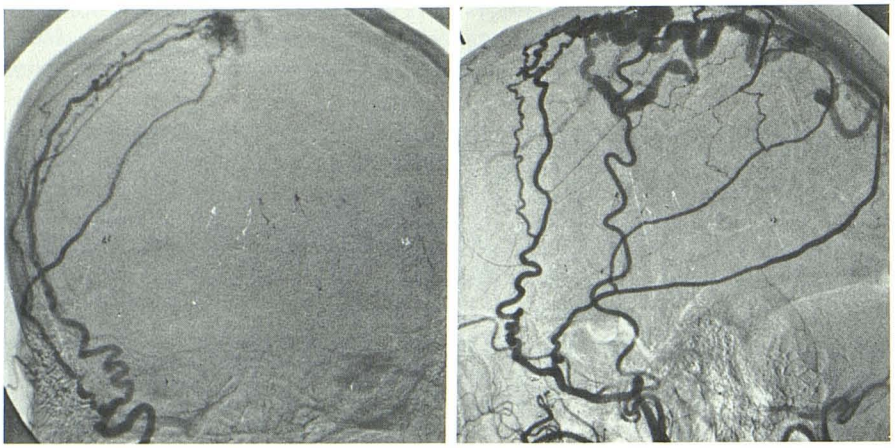

Fig. 3.—Patient 5. Right anteroposterior (*A*) and lateral (*B*) views, external carotid artery angiograms, with dilated middle meningeal artery shunting to dilated interhemispheric cortical vein, which drains to superior sagittal sinus.

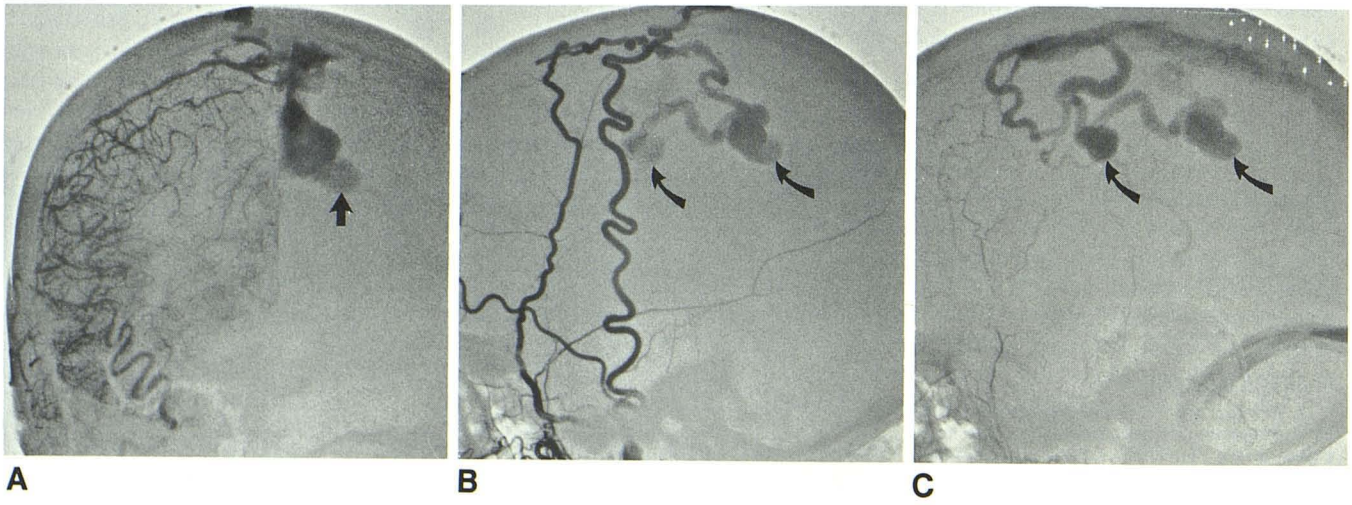

Fig. 4.—Patient 4.
***A*, Right common carotid angiogram with dural arteriovenous malformation supplied by middle meningeal and superficial temporal arteries with venous drainage to dilated cortical vein with varicies (*arrow*).**
***B* and *C*, Right external carotid angiogram, early (*B*) and late (*C*) arterial phase, with drainage to dilated cortical vein with varicies (*arrows*) and delayed drainage to superior sagittal sinus.**

region and the superior sagittal sinus, was treated with PVA and was completely cured. The second patient (patient 4) (Fig. 4), discussed above, was treated by direct puncture of both superficial temporal arteries and injection of IBCA, resulting in a complete cure. The third patient (patient 5) (Fig. 3) was treated twice with embolization of both middle meningeal arteries using both IBCA and PVA, which resulted in a 90% decrease in the size of the fistula. A follow-up angiogram at 1 year showed complete obliteration of the fistula. The fourth patient (patient 1) (Fig. 2) was treated with PVA embolization, resulting in complete closure of the fistula.

Embolization alone of dural fistulas in the posterior fossa and cavernous sinus region is often curative [7]. However, the midline location of the superior sagittal sinus and multiplicity of feeders makes transvascular obliteration of the nidus more difficult. Often the hypertrophied and tortuous middle meningeal or superficial temporal feeding arteries prevent placement of the embolization catheter close to the nidus, making precise deposition of liquid adhesive agents difficult. The recent advances in small catheter and steerable guidewire technology have greatly reduced this problem. As with embolization in other locations, proximal occlusion of a feeding arterial pedicle is seldom effective, and usually results in recruitment of collateral meningeal supply that is often more difficult to treat. Deposition of liquid embolic agents distal to the nidus must also be avoided because this would increase the pressure within the nidus and could increase both the symptoms and the risk of hemorrhage. The venous drainage of DAVMs associated with the superior sagittal sinus is either to the cortical veins or to the sinus itself, and occlusion of these large vascular structures may have disastrous results.

Embolization and Surgery

Surgical excision of the involved dural sinus, although technically difficult, is often curative for DAVMs involving the posterior fossa [4]. Surgical excision of a patent superior sagittal sinus posterior to the rolandic vein inflow may result in cerebral edema, venous hemorrhage or infarction, or death [5]. The size and duration of the fistula, adequacy of venous collaterals, and direction of flow all enter into the decision as to which treatment modality offers the greatest possibility of cure with the least risk to the patient.

Several combined neuroradiologic and surgical techniques were employed to treat the last three patients in this series.

Patient 6 (Fig. 5) is a 48-year-old woman who presented with a right subdural hematoma. Angiography revealed a DAVM that involved the walls of the middle third of the superior sagittal sinus near the rolandic inflow and was supplied by both middle meningeal arteries. Because of the small caliber of the feeding middle meningeal arteries, transvascular embolization was considered to be technically difficult.

The location of the fistula near the rolandic inflow in the middle third of the sinus precluded surgical excision of the superior sagittal sinus without significant risk of morbidity or death. A combined neuroradiologic and neurosurgical approach was attempted. Bilateral craniotomies on either side of the superior sagittal sinus were performed. The subdural hematoma was drained and four feeding branches of the middle meningeal arteries (anterior and posterior branches) were identified and catheterized with 2-French catheters. Intraoperative angiography confirmed the supply to the DAVM, and embolization with 0.1–0.15 ml of IBCA per feeding arterial pedicle resulted in complete obliteration of the fistula. Intraoperative angiography with selective external and internal injections confirmed the obliteration of the fistula and preservation of the superior sagittal sinus. A follow-up angiogram confirmed the obliteration of the DAVM. The patient was discharged with complete resolution of her symptoms and without neurologic deficits.

Patient 2 (Fig. 6) had severe headaches for 32 years. An angiogram revealed bilateral supply from dilated middle men-

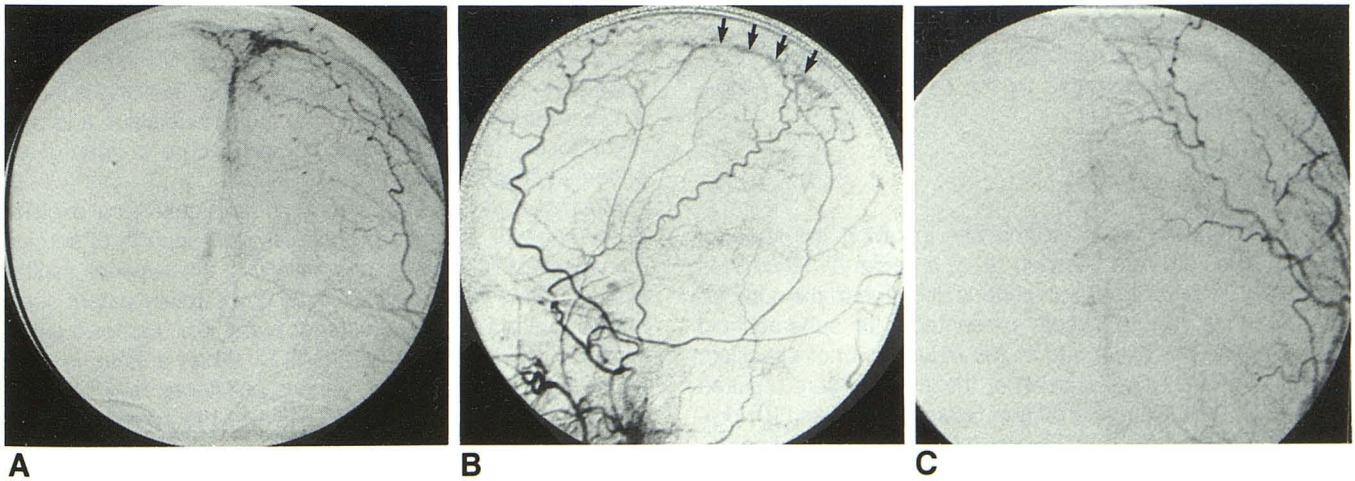

Fig. 5.—Patient 6, who presented with weakness resulting from a subdural hematoma.
***A*, Left external carotid angiogram, anteroposterior view, with dural arteriovenous malformation involving walls of superior sagittal sinus.**
***B*, Left external carotid angiogram, lateral view, showing site of fistula in middle third of superior sagittal sinus (*arrows*).**
***C*, Left external carotid angiogram, anteroposterior view, after intraoperative embolization of feeding arteries and complete obliteration of dural arteriovenous malformation. Similar supply from right middle meningeal artery was also obliterated intraoperatively.**

Fig. 6.—Patient 2.
***A*, Right internal maxillary angiogram, lateral view, with dilated middle meningeal artery and superficial temporal artery supply to superior sagittal sinus fistula.**
***B*, Anteroposterior view, external carotid angiogram, shows dilated superior sagittal sinus and reflux drainage into cortical veins.**
***C*, Lateral skull radiograph after preoperative embolization with spheres and balloons (*arrows*) in middle meningeal artery, superficial temporal artery, and occipital artery feeders. Successful surgical excision of involved superior sagittal sinus followed.**

ingeal, superficial temporal, and occipital arteries. Because of the massive supply it was decided that preoperative embolization followed by surgical excision would be the most effective means to achieve a cure. Surgical excision was considered feasible because chronic venous hypertension in the superior sagittal sinus caused reversal of flow and presumably the development of adequate venous collaterals to drain the cortex once the sinus was resected. Preoperative embolization with Silastic spheres and detachable silicone balloons in all six feeders was followed by surgical resection of the superior sagittal sinus. A dural patch graft was used to close the defect from the resected superior sagittal sinus. The patient tolerated the procedure without developing neurologic deficits and had complete resolution of her symptoms.

The third patient, previously discussed in a published case report [8], had multiple embolizations and surgical procedures culminating in surgical resection of the superior sagittal sinus. Treatment was complicated by the development of paraparesis after resection.

Discussion

Dural arteriovenous malformations involving the superior sagittal sinus are rare. Aminoff [9] in a series of 16 DAVMs described three patients with venous drainage to the superior sagittal sinus, two of whom presented with subarachnoid hemorrhage. The exact site of the nidus was not specified, however, and surgical excision of the involved dura resulted in cure. In 1966 Ramamurthi and Balasubramanian [10] presented a single case of a 23-year-old woman with a spontaneous malformation fed bilaterally by occipital and middle meningeal arteries with drainage to the posterior superior sagittal sinus. These authors noted an absence of internal carotid supply and reflux into cortical veins from the superior sagittal sinus. They ligated one external carotid artery and the occipital and middle meningeal arteries on the contralateral side with symptomatic improvement, but warned that ligation of feeding vessels was not always effective. In 1967 Dennery and Ignacio [11] described a traumatic dural fistula supplied by superficial temporal and frontal arteries with drainage to the superior sagittal sinus. They ascribed the symptoms of tremor, rigidity, and confusion to steal from the internal carotid artery, although venous hypertension may be more plausible. Ligation of the superficial temporal and frontal arteries resulted in no improvement. After stripping the bone periosteum and blocking multiple emissary vessels, a complete cure was achieved. Several other authors have described DAVMs that drained to the superior sagittal sinus, but the site of the nidus was on the dural convexity adjacent to it [12–14].

Two of the seven patients in our series presented with hemorrhage, a higher percentage than DAVMs in other locations [15]. Intravascular embolization alone is highly effective in the treatment of DAVMs in the cavernous sinus and posterior fossa, and resulted in complete cure in four of six patients in this series.

Much of our knowledge about the risks of surgical excision of the superior sagittal sinus comes from reports of surgical management of meningiomas involving the superior sagittal sinus [5, 16, 17]. Surgical excision of a partially patent superior sagittal sinus, in the posterior two-thirds, carries a significant risk of neurologic deficits [17]. When a sinus is completely occluded by tumor, venous collaterals may have developed that make surgical excision of the superior sagittal sinus safer. Severe morbidity can still occur, particularly in the region of the rolandic vein inflow [5]. Similarly, surgical excision of a patent superior sagittal sinus in a small DAVM carries a high risk. Although dural and vein grafts have been described for treatment of the superior sagittal sinus with

tumor infiltration, DAVMs often occupy a long segment of dura making this surgical maneuver difficult [18, 19]. Drainage from bridging veins may also be compromised with such an approach. With this knowledge, a combination of surgery and embolization may be optimal for fistulas that are inaccessible or difficult to embolize. Feeding artery ligation should be avoided at all costs; for while this procedure is occasionally curative, the collateral supply, which is difficult to embolize or surgically interrupt, will usually keep the fistula open.

In patients with large, long-standing DAVMS, surgical resection may be both safe and curative. The high pressure in the arterialized sinus induces venous collaterals that minimize surgical risks of excision. Because of the marked vascularity of the dura surrounding the large DAVMs, aggressive preoperative embolization should be performed, if possible, to minimize blood loss. Only in preoperative situations is proximal ligation recommended, and the interval between embolization and surgery should be short to minimize the risk of developing vascular collaterals.

In conclusion, DAVMs involving the superior sagittal sinus are rare; but because of their location they may be accompanied by a wide variety of symptoms and require unusual and aggressive forms of therapy. A combined surgical and neuroradiologic approach is sometimes necessary to optimize the chance for patient cure.

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