

Transvenous Embolization of Dural Fistulas Involving the Transverse and Sigmoid Sinuses

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Eleven patients with dural fistulas involving the transverse and sigmoid sinuses were treated by transvenous embolization with coils or liquid adhesives. Seven patients underwent preoperative embolization of the external supply followed by direct surgical exposure of the sinus: liquid adhesives were used in four patients and coils in the remaining three. Four of these patients had complete obliteration of their fistulas and there was 95% reduction in the remaining three. Four patients had transvenous placement of coils from a transfemoral approach. In three, the ipsilateral sigmoid sinus was thrombosed and a contralateral approach across the torcular herophili was used. Coils were used in all four patients; one patient also had liquid adhesives placed within the sinus. Complete cure was achieved in one patient, 95% reduction in another, and 50% and 40%, reductions in the remaining two. Two transient complications occurred, one related to venous occlusion secondary to liquid adhesives and another related to transient occlusion of the vestibular aqueduct.

Obliteration of dural fistulas involving the transverse and sigmoid sinuses can be achieved by placement of embolic material within the involved sinus from a transvenous approach; both coils and liquid adhesives can achieve this goal.

Dural arteriovenous fistulas (AVFs) are connections between dural arteries and venous sinuses. Recent evidence suggests these lesions are acquired after dural sinus thrombosis [1, 2]. Although spontaneous closure has been reported [3], the majority remain patent and can present with a wide spectrum of clinical signs and symptoms such as bruit, headache, dementia, neurologic deficits, and hemorrhage. Treatment techniques have evolved as the natural history of the disease has been elucidated. Feeder artery ligation has largely been abandoned as a treatment because of the development of extensive collaterals that keep the fistula open [4, 5]. Direct surgical resection of the involved dural sinus has become an accepted treatment; however, because of the extensive vascularity of the surrounding dura, bone, and subcutaneous structures, significant hemorrhage can result [6]. More recently, transarterial embolization has become an accepted treatment for dural fistulas [7, 8]. Advances in microcatheter and guidewire technology have made subselective embolization of feeding arteries technically easier. Despite these advances, some fistulas remain patent after embolization. In others, dural supply from the internal carotid artery or vertebral artery may be difficult or hazardous to embolize. Patients who have had prior surgical ligation of feeding arteries may not have a safe vascular access for transarterial embolization.

Over the past 2 years, we have developed an alternative treatment for patients with dural fistulas not suitable for transarterial embolization. The treatment involves placement of embolic material into the involved dural sinus from transfemoral venous access or direct surgical exposure. The indications, choice of embolic agent, and potential complications are summarized in this report.

Materials and Methods

Eleven patients with dural fistulas involving the transverse and sigmoid sinuses were treated by transvenous embolization from June 1986 through November 1987 (Table 1).

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TABLE 1: Summary of Transverse and Sigmoid Sinus Dural Arteriovenous Fistulas Treated by Transvenous Embolization

Case No.	Age	Gender	Venous Access	Fistula Location	Embolic Agent	Outcome	Clinical Follow-up (months)
1	40	M	Surgery	R transverse sinus	IBCA	95% reduction	20
2	70	M	Surgery	L transverse sinus	IBCA	Cure	16
3	47	M	Surgery	R transverse sinus	IBCA	Cure	14
4	55	M	Surgery	L transverse sinus	IBCA	95% reduction	12
5	67	F	Surgery	L transverse sinus, sigmoid sinus	Coils	Cure	8
6	45	F	Transfemoral	R transverse sinus, sigmoid sinus	Coils, IBCA	40% reduction	14
7	27	F	Transfemoral	R transverse sinus, sigmoid sinus	Coils	95% reduction	8
8	30	M	Transfemoral	L transverse sinus, sigmoid sinus	Coils	50% reduction	7
9	55	F	Transfemoral	L sigmoid sinus	Coils	Cure	7
10	27	F	Surgery	L transverse sinus, sigmoid sinus	Coils	95% reduction	6
11	37	F	Surgery	L transverse sinus, sigmoid sinus	Coils	Cure	5

Note.—Complications occurred in only two cases; venous occlusion occurred in case 3 and transient vertigo in case 9. R = right; L = left; IBCA = isobutyl 2-cyanoacrylate.

The indications for treatment included six patients with neurologic decline (two hemorrhages, three declining vision, and one vertigo), seven with bruit, and 10 with headache.

Seven patients were treated by direct surgical exposure of the dural sinus, intraoperative puncture of the sinus, and embolization with Gianturco coils* and/or isobutyl-2-cyanoacrylate (IBCA).† Pre-operative transarterial embolization was performed in all seven patients to reduce the size of the fistula and minimize the vascularity of surrounding structures. In one patient with a large transverse sinus fistula, staged surgical interruption of the posterior meningeal branch of the vertebral artery and tentorial branches of the internal carotid artery was performed before final intraoperative embolization.

In three patients (cases 1, 3, and 4), the dural sinus was exposed, and arterialized veins draining the involved sinus were ligated to prevent reflux of liquid adhesive material into normal cortical veins. The involved dural sinus was then isolated, either by surgical ligation or with the use of a balloon occlusion catheter placed transfemorally into the ipsilateral internal jugular vein (case 1). The involved segment of sinus was punctured and digital subtraction angiogram (DSA) obtained. A mixture of IBCA mixed with iophendylate (Pantopaque)‡ was injected by using real-time DSA.§ In case 2 the dural fistula no longer communicated with the dural sinus (cortical drainage). The arterialized vein was identified, ligated, and punctured proximal to the ligature. A mixture of IBCA and Pantopaque was injected into the fistula site during real-time DSA. DSA images were obtained from a transfemoral catheterization in the operating room. Follow-up angiograms were obtained at 2–4 weeks.

In three patients (cases 5, 10, and 11) the dura overlying the transverse sinus was exposed posterior to the involved segment and punctured with an 18-gauge single-wall needle (Cook, Inc.). A 5.5-

French sheath was placed into the dural sinus, and through this, a 5-French catheter was inserted into the most caudal extent of the involved sigmoid sinus. Multiple Gianturco coils (Cook, Inc.), 0.038-in. (0.097-cm) wire diameter with coil sizes 5–8 mm in diameter, were placed into the involved segments of transverse and sigmoid sinuses. The coils were packed tightly to ensure complete thrombosis. When the most medial aspect of the involved sinus was occluded, dark venous blood could be aspirated as opposed to bright red arterialized blood at the beginning of the procedure. An oxygen content measured in one case confirmed unsaturated venous blood at the completion of the procedure.

In the four remaining patients (cases 6–9), transvenous embolization was performed from a femoral vein access. DSA was first performed to document the site of the fistula. Transarterial embolization was not performed. A 1-cm washer was placed on the ipsilateral mastoid bone for measurement of the diameter of the involved sinus and to permit accurate sizing of the coil diameter needed for sinus occlusion. The femoral vein was then punctured, and a 7-French catheter¶ was advanced into the ipsilateral or contralateral internal jugular bulb. A contralateral approach was used in three patients because the ipsilateral approach was thrombosed. Systemic anticoagulation was instituted with a 5000-unit bolus of heparin with 2500 U/hr thereafter. A 3-French Teflon¶ or 3.2- or 4.2-French Tracker catheter** was advanced coaxially through the 7-French catheter with the use of a steerable 0.14- or 0.22-in. (0.36- or 0.56-cm) guidewire (Target Therapeutics). Embolic agents placed through the catheters included platinum wire coils, 0.10- to 0.18-in. (0.25- to 0.46-cm) diameter (Target Therapeutics); Gianturco coils, 0.025-in. (0.064-cm) diameter (Cook, Inc.); and/or IBCA (Ethicon, Inc.). Angiograms were obtained during the procedure to ensure thrombosis of the

* Cook, Inc., Bloomington, IN.

† Ethicon, Inc., Somerville, NJ.

‡ Lafayette Pharmacal, Inc., Lafayette, IN.

§ Diasonics, Salt Lake City, UT.

¶ USCI, Billerica, MA.

** Meditech, Watertown, MA.

** Target Therapeutics, Mountain View, CA.

fistula. After embolization, a control angiogram was obtained from all possible arterial sources. Follow-up angiograms were obtained between 1 and 2 months.

Results

Seven patients underwent preoperative embolization followed by direct surgical exposure and embolization with coils or liquid adhesives. All seven had follow-up angiograms with complete angiographic cure in four and 95% reduction in the remaining three (cases 1, 4, and 10). The clinical follow-up period was 5–20 months (mean, 11.4 months).

Four patients (cases 6–9) underwent transfemoral venous embolization with coils. One patient (case 6) also required placement of liquid adhesives. There was complete angiographic cure in one patient, 95% obliteration in one, and reductions of 50% and 40% in the remaining two. In all patients, the segments of sinus that were initially occluded with coils remained occluded. The inability to produce complete obliteration of the fistula in three patients was a failure to place coils within the entire involved segment of the fistula. The clinical follow-up period was 7–14 months (mean, 9 months).

Two transient symptomatic complications were related to transvenous embolization. Liquid adhesives migrated from the desired site within the transverse sinus through a transverse pontine vein into the anterior pontomesencephalic venous system in case 3. In the second patient treated by transvenous placement of coils (case 9), the development of transient vertigo immediately followed closure of the fistula. The patient was treated with transdermal scopolamine^{††} transcutaneously for 2 days. She recovered without deficits. The suspected mechanism for the development of vertigo in this case was transient mechanical occlusion of the vestibular aqueduct from the thrombosed sinus. An asymptomatic complication occurred when a coil to be placed in the transverse sinus was inadvertently deposited into the superior sagittal sinus. This coil was removed from the sinus by careful guide-wire manipulation and embolized to the lungs without symptoms.

Representative Case Reports

Case 3

A 47-year-old man had progressive dementia and visual loss secondary to a large fistula located in the right transverse and sigmoid sinuses (Figs. 1A–1C). The distal sigmoid sinus was thrombosed with venous drainage diverted to the contralateral sinuses and cortical veins. The external carotid supply was preoperatively embolized with polyvinyl alcohol particles. The posterior meningeal artery and meningohypophyseal arteries were surgically interrupted and the draining arterialized veins were ligated. A 20-gauge needle was used to puncture the involved sinus and IBCA mixed with Pantopaque was injected. Some embolic mixture was noted to flow into an unrecognized transverse pontine vein (Fig. 1D). The patient awoke from surgery neurologically intact but declined into a coma. He was treated

with anticoagulants and recovered completely. Follow-up angiography (Figs. 1E and 1F) demonstrated complete fistula obliteration.

Case 5

A 67-year-old woman had a 2-year history of left ear bruit and severe headaches. She had undergone two prior embolization procedures with polyvinyl alcohol particles at another institution without improvement in symptoms, suffering a seventh nerve palsy from the second embolization. An angiogram at the time of referral to our institution revealed a dural AVF involving the left transverse and sigmoid sinuses. The arterial supply was from tentorial branches of the left internal carotid artery and posterior temporal branches of the posterior cerebral artery; minimal supply was from the left external carotid artery (Figs. 2A and 2C). There was thrombosis of the distal left sinus and venous drainage to the contralateral sinuses. The posterior auricular and middle meningeal arteries were preoperatively embolized with polyvinyl alcohol sponge particles with little decrease in the overall size of the fistula. A craniotomy was performed with removal of a bone flap posterior to the involved transverse sinus. The sinus was entered, and both a 5-French catheter and 5.5-French sheath were advanced to the most caudal extent of the sigmoid sinus to the point of the occlusion. Thirty-eight Gianturco coils were placed into the sigmoid and transverse sinuses with the use of real-time digital subtraction (Figs. 2B and 2E). At the conclusion of the procedure only dark venous blood could be aspirated from the catheter as opposed to the bright arterialized blood at the beginning of the procedure. A follow-up angiogram 16 days after embolization showed complete obliteration of the fistula; the patient recovered without new deficits.

Case 9

A 55-year-old woman developed severe pain and a pulsatile bruit. A prior embolization was unsuccessful secondary to spasm of the occipital artery, precluding safe transarterial embolization. From a transfemoral venous access, a catheter was navigated into the involved ipsilateral transverse sinus, which had severe narrowing (Fig. 3B). Through a 4.2-French Tracker catheter placed into the diseased sinus, multiple coils were positioned. An angiogram during the embolization demonstrated subtotal occlusion of the fistula (Fig. 3C); therefore, additional coils were placed from a contralateral approach until complete thrombosis had occurred (Fig. 3E). Mild vertigo after the procedure was presumed to be secondary to transient mechanical occlusion of the outflow of the vestibular duct. This was treated effectively with transdermal scopolamine; the patient subsequently recovered with total alleviation of her symptoms.

Case 7

A 27-year-old woman had severe headaches, vertigo, and bruit secondary to dural AVF involving the right sigmoid and transverse sinuses (Figs. 4A and 4B). There was complete thrombosis of the distal ipsilateral sigmoid sinus and venous drainage to cortical veins and the contralateral sinuses. From a contralateral approach, a 3.2-French Tracker catheter was positioned within the sigmoid sinus and platinum wire coils were placed. This catheter was exchanged for a stiffer 3-French Teflon catheter, and 0.025-in. (0.064-cm) coils were positioned in the transverse sinus fistula (Fig. 4D). The patient had resolution of her headaches, vertigo, and bruit. A follow-up angiogram at 2 months demonstrated a small residual fistula (Fig. 4E) at the transverse and sigmoid sinus junction where a paucity of coils had been placed. This was treated by transarterial occlusion with IBCA resulting in complete fistula closure.

^{††} Transderm patch, Ciba Pharmaceutical Co., Summit, NJ.

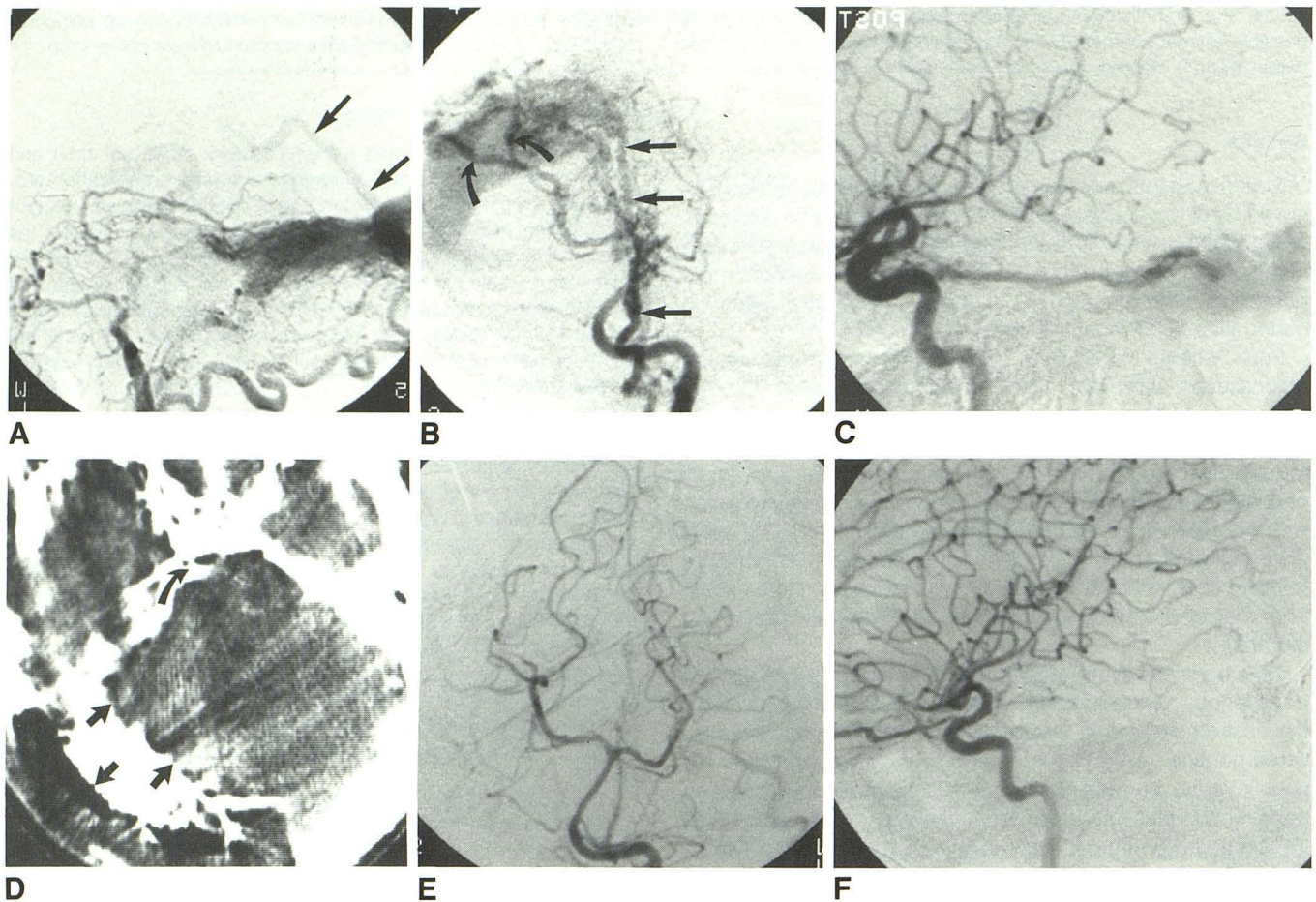


Fig. 1.—Case 3.

A, Right external carotid injection, lateral view, shows dural fistula with cortical reflux into straight sinus (arrows).

B, Left vertebral injection, Towne's projection, shows hypertrophied posterior meningeal (straight arrows) and posterior cerebral (curved arrows) supply to same fistula.

C, Right internal carotid injection, lateral view, shows supply from marginal tentorial artery.

D, Nonenhanced CT scan after intraoperative embolization shows high-density embolic material within sinus (straight arrows) with extension into transverse pontine vein (curved arrow).

E, Right vertebral injection, Towne's projection, after intraoperative embolization shows obliteration of supply.

F, Right internal carotid injection, lateral view, shows obliteration of fistula.

Discussion

Dural fistulas are unique vascular abnormalities comprising numerous tiny connections between branches of dural arteries and a venous sinus. Because of the extensive collateral network and rich vascularity of the dura [9], attempts at feeder artery ligation or proximal embolic occlusion are largely ineffective. Placement of embolic materials within the nidus of the fistula can result in cure. Our own experience with transarterial embolization has resulted in complete cure in only 59% of patients treated [10]. In many patients the dural supply arises from intracranial vascular pathways such as the posterior meningeal branch of the vertebral or tentorial branches of the internal carotid artery. Although transvascular embolization of these pathways is technically possible [11], the risk of embolic reflux and stroke makes these less desirable. If embolic material flows through the nidus and occludes venous drainage, aggravation of symptoms may result, with

diversion of venous drainage into cortical pathways. Although surgical excision of the involved sinus is possible, massive intraoperative hemorrhage can occur because of the rich vascularity of the surrounding structures [6]. Attempts to occlude dural fistulas by thrombosis of the involved dural sinus were first described by Mullen [12]. We have used a similar approach with the placement of embolic materials, either coils or liquid adhesives, within the involved dural sinus. This was first performed with direct surgical exposure of the dural sinus and intraoperative embolization; more recently, a transfemoral venous approach has been used.

Our initial experience involved surgically disconnecting the involved dural sinus from arterialized draining veins, isolating the involved sinus, and injecting liquid agents into the sinus. Because of the high arterial pressure within the involved sinus, there is often retrograde drainage of blood away from the sinus into cortical veins. These cortical pathways have developed adequate venous collaterals and tolerate interruption of

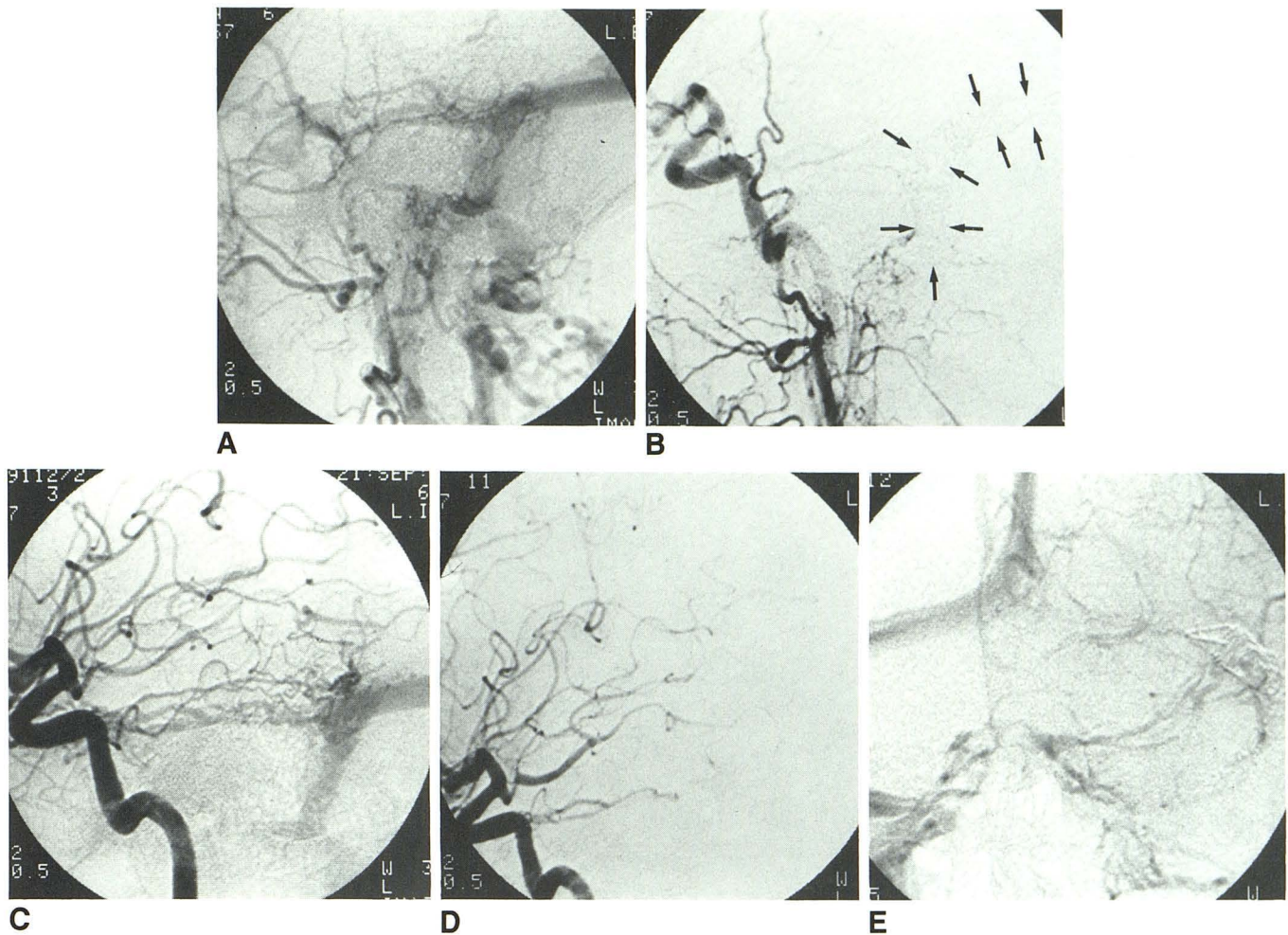


Fig. 2.—Case 5.

A, Left external carotid artery, lateral view, shows dural fistula involving transverse and sigmoid sinuses.

B, Same vessel after intraoperative transvenous embolization with 38 Gianturco coils (arrows) shows obliteration of fistulas.

C, Left internal carotid artery injection, lateral view, shows supply from tentorial branches of meningohypophyseal trunk to transverse sinus.

D, Same vessel after embolization with occlusion of fistula.

E, Left internal carotid artery injection, anteroposterior view, venous phase, shows occlusion of involved sinuses by multiple coils placed intraoperatively.

their connection with the dural sinus. Disconnection is important, if liquid adhesive embolic agents alone are contemplated, to prevent the flow of embolic agents into these cortical veins. When these connections have been interrupted and the sinus isolated by occluding its outflow, complete stasis is often observed after injection of contrast material or embolic agents. One complication occurred early in our series when a small amount of IBCA passed from an involved transverse sinus through an unrecognized transverse pontine vein into the anterior pontomesencephalic vein, producing venous occlusion. The patient declined neurologically initially but recovered fully after anticoagulant therapy. To prevent this potentially devastating complication and eliminate the need for surgical interruption of draining veins we now use metal coils placed into the affected sinus. This has been successful as a treatment alone or as a mechanism to slow the flow enough to allow liquid adhesive placement. Platinum or steel coils have the advantage of thrombogenicity, and, if properly

sized, they remain within the sinus, producing thrombosis. Advances in microcatheter technology have allowed us to reach even completely occluded dural sinuses from a contralateral transvenous route (Fig. 3). The small size of these catheters, however, limits the choice of embolic material. We initially used platinum wire coils measuring 0.010–0.018 in. (0.025–0.046 cm) in diameter as embolic agents through a 3.2-French Tracker catheter. The small diameter and short length of the coil segments makes placement and thrombosis difficult. This accounts, in part, for the low cure rate of our initial patients treated with transvascular embolic material. Although larger catheters (3-French Teflon or 5-French polyethylene) can deliver larger coils that would be more effective in obliteration of the fistula, their stiffness and size limits their use. Very recently we have had the opportunity to evaluate a larger version of the Tracker catheter that can deliver 0.025-in. (0.64-cm) coils. This catheter was used in case 9 to reach the transverse sinus from a contralateral approach.

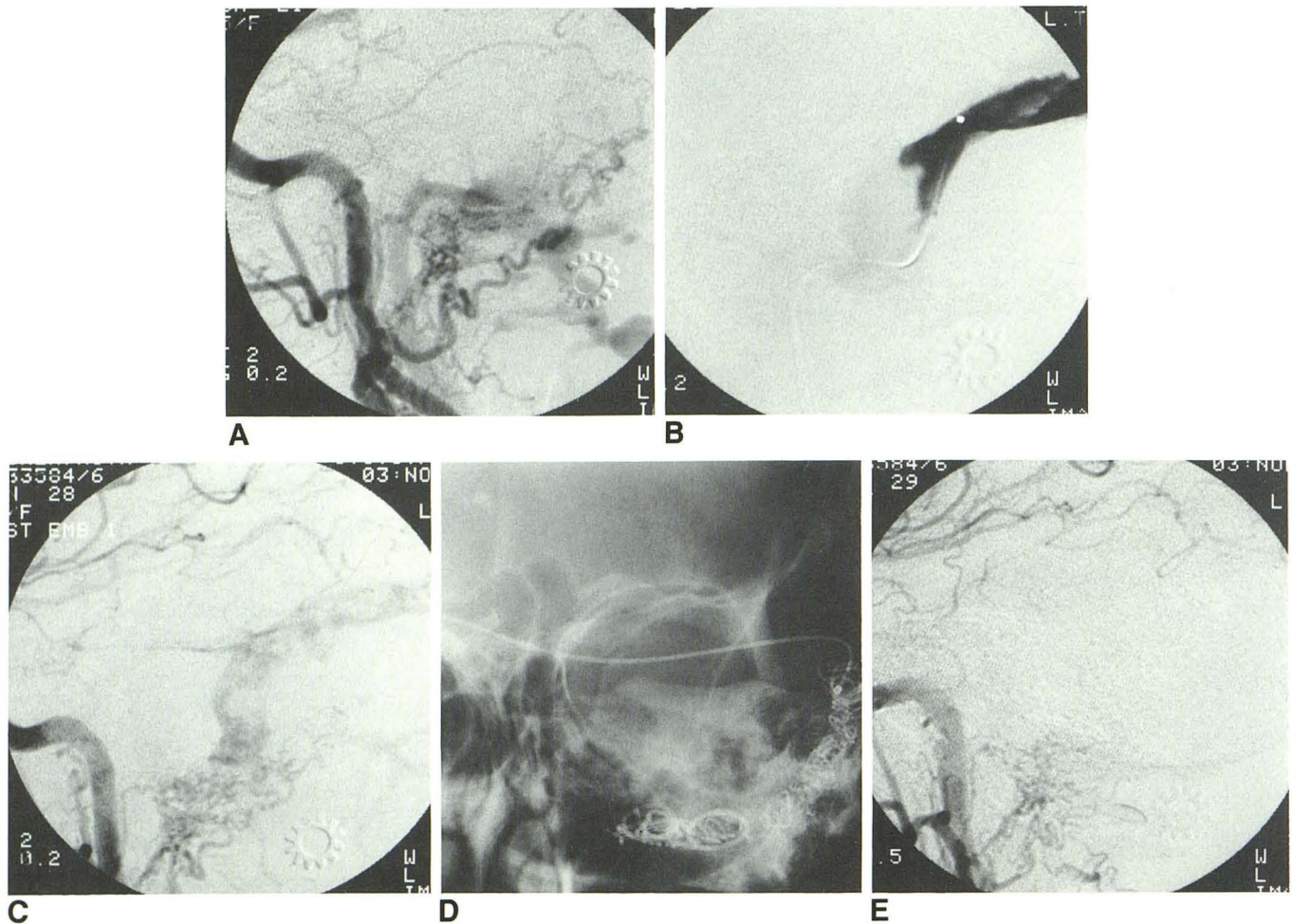


Fig. 3.—Case 9.

- A**, Left common carotid injection, lateral view, shows dural fistula involving sigmoid and transverse sinuses with venous drainage to collaterals. Note 1.0-cm washer used for measuring size of sinus.
- B**, Catheter has been placed from transvenous femoral route into narrowed transverse sinus.
- C**, Left common carotid injection after partial embolization shows filling defects in sinus (coils) but persistent supply to fistula.
- D**, Plain radiograph, anteroposterior view, shows more coils being placed from contralateral transfemoral venous approach.
- E**, Left common carotid injection after embolization shows complete obliteration of fistula.

Several complications may occur that are unique to this treatment technique. If inadequate coils are placed within a segment of diseased sinus with cortical venous drainage, diversion of arterialized blood to these veins could occur and result in neurologic deficit, hemorrhage, or venous infarction. Asymptomatic cortical drainage occurred in case 7 with the remaining fistula arising from the segment of sigmoid sinus that was sparsely filled with platinum coils. This small asymptomatic residual fistula was obliterated by transarterial embolization. By placing adequate emboli within the sinus, especially at the origin of these veins, this complication can be avoided. If metal emboli are used with coil diameters smaller than the segment to be occluded, then migration can occur. We have avoided this complication by carefully measuring the size of the diseased sinus and by using coils of appropriate sizes. In addition, intertwining of the coils can promote their stability.

If the embolic agents occlude cortical veins in adjacent dural sinus not exposed to the high venous pressure, then venous infarction may occur. Injections of contrast material through the venous catheter can demonstrate the direction of flow within the vein (either toward or away from the dural sinus), and care to place the emboli only within the diseased segment can prevent this potential complication. Similarly, placement of coils into a segment of sinus that still has venous drainage toward the involved sinus (either cortical or sinus drainage) could risk venous infarction or hemorrhage. One must be confident that the flow in these veins is away from the involved sinus if this treatment is to be undertaken. Most of the fistulas that meet these hemodynamic criteria have either venous occlusive disease or a large fistula or both. Patients who have cortical venous drainage away from the sinus are at high risk to develop hemorrhage and therefore require definitive treatment. The decision to treat any patient

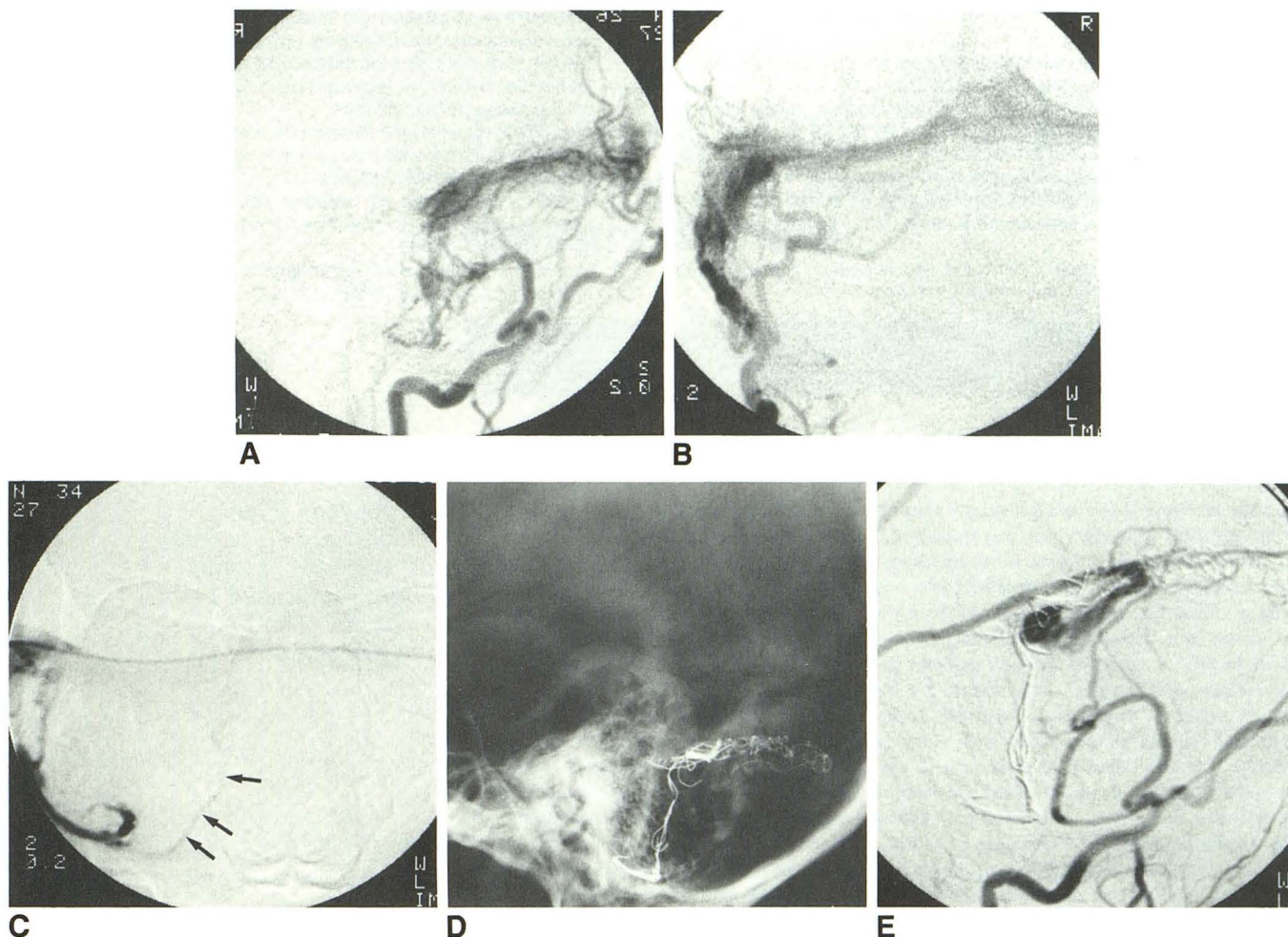


Fig. 4.—Case 7.

A and B, Right occipital artery injection, lateral (A) and anteroposterior (B) views, shows supply to both sigmoid and transverse sinus dural fistulas. Note contralateral drainage secondary to distal sigmoid sinus thrombosis. Additional supply arose from middle meningeal, ascending pharyngeal, and vertebral arteries.

C, Anteroposterior projection, sigmoid sinus injection. Catheter has been placed from transfemoral approach through contralateral sinus across torcular herophili into sigmoid sinus. Note cortical drainage (arrows).

D, Plain radiograph after embolization shows dense platinum wires in sigmoid sinus and 0.025-in. (0.064-cm) Gianturco coils in transverse sinus.

E, Right occipital artery angiogram, lateral view, at 2-month follow-up, shows small residual dural fistula at transverse sigmoid junction.

must take into account the natural history, projected risks, anticipated benefits, and potential complications.

Comparison of surgical vs transfemoral approaches reveals a higher cure rate in patients treated with the direct surgical route. This route allows more embolic material to be placed into the sinus. In addition, the surgical cases received preoperative transarterial embolization, while the transfemoral cases did not, which may also account for the difference.

In conclusion, placement of embolic material within the diseased segment of a dural sinus associated with a fistula can result in complete obliteration of the fistula. Both liquid adhesives and metal coils can produce occlusion from a transvenous approach. Coils have several advantages over liquid agents: more precise deposition, decreased risk of migration, and reduced need for surgical intervention. Our preliminary experience has taught us the need to place ade-

quate embolic material to ensure thrombosis and cure. As our experience with this technique increases, coupled with advances in catheter and coil technology, the need for surgical intervention may decrease. Long-term follow-up is needed to assess the role of transvenous occlusion of dural fistulas in comparison with more established methods as transarterial embolization. In selected patients with symptomatic dural fistulas involving the transverse and sigmoid sinuses, transvenous embolization can be an effective primary treatment.

REFERENCES

1. Houser OW, Campbell JK, Campbell RJ, Sundt TM. Arteriovenous malformation affecting the transverse dural sinus—an acquired lesion. *Mayo Clin Proc* 1979;54:651-661
2. Chaudhary M, Sachdev VP, Cho SH, Weitzner I Jr, Puljic S, Huang YP.

- Dural arteriovenous malformation of the major venous sinuses: an acquired lesion. *AJNR* **1982**;3:13-19
3. Bitoh S, Sakaki S. Spontaneous cure of dural arteriovenous malformation of the posterior fossa. *Surg Neurol* **1979**;12:111-114
 4. Kosnik EJ, Hunt WE, Miller CA. Dural arteriovenous malformations. *J Neurosurg* **1974**;40:322-329
 5. Kuhner A, Krastel A, Stull W. Arteriovenous malformations of the transverse dural sinus. *J Neurosurg* **1976**;45:12-19
 6. Sundt TM, Piepgras DG. The surgical approach to arteriovenous malformations of the lateral and sigmoid dural sinuses. *J Neurosurg* **1983**;59:32-39
 7. Picard L, Bracard S, Mallet J, Per A, et al. Spontaneous dural arteriovenous fistulas. *Semin Intervent Radiol* **1987**;4:219-240
 8. Lasjaunias P, Halimi PH, Lopez-Ibor L, Sichez JP, Hurth M, Tribolet ND. Traitement endovasculaire des malformation vasculaires dures (MVD) pures spontanees: revue de 23 cas explores et traites entre mai 1980 et octobre 1983. *Neurochirurgie* **1983**;30:207-223
 9. Kerber CW, Newton TH. Macro and micro vasculature of the dura mater. *Neuroradiology* **1973**;6:175-179
 10. Halbach VV, Higashida RT, Hieshima GB, Goto K, Norman D, Newton TH. Dural fistulas involving the transverse and sigmoid sinuses. Results in 28 patients. *Radiology* **1987**;163:443-447
 11. Halbach VV, Higashida RT, Hieshima GB, Hardin C. Embolization of branches arising from the cavernous portion of the internal carotid artery. *AJNR* **1989**;10:143-150
 12. Mullan S. Treatment of carotid cavernous fistulas by cavernous sinus thrombosis. *J Neurosurg* **1979**;50:131-144