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Imaging of the Saphenous Vein Graft Bypass of the Cavernous Carotid Artery

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PURPOSE: To describe the radiographic appearance of the interpositional carotid saphenous vein graft and to compare the efficacy of MR angiography with conventional angiography in determining graft patency and identifying graft irregularities. **METHODS:** The authors examined saphenous vein graft bypasses of the cavernous carotid artery in 14 patients using CT, MR, and conventional and MR angiography. **RESULTS:** The course of the graft was typically more inferior, lateral, and anterior than the course of the native vessel. Mild irregularities were found in four of the grafts, but all four "filled out" in a period of months. Time-of-flight angiography was comparable to conventional angiography in four of five patients. Phase-contrast angiography was comparable to conventional angiography in nine of nine cases. **CONCLUSIONS:** MR angiography is a useful screening modality in the postoperative evaluation of vascular grafts.

Index terms: Blood vessels, grafts; Angiography, comparative studies; Magnetic resonance angiography (MRA); Arteries, carotid

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Surgical repair of neoplastic or vascular lesions of the cavernous sinus often requires sacrifice of the internal carotid artery (ICA). Although the majority of patients are able to tolerate the loss of one ICA, 17% to 30% of patients will suffer either immediate or delayed neurologic deficits related to poor collateral circulation (1–5). In these cases, some form of vascular bypass is usually indicated.

Common means of revascularization have included superficial temporal artery-to-middle cerebral artery (STA-MCA) anastomosis, subclavian artery-to-middle cerebral artery bypass, an external carotid artery-middle cerebral artery long venous graft, and branch venous graft (6–14). There are also two procedures for interposition venous grafts: the longer graft connecting the extracranial ICA with the supraclinoid ICA and a shorter graft connecting the petrous to the supraclinoid portion of the ICA (15–17).

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The purpose of this study is to describe the radiographic appearance of the interpositional carotid saphenous vein graft and to compare the efficacy of magnetic resonance angiography (MRA) and conventional angiography in determining graft patency and identifying graft irregularities.

Materials and Methods

Fourteen patients (11 women, three men, mean age 48 years) with skull base lesions received short segment saphenous vein grafts for bypass of the cavernous ICA (n = 13) or vertebral artery (n = 1) based on clinical and preoperative radiographic assessment, including MR, computed tomography (CT), conventional angiograms, balloon test occlusions and xenon-enhanced CT cerebral blood flow studies (Table 1). Postoperatively, 2-D phase contrast angiography (PCA) was performed in nine patients; 3-D time-of-flight (TOF) MRA in five patients.

CT was performed on a 9800 scanner (General Electric, Milwaukee, WI), and MR was performed on a 1.5-T superconducting unit (General Electric, Signa System). The following MR sequences were obtained: sagittal spin-echo 500/10/1 (TR/TE/excitations), 128 × 256 matrix, 24-cm field of view, 5-mm section thickness, and 1-mm intersection skip; axial spin-echo 400-500/20/4 images with a 192 × 256 matrix, 16-cm field of view, 3-mm section thickness, and 1-mm intersection skip; coronal 400-500/20/2-4 with a 16-cm field of view, 5- or 3-cm section thickness, and 1-

TABLE 1: Summary of patients

Case No.	Age (years)/ Sex	Lesion	Presenting Symptoms	BTO Results	Type of Anastomosis	
					Proximal	Distal
1	64, F	Meningioma	Diplopia; left facial weakness	Group III	End-to-end	End-to-end
2	50, F	Meningioma	Headaches; left V2 numbness	Group II	End-to-end	End-to-side
3	61, F	Meningioma	Heachaches; tingling left ear and eyebrow	Group III	End-to-end	End-to-side
4	48, M	Cranio-pharyn-gioma	CSF rhinorrhea	Group II	End-to-end	End-to-side
5	28, F	Neuroma (vertebral artery by-pass)	Headaches; poste-rior neck mass	Group I	End-to-end	End-to-end
6	32, F	Meningioma	Headaches; diplopia	Group III	End-to-end	End-to-side
7	47, F	Meningioma	Diplopia; right facial pares-thesias	Group III	End-to-end	End-to-side
8	41, F	Pseudo-aneurysm	Epistaxis	NA	End-to-end	End-to-end
9	51, F	Meningioma	Left upper lip numbness	Group III	End-to-end	End-to-end
10	45, F	Meningioma	Diplopia	Group I	End-to-end	End-to-end
11	48, M	Squamous cell carci-noma	Orbital apex mass	Group II	End-to-end	End-to-end
12	59, M	Meningioma	Diplopia	NA	End-to-end	End-to-side
13	64, F	Meningioma	Multiple previous surgeries	Contralateral decrease	End-to-end	End-to-side
14	34, F	Meningioma	Diplopia	Group II	End-to-end	End-to-side

Note.—BTO = balloon test occlusion; CSF = cerebrospinal fluid; NA = not available.

mm intersection skip factor; axial 4000/34-85/1 with a 192 × 256 matrix, 20-cm field of view, 5-mm section thickness, and 1-mm intersection skip factor.

The MRA sequences were as follows: PCA, 2-D gradient Fourier transform echo sequence 50/18/16, 30° flip angle, 128 × 256 matrix, 24-cm field of view, 20- to 60-mm section thickness, 15- to 30-cm/sec flow-encoding velocity in sagittal, coronal, and axial planes; TOF angiography, 3-D Fourier transform spoiled gradient echo (SPGR) volume acquisition 35/6-8/1, 15° flip angle, 256 × 256 matrix, 24-cm field of view, a single 4.5-cm column divided into 64 .7-mm partitions in the axial plane.

Test occlusion of the ICA coupled with xenon-enhanced CT blood flow measurements were obtained in 12 patients. The technique has been described in detail (18). Briefly, a balloon-tipped double-lumen catheter is used to occlude the ICA during a 15-minute clinical trial. If the patient remains neurologically stable during the clinical trial, the balloon is deflated and the patient is transported to the CT scanner. The balloon is then reinflated and a two-level xenon cerebral blood flow study is performed.

Results

Of the 12 patients who underwent balloon test occlusions, two had no decrease in blood flow (group I), four had a mild global decrease in blood flow (group II), five demonstrated a marked asymmetric decrease in blood flow on the side of the occlusion (group III), and one had a decrease in the hemisphere contralateral to the occlusion. Two patients did not have a balloon test occlusion: one had emergent bypass surgery, and the other suffered a dissection during the clinical portion of the balloon test occlusion and therefore had no xenon cerebral blood flow measurements (Table 1).

Six patients had multiple conventional angiographic follow-ups (Figs. 1-4). Four demonstrated inferior displacement (sagging) of the graft over time (Figs. 2A and 2B). Of four grafts that demonstrated early postoperative irregularities by conventional angiography, four "filled out" in a period of months (Fig. 2B).

TOF MRA was performed in five patients. Good correlation with conventional angiography was found in four of the five patients. In one patient, TOF images did not visualize the distal portion of the graft (Figs. 4I-4J). PCA was per-

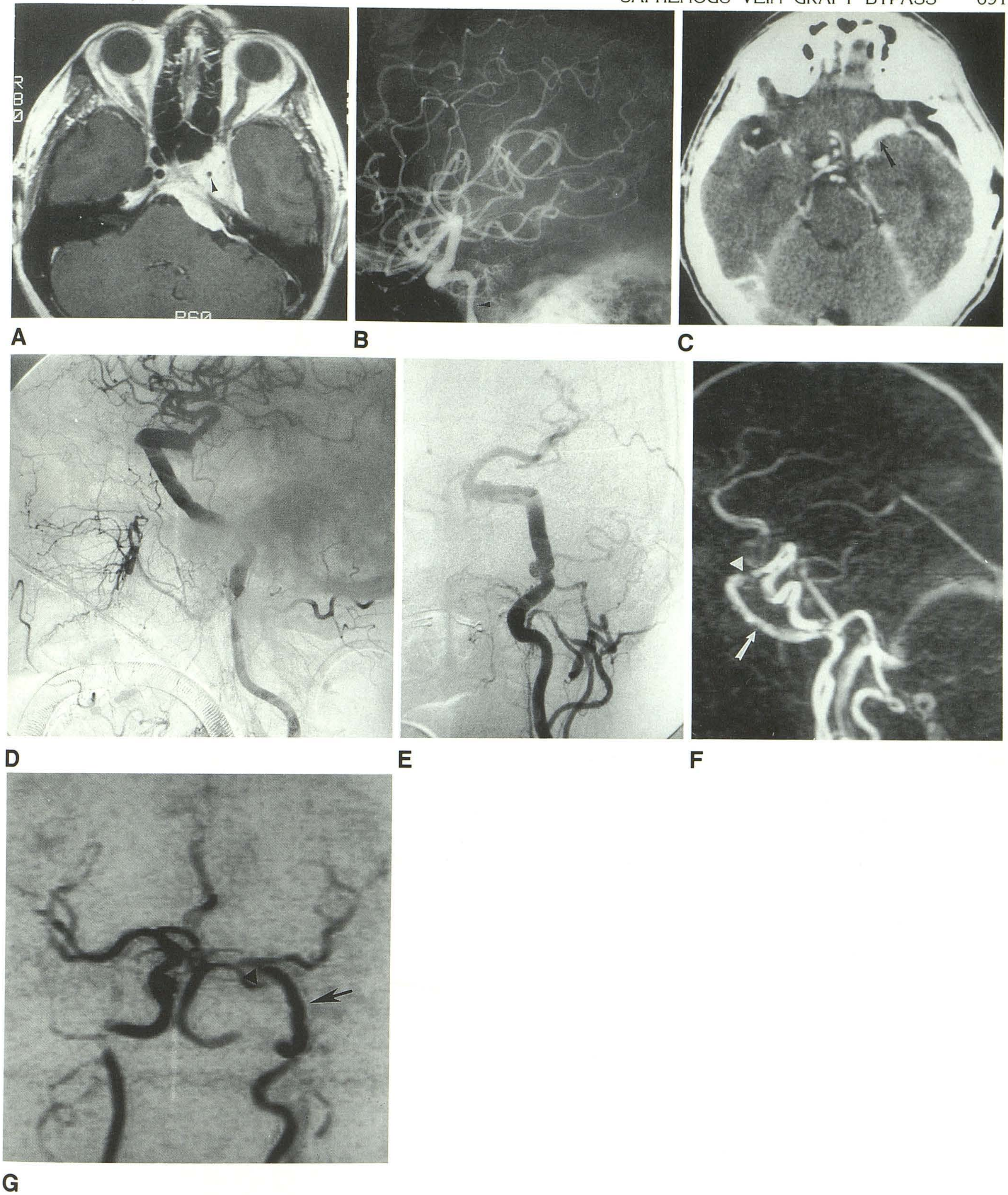

Fig. 1. Fifty-year-old woman with left cavernous sinus meningioma.

A and *B*, Left cavernous sinus meningioma narrowing the internal carotid artery (*arrowhead*).

C, Postoperative contrast-enhanced CT on day of surgery shows a linear homogeneously enhancing graft adjacent to/within the surgical flap coursing medially toward the suprasellar region (*arrow*).

D and *E*, One-day postoperative conventional angiogram demonstrates end-to-end proximal anastomosis of the saphenous vein graft to the horizontal petrous ICA. The graft then courses under the temporal lobe, anterior to the temporal tip, anastomosing end-to-side with the supraclinoid ICA.

F and *G*, Five-month postoperative phase contrast angiograms. The graft (*arrow*) is well demonstrated except distally near the end-to-side anastomosis. This may be caused by turbulent or vortex flow (*arrowhead*).

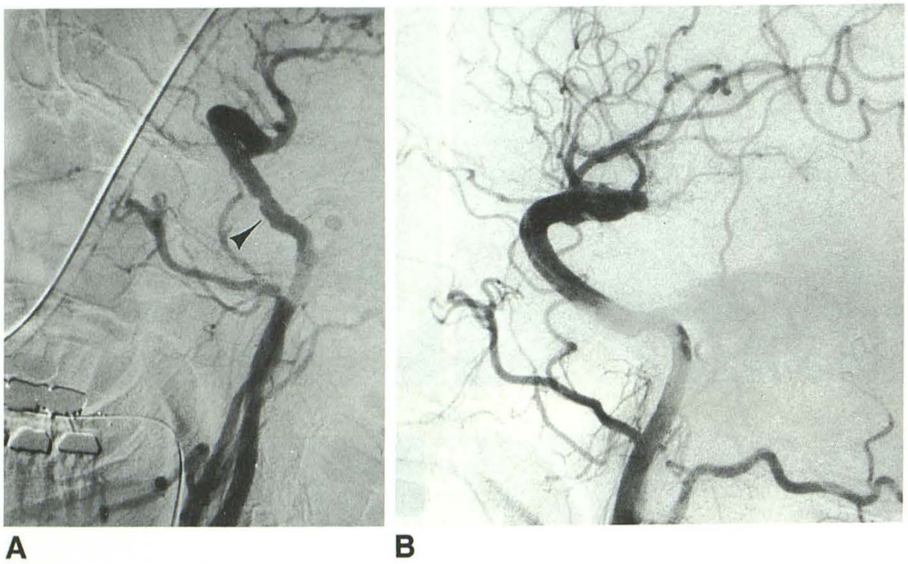

Fig. 2. Forty-eight-year-old man with craniopharyngioma.

A, One-day postoperative conventional angiogram shows graft with irregular proximal segment (*arrowhead*).

B, Repeat conventional angiogram 2 months later demonstrates that the proximal segment "filled out." The graft also courses more inferiorly than before.

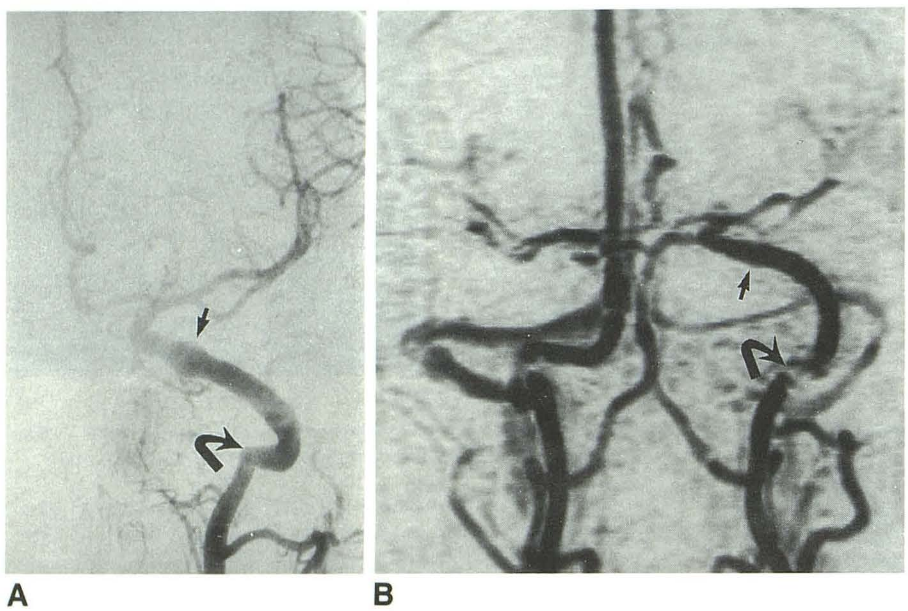

Fig. 3. Sixty-one-year-old woman with left cavernous sinus meningioma.

A, One-month postoperative conventional angiogram shows a focal oval enlargement of the lumen representing a valve (*straight arrow*). The proximal anastomosis is angulated but widely patent (*curved arrow*).

B, Valve is more subtle on 2-month postoperative PCA (*arrow*). Note that the proximal anastomosis appears stenotic (*curved arrow*). This false-positive finding is presumably secondary to turbulent and vortex flow because of the sharp angulation at the anastomosis.

formed in nine patients and correlated well with conventional angiography in all nine patients.

All grafts remained patent and demonstrated no signs of stenosis.

Discussion

In managing patients with cavernous sinus lesions for which surgical resection of the ICA may be required, it is important to evaluate preoperatively collateral circulation. This is done to determine whether some form of revascularization is indicated and if so, to determine what precautions must be taken when ICA flow is interrupted during the bypass procedure. Elevated blood pressure combined with high-dose barbiturates or etomidate has been commonly used to protect ischemic brain tissue (19, 20). Often, especially when the patient is young, the surgeons elect to perform the bypass despite favorable collateral circulation. This is done to reduce the risk of ipsilateral ischemic deficits (21–25) or contralateral de novo aneurysm formation (26) later in life.

At our institution, collateral circulation is assessed with a 15-minute balloon test occlusion of the ICA coupled with measurement of cerebral blood flow by xenon-enhanced CT. Most patients tolerate the 15-minute occlusion without neurologic deficits. However, a significant percentage of those patients demonstrate a marked decrease in cerebral blood flow on the side of the occlusion, signifying stroke risk following carotid sacrifice. Five of 12 patients evaluated demonstrated a significant decrease in flows with carotid artery occlusion. In the remaining seven patients eval-

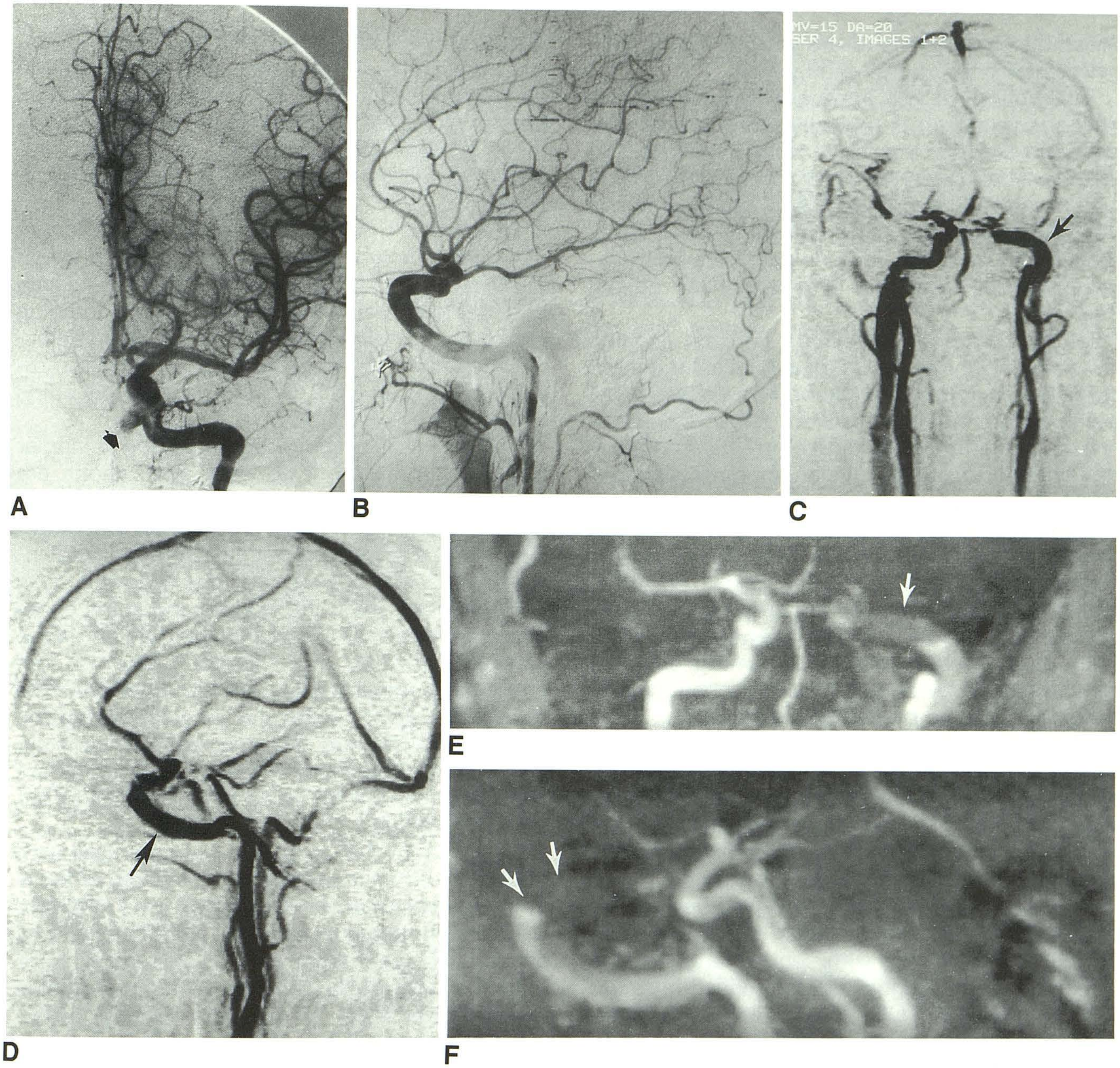

Fig. 4. Forty-one-year-old woman with pseudoaneurysm after transphenoidal surgery.

A, Preoperative conventional angiogram demonstrates pseudoaneurysm (*arrow*).

B-D, Conventional angiography 8 months after surgery (*B*), and PCA (*C* and *D*) 33 months after surgery show graft in typical location (*arrow*).

E-F, TOF MRA 33 months after surgery. In this case, visualization of the distal graft was not possible with TOF because of saturation effects (*arrows*).

uated, cavernous carotid bypass was usually indicated because of their young ages.

The operative technique of the saphenous vein graft bypass of the cavernous carotid has been described in detail (17, 27). Briefly, the cavernous sinus is approached via a frontotemporal craniotomy. A segment of the greater saphenous vein approximately 7 cm in length is harvested from the thigh. Eventually, this is trimmed to a length of 5 to 6 cm. Distal anatomosis to the supraclinoid segment of the ICA is performed first. This is done in an end-to-end fashion if the ophthalmic artery is sacrificed or if there is a sufficient length of the ICA proximal to the ophthalmic artery. Otherwise, an end-to-side anastomosis is performed to the supraclinoid carotid, preserving the ophthalmic artery but having the disadvantage of increased turbulence at the anastomotic site.

Proximal anastomosis to the petrous ICA is then performed in an end-to-end fashion.

The course of the interpositional carotid saphenous vein graft is typically more inferior, lateral, and anterior than that of the native vessel (Fig. 1). Additionally, in a majority of the patients with multiple angiographic follow-ups (four of six) the grafts displace more inferiorly over time, presumably because of shrinkage of postoperative scar and resolution of surgical flap edema (Fig. 2).

Other common radiologic findings include valves (typically seen as a focal oval enlargement of the lumen (Fig. 3)) and tied-off branching veins, which should not be mistaken for pseudoaneurysms. The grafts often appear irregular and narrow on early postoperative angiograms (within 1 week of surgery), especially at the proximal anastomotic site. This may be due to spasm induced by the harvesting procedure, suturing, or subendothelial edema (28, 29). On follow-up angiograms a few months later, the irregularities "filled out" in four of four patients examined (Fig. 2). Thus, mild irregularities or narrowing seen on early angiography are a temporary phenomenon and should not be particularly worrisome.

All of the grafts in our study remained clearly patent and demonstrated no signs of early stenosis. Long-term follow-ups of carotid saphenous vein grafts have not been performed, although one patient in our series had an angiographically patent graft for 33 months after surgery.

MR imaging of flowing blood can be used to assess vessel patency, in some cases obviating the need for follow-up with conventional angiography. MR angiography can be divided into two broad categories: TOF (30, 31) and phase-contrast angiography (32, 33).

TOF MRA relies upon a process described as "flow-related enhancement." When flowing blood containing fresh unsaturated spins enters the imaging volume, it produces maximum signal intensity. The stationary tissue, however, is saturated, having experienced repeated radio frequency pulses, and therefore has little signal intensity.

Ideally, flow velocity should be sufficient to allow fully magnetized blood to traverse the entire imaging volume between successive radio frequency pulses. When blood flow is slow, however, the blood becomes saturated as it moves through the imaging volume, and signal intensity decreases. Because saphenous vein grafts are often larger in diameter than the native vessel, blood velocity can be slower. This can lead to poor visualization of the distal graft by 3-D TOF angiography (Fig. 4E and 4F). This limitation can be partially addressed by increasing repetition time or using bolus intravenous contrast during the TOF acquisition (Kanal E., et al, paper presented at the annual meeting of the RSNA, December 2, 1991, Chicago, IL).

PCA differs from TOF angiography in a variety of ways: 1) flow is detected as it courses within the imaging plane, as opposed to TOF, which best detects flow perpendicular to the imaging plane, 2) PCA allows quantitation of blood velocity in addition to an assessment of vessel morphology, and 3) PCA detects flow by encoding spin velocity as a phase shift.

The PCA is attained through the use of bipolar magnetic gradients. Two data acquisitions are obtained. In the first acquisition, the bipolar gradient is applied as a positive and then a negative lobe. For the second data acquisition, the gradient is reversed with a negative lobe followed by a positive lobe. Thus, the nonmoving spins experience a phase shift of equal magnitude but in the opposite direction and therefore have no net phase shift. Moving spins, on the other hand, lie at different points along the gradient during the two acquisitions and therefore experience a net phase shift. Data from the two acquisitions are then subtracted from each other, canceling out stationary tissue.

Two factors that may lead to signal loss with MRA are turbulent and vortex flow. Both of these phenomena can occur distal to an area of stenosis, overestimating its severity. Additionally, flow disturbances can occur at the anastomotic sites (Fig. 3B), especially those with an end-to-side configuration (Figs. 1F and 1G). Finally, turbulence at the site of a graft valve can lead to a focal decrease in signal.

TOF angiography was comparable to conventional angiography in four of five patients. In one case (Fig. 4), poor visualization of the distal graft was probably caused by the cumulative saturation of slower flowing blood secondary to the increased graft diameter relative to the native vessel. The distal runoff supplied by the graft is also poorly seen as a result of these effects. In TOF studies, there is increased saturation of the flowing blood as it travels deeper into the imaging volume. This effect limits visualization of the distal vessels and therefore limits the effective imaging volume. In Figure 4, the intracranial vessels are poorly seen, as they are deep within the imaging volume. The imaging volume or slab in this case was selected to optimize the evaluation of the graft.

The large volume that can effectively be imaged with PCA is a distinct advantage over single 3-D volume TOF studies. Newer techniques such as multiple overlapping thin-slab acquisition (34) using multiple thin slabs may address these limitations, although longer imaging times are currently required.

PCA was comparable to conventional angiograms in nine of nine cases in determining vessel patency. Increased use of intracranial bypass procedures such as the interpositional carotid saphenous vein graft has made familiarity with their radiographic appearance essential. Additionally, the role of TOF angiography and PCA in the management of these patients must continue to be explored. Our preliminary results suggest that MRA can be used as a screening modality to evaluate postoperative patency of vascular grafts. This can be performed at the time of routine cross-sectional MR imaging used to assess evidence of tumor recurrence.

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