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MR Imaging After Surgery for Vertebrobasilar Aneurysm

Michael F. Brothers^{1,2}
 Allan J. Fox¹
 Donald H. Lee¹
 David M. Pelz¹
 John P. Deveikis^{1,3}

We examined the safety and utility of high-field MR in patients who had surgery for cerebral aneurysms of the vertebrobasilar system. Eighteen posterior (and three coincidental anterior) circulation aneurysms were treated. Twenty-one MR scans were obtained at a mean postoperative interval of 7.2 days. The mean size of the preoperative vertebrobasilar aneurysm was 2.2 cm; six were giant (>2.5 cm) and eight were large (>1.5 , ≤ 2.5 cm). In 17 patients, Sugita nonmagnetic clips were used. In one other, a Drake tourniquet was used. No ill effects occurred from scanning with a high-field imaging unit at 1.5 T. The MR clip artifact was much less obtrusive than that on CT. In 11 cases, the aneurysm could be partially imaged postoperatively, mainly in very large aneurysms or in those treated by clipping the parent vessel. Of these, two revealed residual lumina on MR and nine looked completely thrombosed. Postoperative angiography showed that in four of the thrombosed-appearing aneurysms a residual lumen with a mean diameter of 1.0 cm had been missed. In the patient imaged after application of a Drake tourniquet, no artifact was seen, and a good assessment of progressive partial thrombosis was obtained. Evolution of the signal intensity of new aneurysm thrombus, in those minimally or not obscured by artifact, coincides with patterns previously described for hemoglobin in intracerebral hematomas. The earliest hyperintensity could be seen in either the periphery or the center of the new thrombus. All 15 patients examined with new postoperative deficits showed appropriate lesions, mainly small brainstem ischemic foci. Postoperative CT (performed in all but four of these patients) missed over 80% of these lesions, mainly owing to artifact from clip or bone.

We conclude that MR is better than CT in the postoperative assessment of aneurysm patients, particularly in demonstrating small zones of ischemia. High-field MR scanning is safe if nonmagnetic surgical clips are used. MR is not accurate in assessing residual lumina.

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¹ Department of Diagnostic Radiology and Clinical Neurological Sciences, University Hospital, University of Western Ontario, London, Ontario, Canada.

² Present address: Department of Radiology, Duke University Medical Center, P.O. Box 3808, Durham, NC 27707. Address reprint requests to M. F. Brothers.

³ Present address: Department of Radiology, Georgetown University School of Medicine, 3800 Reservoir Rd. N.W., Washington, DC 20007.

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Large or giant aneurysms can be diagnosed accurately from their MR appearance alone [1-6]. The appearance is more characteristic and specific than that shown by CT [7, 8].

Preoperatively, MR imaging is particularly useful in demonstrating regional anatomic relations of the aneurysm and documenting preexisting ischemic lesions. The patent lumen sometimes can be distinguished from intraluminal thrombus. Subacute or chronic hematoma in the subarachnoid space may be detected readily, at a time when it has become iso- or hypodense on CT [9].

MR study of the postoperative aneurysm patient has been limited, likely because of justifiable concerns that aneurysm clip motion during scanning could result in injury [10]. Nonferromagnetic aneurysm clips that do not move in a changing high-strength magnetic field [11-13] have been available for several years from many manufacturers. However, once inside a patient's head, MR-safe clips are not readily distinguished from unsafe ferromagnetic alloy clips. Thus, the word of the surgeon remains the most certain means of determining the type of clip used. In the interest of patient safety, some believe the presence of an aneurysm clip is a contraindication.

cation to MR [10]. Recent reports, however, suggest that scanning patients treated with "MR-compatible" clips is indeed safe [3, 14, 15].

CT alone does not ideally assess the complications of aneurysm surgery. Clip artifact is extensive, and small infarcts, which may be clinically significant, are not well shown [16, 17] owing to the inherent limitations of CT's soft-tissue contrast discrimination and bone and clip artifacts. This report describes our experience with postoperative high-field MR in patients with vertebrobasilar aneurysms.

Materials and Methods

We retrospectively reviewed the hospital records and CT and MR scans of 18 patients in whom cerebral aneurysms of the posterior circulation were surgically treated. The patient group included seven men and 11 women with a mean age of 46 years (range, 17–63). The primary presentation was subarachnoid hemorrhage in six, non-subarachnoid hemorrhage headache in nine, and cranial nerve palsy(ies) in three (including one patient with hemifacial spasm due to a large aneurysm of the vertebrobasilar junction).

Preoperative CT scans were available in 13 patients. The scans usually were 10-mm axial sections with and without IV contrast enhancement. (In other patients CT had been done elsewhere prior to referral.) Postoperative CT was performed in 11 patients at a mean postoperative interval of 4.1 days. A GE 9800 unit, usually without IV contrast material, was used, and 10-mm contiguous axial sections were obtained. Preoperative angiography was available for assessment in all patients; a total of 18 vertebrobasilar aneurysms were revealed. Thirteen aneurysms arose in the region of the basilar bifurcation, two from the basilar trunk, and three from the vertebral or vertebrobasilar junction. The preoperative size of the vertebro-

silar aneurysm was measured on CT or MR scans and categorized according to the greatest cross-sectional dimension, including both patent and thrombosed portions of the lumen: four small aneurysms (<1.5 cm), eight large (>1.5 cm but <2.5 cm), and six giant (>2.5 cm). (Coincidentally, three patients also had a single, small aneurysm in the anterior circulation.) Postoperative angiography was performed in 14 of 18 patients, at a mean postoperative interval of 3.7 days (range, 1–13).

Twenty-one postoperative MR scans were obtained between January 1987 and May 1988, at a mean interval of 7.2 days (range, 1–18 days) after surgery. Indications for postoperative MR included the presence of new neurologic deficits in 15 patients. In three other patients, postoperative MR was performed solely to provide a non-invasive assessment of the status of the aneurysm. Postoperative MR scans were obtained with a 1.5-T GE Signa unit. In all cases, routine spin-echo sagittal 5-mm T1-weighted sections at 500–700/20–25 (TR/TE) and axial 5-mm T2-weighted sections at 2000/35,70 were obtained. Preoperative MR was available for comparison in six patients.

Results

Owing to the large size and difficult location of many of the vertebrobasilar aneurysms, direct clipping of the neck was possible only for seven. For another 11 aneurysms, proximal occlusion or stenosis of the parent vessel was performed; in these, an aneurysm clip alone was used in 10 and a proximal Drake tourniquet alone in one. One giant aneurysm was trapped with two aneurysm clips. More than one operation (i.e., to move or add clips or tighten a Drake tourniquet) was performed in five patients. On postoperative angiography, complete nonfilling of the aneurysm was demonstrated in

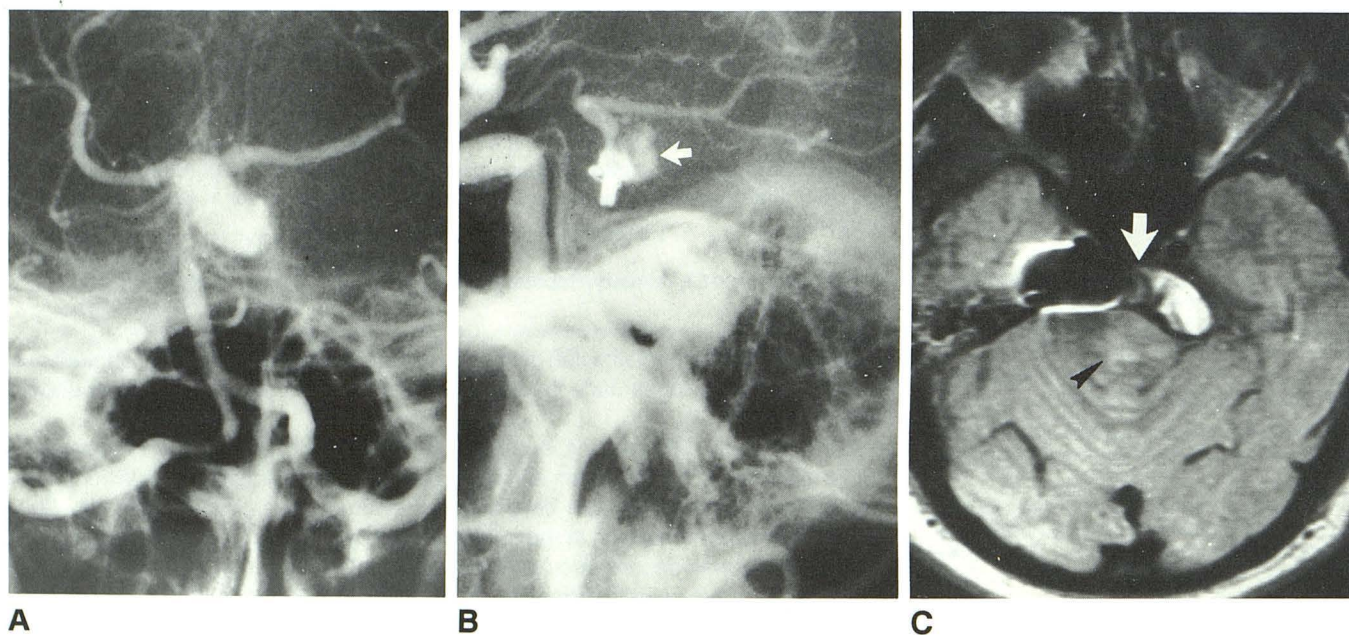


Fig. 1.—Distal basilar aneurysm treated by occlusion of basilar trunk above level of superior cerebellar arteries.

A, Preoperative left vertebral arteriogram, anteroposterior view.

B, Left carotid arteriogram, lateral view, 1 day after surgery. Note clipped basilar artery and partial thrombosis of aneurysm (arrow), filling via posterior communicating artery.

C, MR image 4 days after surgery. Aneurysm is filled by high- and low-signal thrombus. True residual lumen at neck (arrow) is obscured by clip artifact. Infarct is seen in upper pons (arrowhead). Patient showed new right hemiparesis and inability to adduct left eye.

eight. A residual lumen was found in six, with an average maximum diameter of 13.3 mm; in all of these patients, proximal parent vessel clipping was the primary therapy. In four patients, no postoperative angiography was performed: In two, direct clipping of the aneurysms was performed and the surgeon thought further angiography was unnecessary; in one, the aneurysm was trapped and evacuated; and in one, proximal occlusion of a vertebral artery was achieved by clipping for a giant vertebral aneurysm.

The MR examination was tolerated well by all patients, and no ill effects occurred from scanning. All aneurysm clips used were the Sugita (Downs Surgical, Inc., Wilmington, MA) non-magnetic type, constructed of cobalt chrome. At our institution all previous types of aneurysm clips were replaced with the Sugita type several years ago to ensure uniformity and safety in patient evaluation. No patient in whom an aneurysm clip was placed at an outside institution was accepted for MR scanning, as we cannot be absolutely sure of the clip material. The Drake tourniquet includes a slightly radiopaque marker made of tantalum, measuring only a few millimeters.

The artifact produced by the aneurysm clip had a characteristic appearance (Fig. 1): Centrally, there was complete absence of signal of variable shape, depending on the relative orientation of the clip and scan plane. Usually there was a rim of high signal in the frequency-encoded axis at one or both margins. Clip artifacts averaged 2.9 cm in size, obviously dependent on the number and size of aneurysm clips used. The Drake tourniquet did not produce detectable artifact.

Aneurysm Visualization

The vertebrobasilar aneurysm was itself at least partially visible adjacent to the Sugita clip artifact in 10 cases, and was completely obscured by it in seven. The aneurysm treated by the proximal Drake tourniquet was well seen. As expected, the larger aneurysms were imaged more readily and less obscured by artifact. Partial visualization of the postoperative aneurysm was more likely in those cases treated by proximal vessel occlusion (Figs. 1–6) than in those treated by direct clipping, as the metallic artifact was accord-

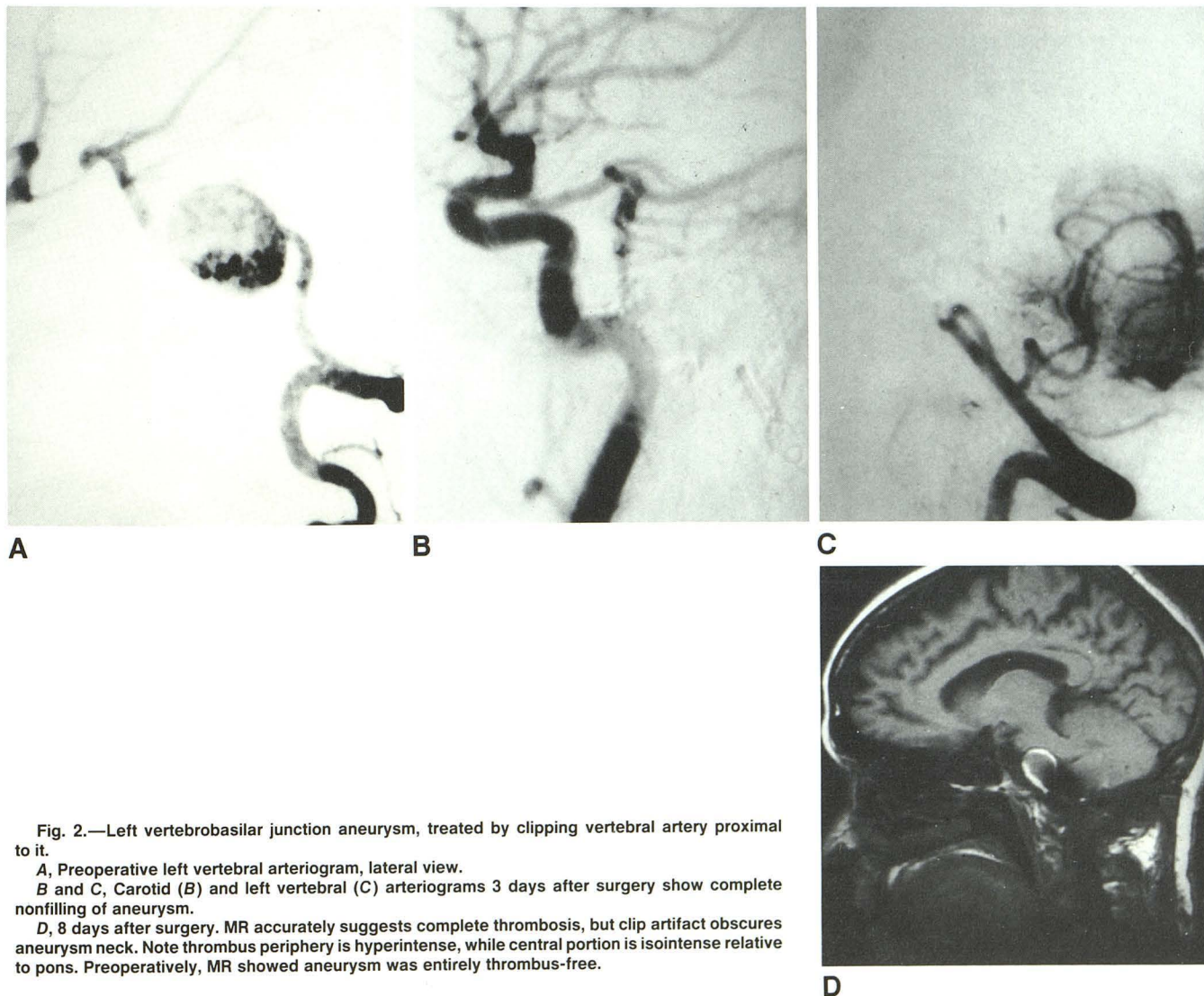


Fig. 2.—Left vertebrobasilar junction aneurysm, treated by clipping vertebral artery proximal to it.

A, Preoperative left vertebral arteriogram, lateral view.

B and C, Carotid (B) and left vertebral (C) arteriograms 3 days after surgery show complete nonfilling of aneurysm.

D, 8 days after surgery. MR accurately suggests complete thrombosis, but clip artifact obscures aneurysm neck. Note thrombus periphery is hyperintense, while central portion is isointense relative to pons. Preoperatively, MR showed aneurysm was entirely thrombus-free.

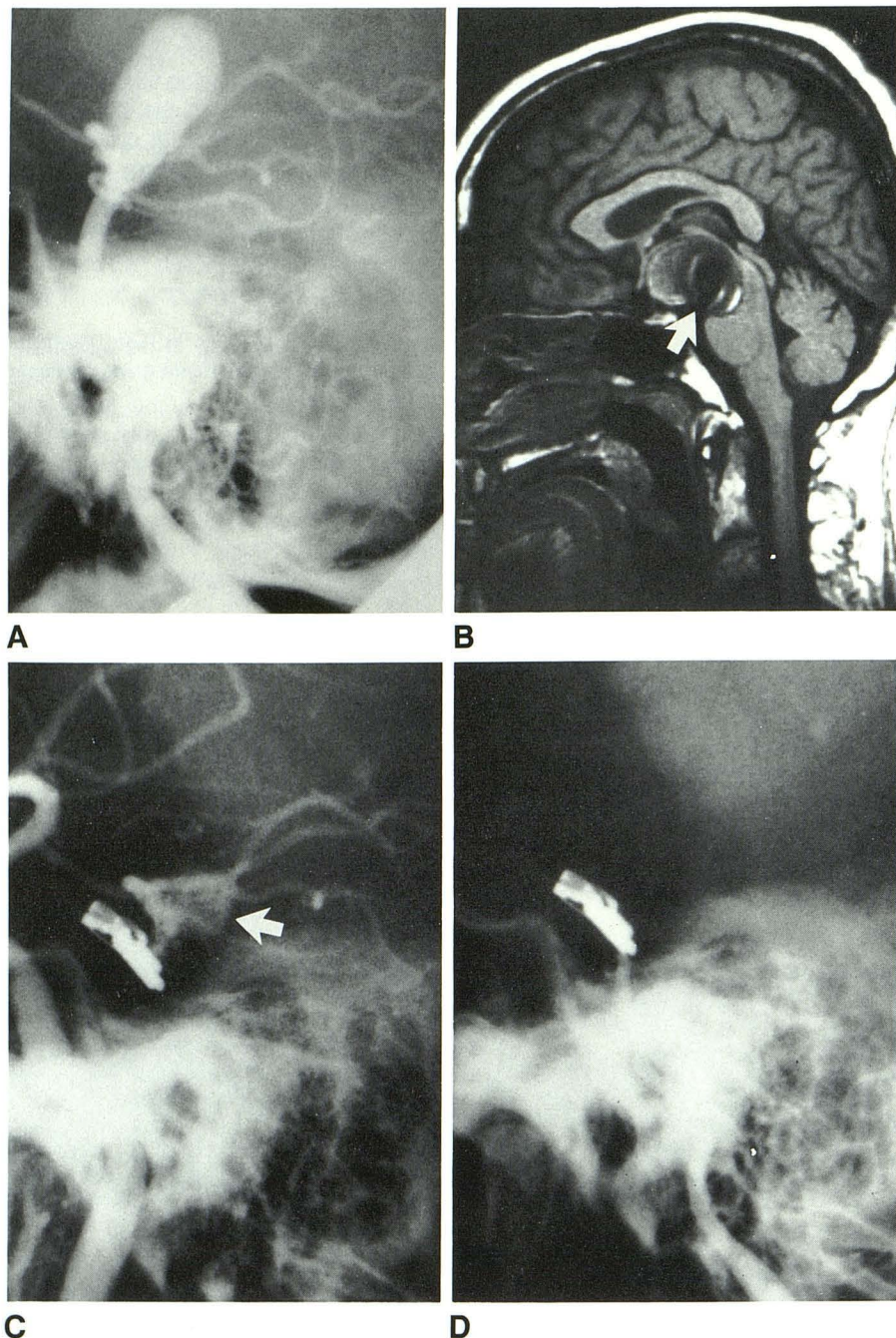


Fig. 3.—Aneurysm of basilar tip.

A, Preoperative vertebral arteriogram.

B, Preoperative MR image. Most of aneurysm is filled with thrombus, appearing hypointense centrally and hyperintense peripherally. Neck and lumen are identified (arrow).

C and D, Carotid (C) and right vertebral (D) angiograms, lateral views, 2 days after clipping of basilar trunk below superior cerebellar artery. Aneurysm still fills (arrow) via posterior communicating arteries, but has partly thrombosed. Basilar artery fills antegrade below clip, retrograde above it.

(Fig. 3 is continued on the opposite page.)

ingly slightly further from the aneurysm and obscuring less of it. Of the seven aneurysms completely obscured by clip artifacts, six had been clipped directly and the proximal parent vessel had been clipped in one. Of the 11 aneurysms in which at least a portion was imaged postoperatively, only one had been clipped directly (Fig. 7).

New Aneurysm Thrombus

The central-most portion of the newly thrombosed lumen could be assessed free of clip artifact in eight patients with

proximal occlusion (e.g., Figs. 1, 2, and 4–6). In this small subset, several findings were suggested: Those aneurysms imaged at less than 1 week postoperatively showed relative hypointensity of new thrombus on both T1- and T2-weighted images. At about 1 week, a transition occurred through isointensity to hyperintensity of thrombus. The transition in intensity on the T2-weighted images lagged behind corresponding changes on the T1-weighted images. New thrombus appeared predominantly hyperintense later than 7–8 days postoperatively.

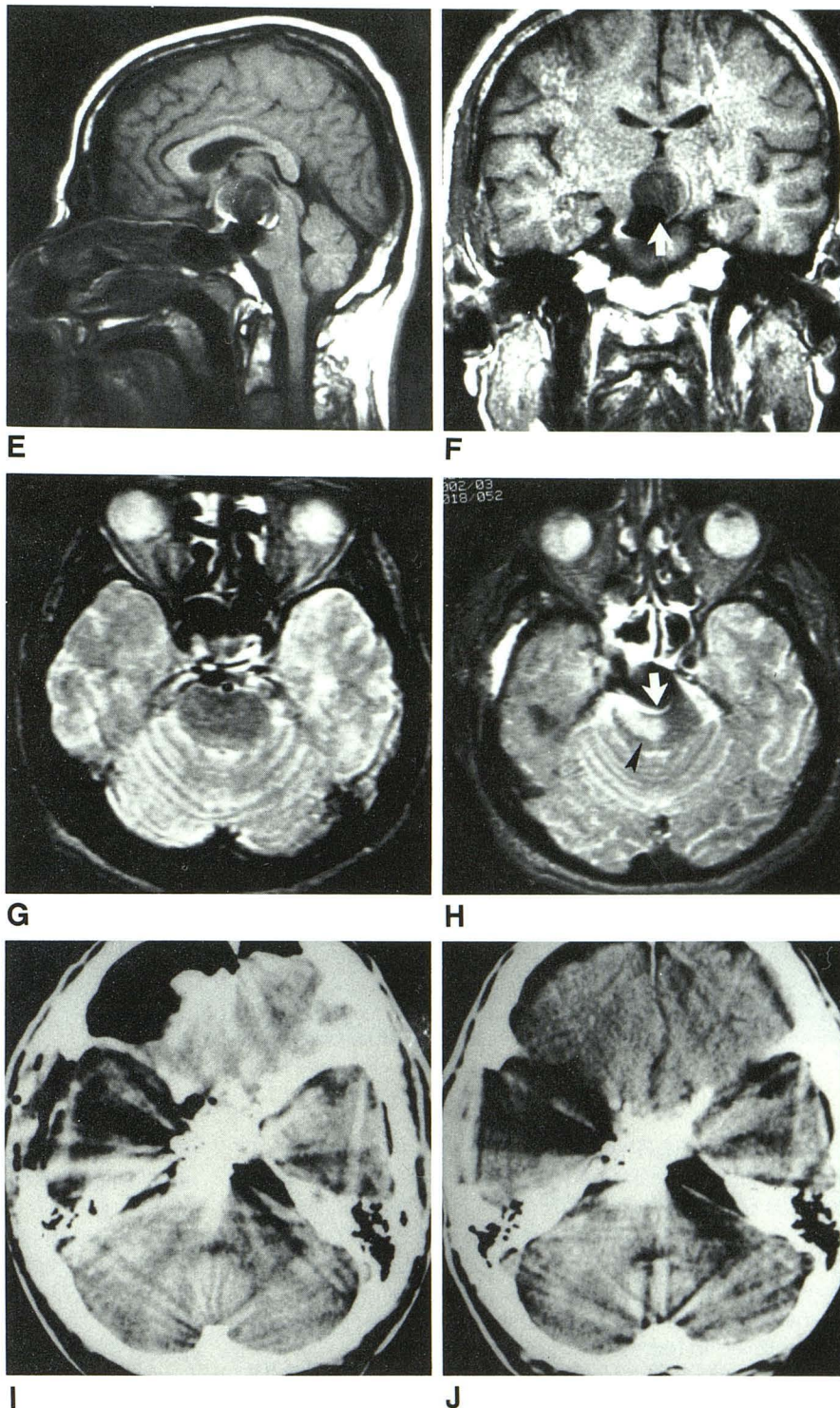
The pattern of thrombus signal intensity across the diameter of the aneurysm could be assessed in the same subset

Fig. 3—(Continued).

E and F, MR images 2 days after surgery. Residual lumen is obscured by clip artifact on sagittal series (E), but coronal T1-weighted scan (F) suggests lumen is present where signal void is more sharply marginated (arrow). It merges inferiorly with blacker clip artifact.

G and H, T2-weighted axial MR scans at level of upper pons, preoperatively (G) and 1 week after surgery (H). A new infarct is seen in right pontine tegmentum and basis pontis (arrow-head), clearly separated from clip artifact (arrow). Patient awoke from surgery with new left hemiplegia.

I and J, CT scans 1 day (I) and 6 days (J) after surgery. Extensive clip and bone artifacts obscure region of pontine infarct.



of eight patients. A variety of patterns was seen. In some, thrombus hyperintensity occurred earliest in the most peripheral portion of the thrombus, appearing progressively less intense centrally (Figs. 2 and 3). However, this pattern was not the rule (Figs. 1 and 4). In one instance of proximal occlusion with complete thrombosis, a unique pattern was observed: The center and periphery of the new thrombus

were slightly hyperintense, while an intermediate zone was hypointense (Fig. 5).

New Ischemic Lesions

In all 15 patients in whom MR was performed after the onset of new postoperative neurologic deficits (Table 1),

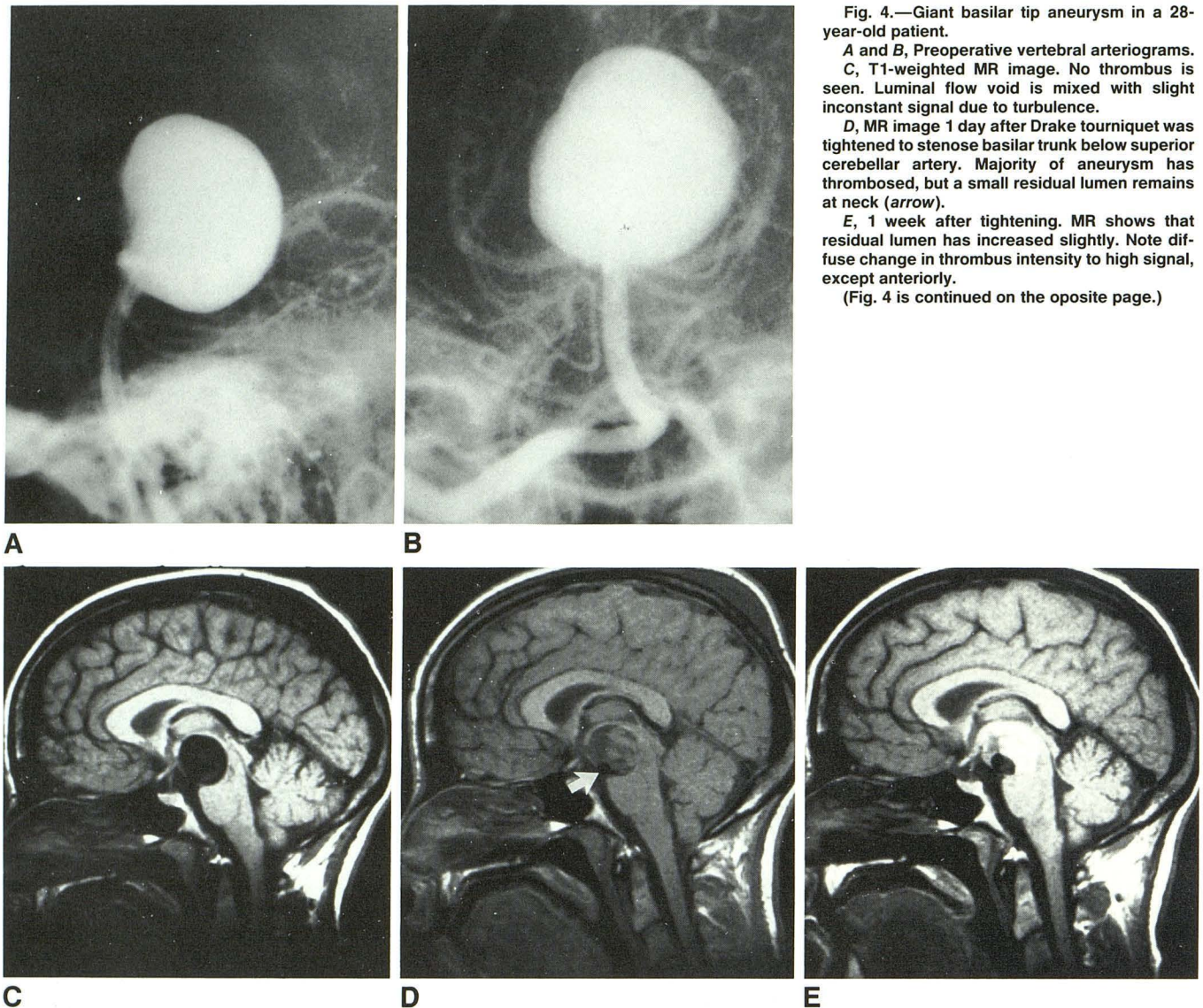


Fig. 4.—Giant basilar tip aneurysm in a 28-year-old patient.

A and B, Preoperative vertebral arteriograms. C, T1-weighted MR image. No thrombus is seen. Luminal flow void is mixed with slight inconstant signal due to turbulence.

D, MR image 1 day after Drake tourniquet was tightened to stenose basilar trunk below superior cerebellar artery. Majority of aneurysm has thrombosed, but a small residual lumen remains at neck (arrow).

E, 1 week after tightening. MR shows that residual lumen has increased slightly. Note diffuse change in thrombus intensity to high signal, except anteriorly.

(Fig. 4 is continued on the opposite page.)

ischemic lesions (foci of hyperintensity on T2-weighted images without associated T1-weighted hyperintensity) were identified on postoperative MR. Preoperative CT and/or MR were available for comparison in 13 patients, and no preexisting corresponding lesion was seen at these locations. In all cases, the lesion was anatomically appropriate to explain the new neurologic findings. Thus, these foci of MR hyperintensity were believed to represent new lesions.

Often the new lesions were small and immediately adjacent to clip artifact in the brainstem (Figs. 1, 3, 4, and 6–9), locations that were poorly evaluated by CT. Postoperative CT was available for comparison in 12 of the 15 patients with new deficits; CT was performed an average of 3 days earlier than MR. In two cases, the new lesion was identifiable (either definite or probable) on CT (Fig. 7) as a zone of hypodensity. In two cases, no lesion was seen; in one of these, CT probably was done too soon postoperatively to demonstrate it (less

than 24 hr). The region of the lesion was completely obscured owing to artifact from the clip or from adjacent bone in seven cases (Figs. 3–6 and 9). Thus, in over 80% of our patients, CT missed the clinically relevant lesion shown on MR. CT revealed no additional lesion not shown by MR.

Two patterns of ischemia were observed. A large zone consistent with occlusion of a posterior cerebral artery, including T2 hyperintensity in the occipital lobe and thalamus, was seen in three patients; all these occurred after direct clipping of a basilar tip aneurysm. Small lesions attributable to injury to the perforating vessels arising from the basilar artery and its major branches were more common; 17 brainstem ischemic foci (excluding thalamus) were noted in 15 patients after surgery. The average lesion size was 0.9 cm (range, 0.2–2.2 cm). Lesions tended to be distributed in a fashion typical for the surgical approach, as illustrated in Figure 10. Direct clipping of basilar tip aneurysms (in eight

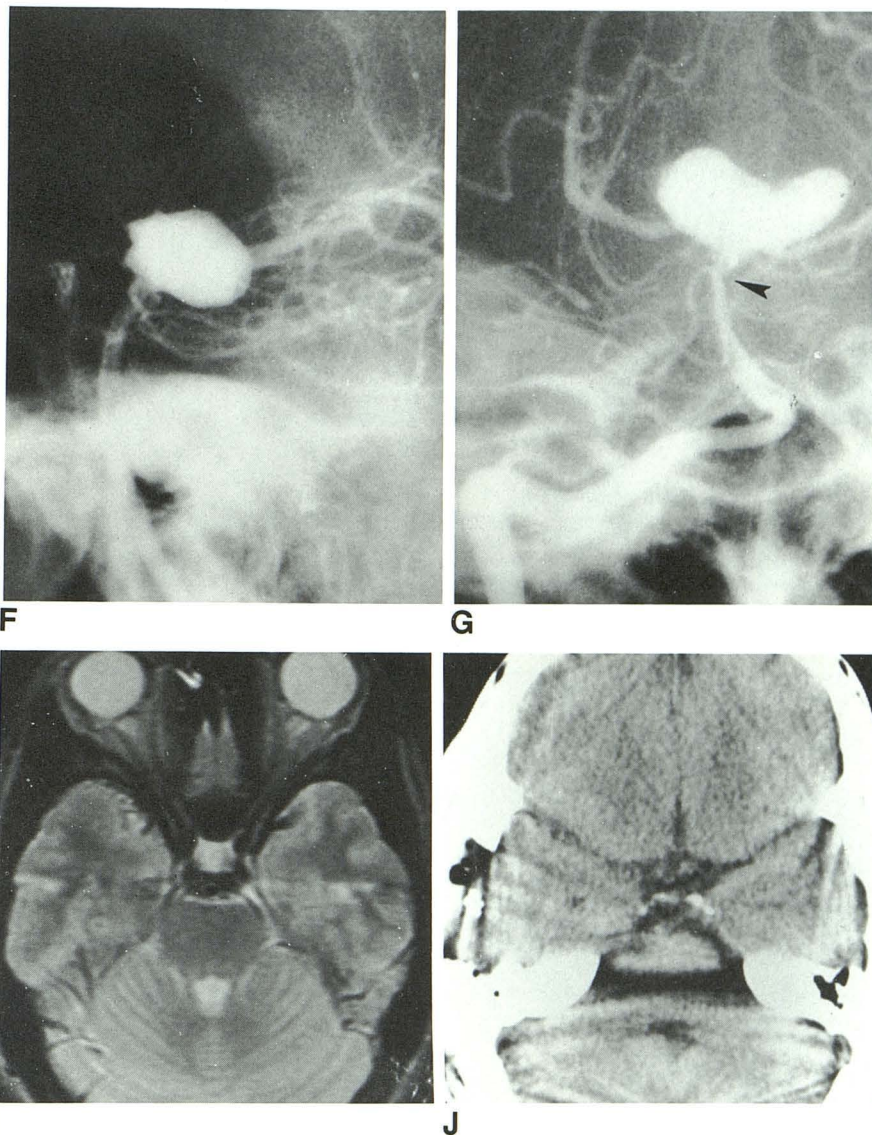
Fig. 4—(Continued).

F and G, Vertebral angiograms at 1 week confirm that aneurysm lumen has enlarged, owing to loosening of tourniquet. Note persistent stenosis (arrowhead) at site of tourniquet.

H, T2-weighted MR image 1 week after surgery. Infarct in upper pons (arrowhead) is associated clinically with mild hemiparesis.

I, Preoperatively at same level. No lesion is seen.

J, CT scan on postoperative day 6. Bone artifact obscures region of interest.



patients) most often resulted in median and paramedian lesions in the upper midbrain (Fig. 8). More laterally positioned infarcts in the pontomesencephalic region (Figs. 3 and 6) followed surgical occlusion or stenosis of the basilar trunk in seven patients. The clip or tourniquet was applied below the superior cerebellar arteries in five of these patients and above in two. In addition, unilateral 1- to 2-cm circumscribed thalamic lesions occurred on direct clipping of basilar tip aneurysms in three cases and after proximal occlusion in one.

Preexisting Lesions

There was evidence suggesting preexisting ischemia on preoperative imaging studies in three patients. A large area of infarction was found in one case in the territory of the right posterior inferior cerebellar artery; in another, extensive old

left mesencephalic and thalamic infarction was seen; another showed only a tiny focus of T2 hyperintensity in the pons (Fig. 9). Marked perianeurysmal hyperintensity on T2-weighted images was noted in two other cases.

Discussion

The diagnostic value of MR scanning of unoperated large cerebral aneurysms has been described [2, 4, 18], but to date postoperative MR in this disease has been limited [3, 14, 15]. Few centers have used MR in this group of patients for fear of possible injury resulting from aneurysm clip motion. Recently, *in vivo* imaging with low- and medium-field-strength units has been reported as safe [14, 15].

The Sugita clip, like other nonmagnetic clips [14, 15], is a source of artifact in MR. The artifact from these metals

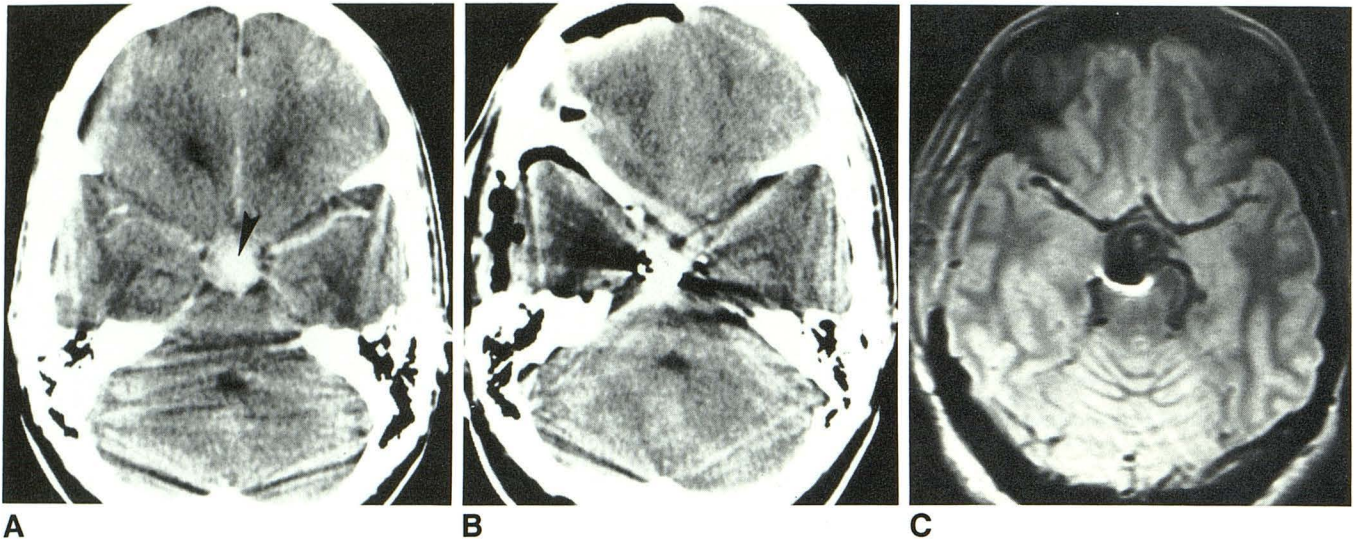


Fig. 5.—Distal basilar trunk aneurysm.
A, Preoperative contrast-enhanced CT scan shows partly thrombosed aneurysm with enhancing patent lumen (*arrowhead*).
B, CT scan 2 days after clipping basilar trunk proximally. Artifact from clip almost completely obscures aneurysm.
C, CT scan 2 days after clipping basilar trunk proximally. Most of aneurysm is visualized adjacent to clip artifact, showing apparently complete thrombosis (confirmed by angiography). Note.—New thrombus is hyperintense centrally and peripherally, with intermediate zone of hypointensity.

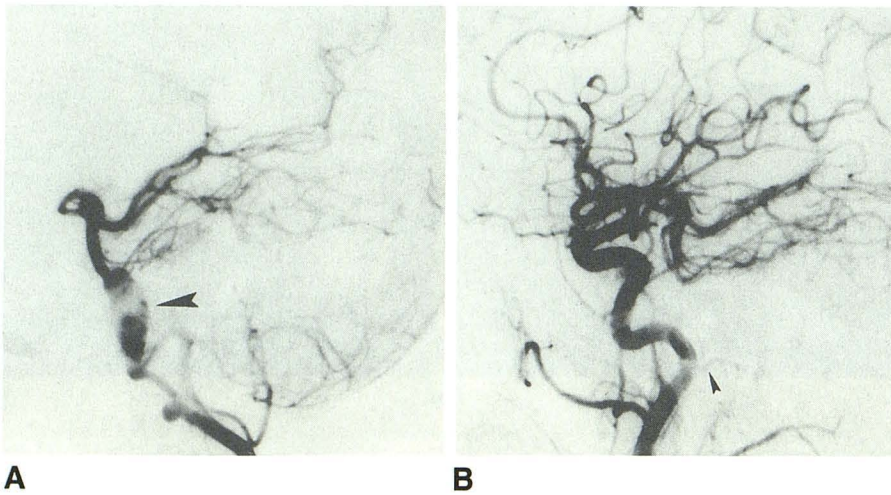


Fig. 6.—Giant midbasilar trunk aneurysm.
A, Preoperative left vertebral arteriogram. Fusiform origin and patent lumen are seen (*arrowhead*).
B, Left carotid angiogram 2 weeks after surgery. Basilar artery has filled retrogradely down to level of anterior inferior cerebellar arteries, but no filling of aneurysm has occurred. Clip (*arrowhead*) was placed to occlude basilar trunk below aneurysm.

C, Preoperative T2-weighted MR image at level of midpons. Note multilaminated aneurysm thrombus and small eccentric lumen with flow void.

D, T2-weighted MR image at same level 17 days after surgery. Lumen is seen to be occluded by high-signal thrombus. New ischemic lesions were found in left tegmentum (*arrowhead*) and midmedulla. Surgery was complicated by intraoperative rupture of aneurysm. Clinically, patient showed new quadriplegia and bulbar palsies.

E, CT scan 3 weeks after surgery. Both aneurysm and brainstem are obscured by artifact.

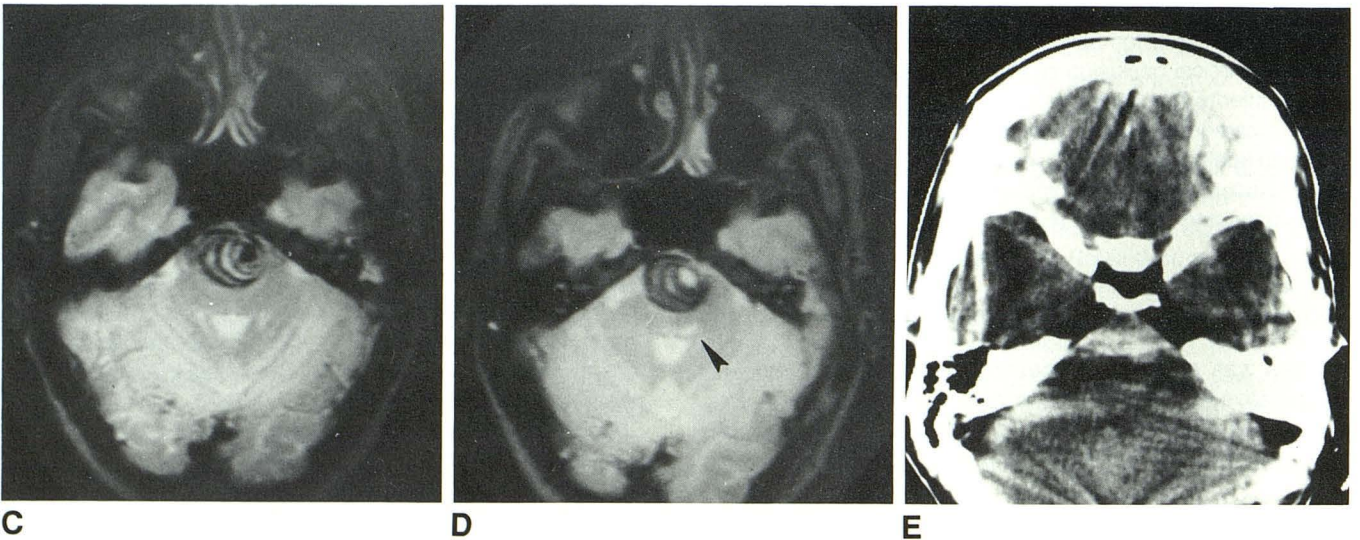


Fig. 7.—Basilar tip aneurysm.

A, Preoperative vertebral angiogram.

B, Vertebral angiogram 2 days after direct clipping of aneurysm neck. Basilar termination was occluded also; intraoperative aneurysm rupture had occurred. Complete angiography showed nonfilling of aneurysm.

C, T2-weighted axial MR scan at 10 days (at level of midbrain). Posterior to clip artifact and high-signal aneurysm thrombus, new infarcts are seen in right tectum and tegmentum (*small arrowhead*) and right occipital lobe (*large arrowhead*). Clinically, patient suffered new left hemiplegia and hemianopia and right oculomotor nerve palsy.

D, CT scan at 11 days. Axial section angulation differed from that used in MR. Note thrombosed dome of aneurysm (*arrow*), tegmental infarct (*small arrowhead*), and occipitotemporal infarct (*large arrowhead*).

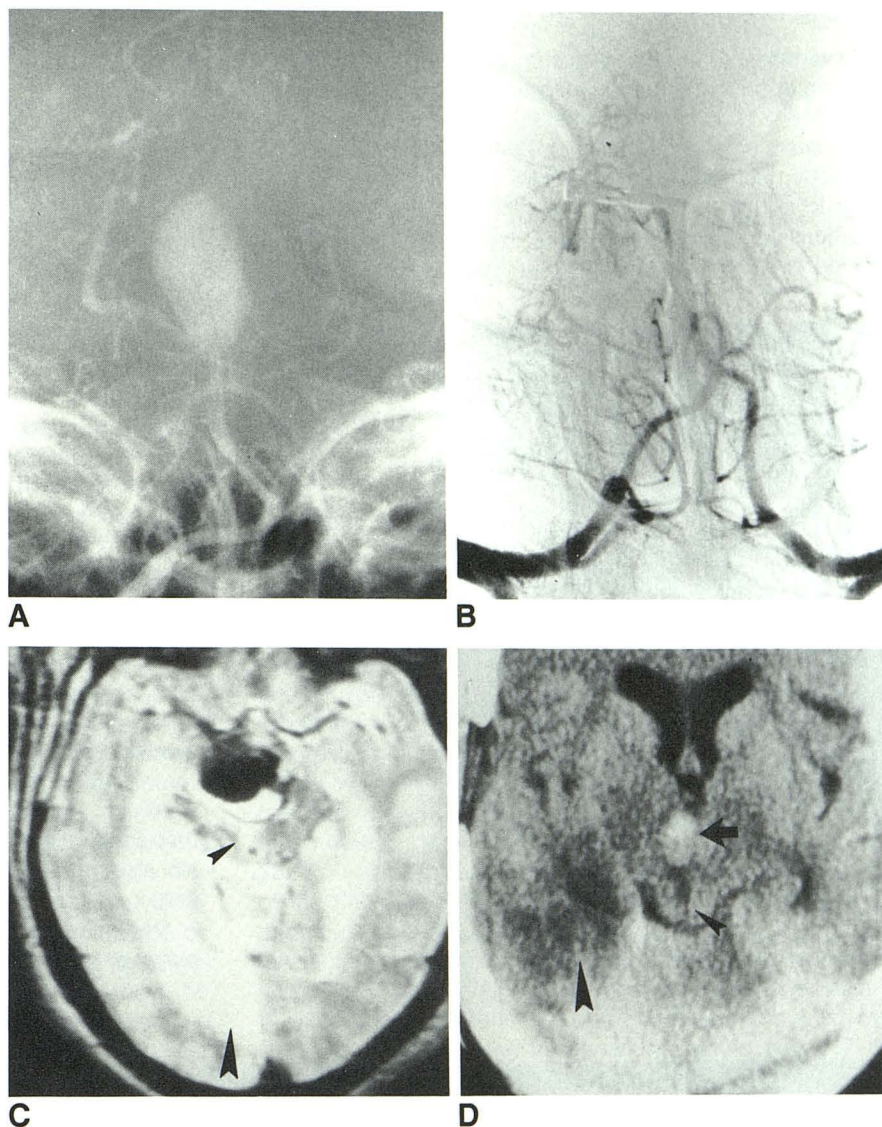


TABLE 1: Clipping Technique and New Postoperative Neurologic Deficits in Patients Treated for Cerebral Aneurysms

| Deficit | No. of Patients* | |
|--|-------------------|---------------------|
| | Direct (n = 8) | Proximal (n = 7) |
| Reduced level of consciousness, including confusion and drowsiness | 2 (2) | 3 (2) |
| Disorders of extraocular movement, excluding unilateral isolated third-nerve palsy | 2 (2) | 2 |
| Limb weakness (mono-, hemiparesis) | 4 (2) | 6 (2) |
| Cranial-nerve palsy (V–XII) | 0 | 3 (1) |
| Quadriparesis | 0 | 1 (1) |
| Hemianopia | 1 | 0 |
| Ataxia | 1 | 2 |

* Numbers in parentheses indicate those patients who showed some improvement by the time of discharge.

appears very similar to that produced by ferromagnetic materials, though smaller in size; induction of local magnetic eddy currents has been implicated as the mechanism of

artifact production [10]. The artifact significantly obscures regional anatomy, particularly the clipped aneurysm. Despite this, postoperative MR is more informative than CT for several reasons. Ischemic lesions are more detectable owing to (1) the inherently superior soft-tissue contrast resolution of MR; (2) the 2-D Fourier transform reconstruction mode used in MR, which yields a much more limited metallic artifact from the aneurysm clip, compared with the filtered back-projection reconstruction mode used with most CT [10]; and (3) the beam-hardening artifact from basal skull bone that significantly degrades CT images in the posterior fossa but is not present on MR. As a consequence, postoperative MR provides a unique opportunity to demonstrate ischemic lesions close to the clip, near the skull base.

This has particular relevance in the surgery of vertebrobasilar aneurysms, where perforator vessel occlusion is the most important factor in patient morbidity [18–21]. Resultant brainstem infarction, although small in extent, frequently has profound clinical consequences owing to the complex regional anatomy closely packed with tracts and nuclei.

Perforator Occlusions

In vertebrobasilar aneurysm surgery, either direct aneurysm clipping or proximal (hunterian) ligation of the parent vessel is used [18–21]. With these different approaches the surgeon encounters differing anatomy of the regional perforators. The brainstem ischemic lesions complicating these operations appear to cluster in zones typical of the surgical approach, in locations and patterns in keeping with injury to the regional perforators. The blood supply to the brainstem has been



Fig. 8.—T2-weighted MR image shows paramedian midbrain tegmentum infarct (arrow) adjacent to clip artifact 5 days after direct clipping of basilar tip aneurysm. New clinical findings include left internuclear ophthalmoplegia.

described in detail [22]. The internal arrangement of the perforating arteries is orderly and highly predictable, in contrast to the variable large external vessels in the posterior fossa (i.e., the long cerebellar arteries). Each brainstem region has a characteristic perforator pattern. The internal arteries can be divided into four groups: median, short and long laterals, and posterior.

In clipping aneurysms of the basilar bifurcation region directly, the major perforators of concern are the thalamoperforators and the median and paramedian groups entering the interpeduncular fossa to supply the midbrain [18–21]. In comparison, clips or ligatures on the basilar trunk are placed at a more inferior level above or below the superior cerebellar artery, near or at the pons. This surgical approach would place at more risk the lateral perforator groups [23–25]. With either approach, perforator occlusion could result from several factors: inclusion of the perforator in the clip blades, particularly in clipping a basilar tip aneurysm directly; compromise of the perforator origin by parent vessel distortion due to clipping; flow alteration in the vicinity of a clipped parent vessel, leading to thrombosis, which may propagate to involve perforator origin [24, 25]; or direct or indirect injury during surgical exposure of the aneurysm.

In our series, preoperative MR findings were not available for comparison in all cases. However, new neurologic deficits identified after surgery were appropriate in all cases to the "new" lesions found on postoperative MR. In no patient was significant cerebral vasospasm documented on angiography that could also have produced the ischemic lesions. Occasionally, similar perforator-territory infarcts can be seen in the setting of a ruptured aneurysm, without surgical intervention.

The inadequacy of postoperative CT in infarct detection may well have been exaggerated in our study, as the routine

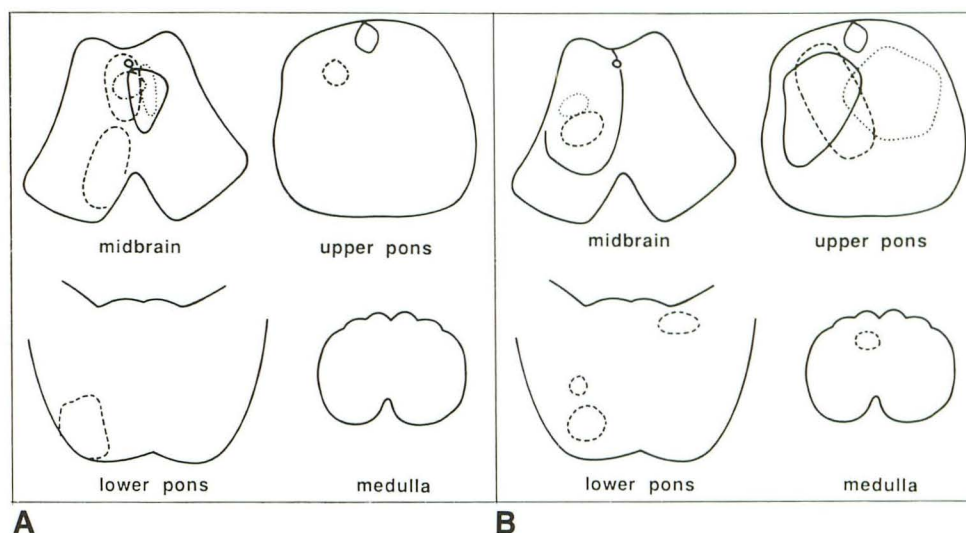


Fig. 9.—A, T2-weighted MR image shows anterolateral basis pontis ischemia (arrowhead) adjacent to clip artifact 3 days after direct clipping of basilar tip aneurysm. Clinically, patient showed new left hemiparesis.

B, Same region on preoperative study. There is no preexisting lesion, but a few tiny foci of probable old ischemic disease are seen in more dorsal pons. Both scans show high-signal subarachnoid hematoma in prepontine cisterns and hydrocephalus with turbulent signal loss in fourth ventricle.

C, Postoperative CT scan, same day as MR. Extensive metallic artifact obscures pons.

Fig. 10.—A and B, Distribution of brainstem ischemia complicating basilar aneurysm surgery for basilar bifurcation aneurysm clipping (A) and basilar trunk occlusion (B). Lesion size and anatomic level of injury are diagrammed as assessed from axial scan.



postoperative scanning parameters used were not optimal for that purpose: 1-cm contiguous axial slices were obtained, and usually noncontrast scans were obtained, as the primary goal was to exclude hematoma or hydrocephalus. Also, postoperative CT was performed earlier than the corresponding MR study. More lesions may well have been detected if CT had been performed at later postoperative intervals [17]; yet, we believe this detection rate is valid and typical for the common postoperative CT assessment of acutely ill patients. Similar findings were recently described for spontaneous brainstem infarcts evaluated with a low-field unit [26].

MR may demonstrate ischemic lesions that are "reversible" [27]; that is, they become minimal or are not visualized on subsequent studies (Fig. 11). As many of our patients had only transient and partially resolving clinical deficits, it may be incorrect to term the ischemic lesions shown on postoperative MR "infarctions." Delayed serial MR studies would be required to resolve this issue.

The patient group studied here was highly selected and biased toward ischemic operative complications, with a preponderance of very large aneurysms in the posterior circulation. It is not appropriate to infer prevalence data from these results: no statement can be made on the rate of complications or the success or failure of aneurysm surgery from these data.

The Postoperative Aneurysmal Lumen

Even on preoperative MR, we have found it difficult to image accurately small patent lumina in mostly thrombosed aneurysms [18]. Yet, a residual patent lumen has serious prognostic implications. This is most relevant in those patients treated with some form of parent vessel ligation [25]. Postoperative MR can demonstrate a residual patent lumen in some cases, but multiple scan planes and sequences may be required to image the aneurysm neck free of nearby clip artifact. Nonvisualization of a lumen in an otherwise thrombosed aneurysm pre- or postoperatively on MR is not a reliable finding; arteriography is still necessary for definitive

evaluation of the aneurysm lumen. Although our surgeons do not routinely use intraoperative angiography, they believe postoperative angiography is important: if an aneurysm is directly clipped, a residual lumen usually will indicate reoperation; if a proximal occlusion/stenosis is performed, a residual lumen is expected early but must be followed to document progressive thrombosis.

The MR appearance of luminal thrombus signal intensity has been described for unoperated aneurysms [1–6] and those treated by balloon occlusion of the parent vessel [5, 28]. In agreement with those studies, and published reports of the MR appearance of hematomas [29], acute or fresh thrombus appeared hypointense in our patients, and became hyperintense with time, usually after 5–7 days. Atlas et al. [2] suggested that the hyperintensity should appear earliest in the luminal aspect of the aneurysm thrombus, assuming that (1) thrombus is deposited in sequentially added layers; (2) the layers are added on the luminal aspect; and (3) evolution of thrombus hemoglobin, from deoxy- to methemoglobin [29], occurs earliest on the luminal aspect of the thrombus owing to better access to oxygenated blood. Our postoperative MR studies, in comparison, often revealed fresh subtotal thrombosis of the previously patent lumen, with hyperintensity usually first seen peripherally. Rather than proximity to oxygenated flowing luminal blood, the explanation for the sequence of intensity changes we observed in recent postoperative aneurysm thrombi may be simply a progression of thrombus age, from center to periphery. It is likely that the observed MR signal intensities are the result of several complex factors: hemoglobin oxidation states may be one, but the relative fibrin and platelet content of thrombus can also directly and independently alter signal intensity [30]. The composition of aneurysm thrombus in these respects is not well understood.

Conclusions

Postoperative MR of cerebral aneurysms provides valuable information not otherwise obtainable. Clinically significant,

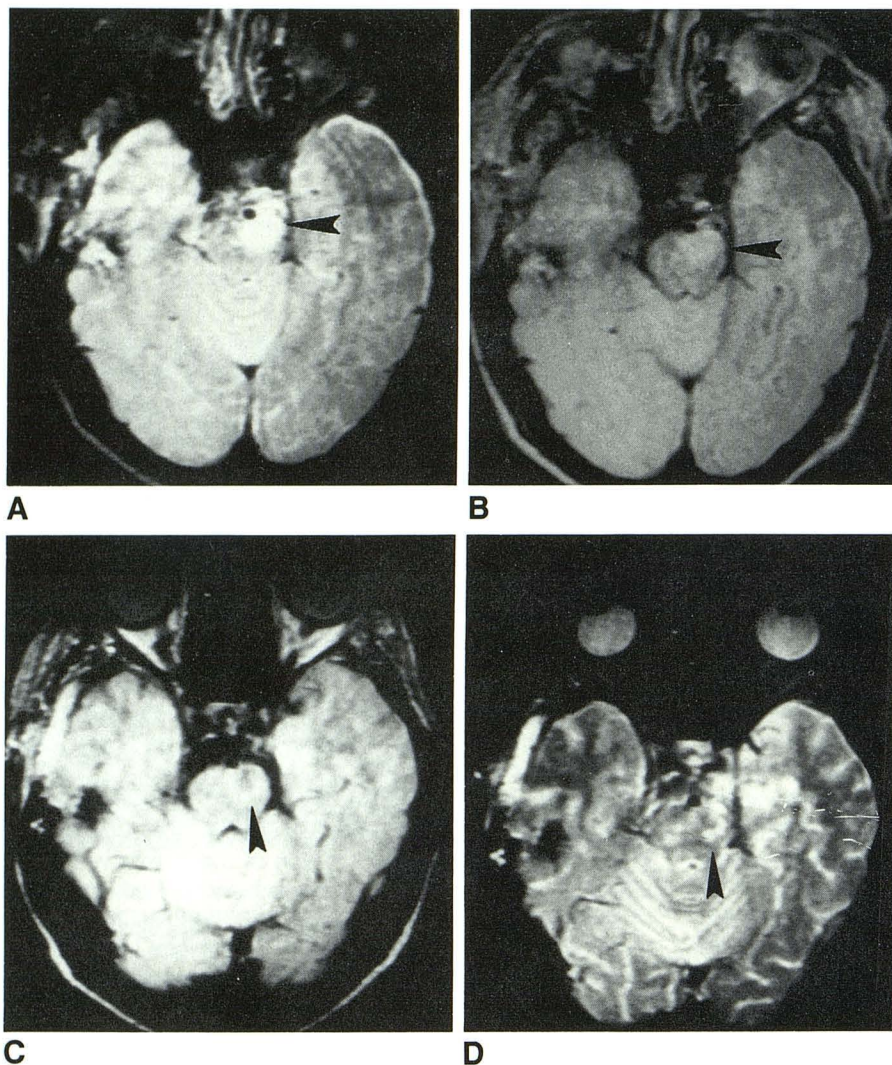


Fig. 11.—“Reversible” ischemic change on MR in patient with giant basilar tip aneurysm. Basilar trunk clipping (below superior cerebellar artery) had been attempted. At surgery, acute severe systemic hypertension occurred when basilar artery was occluded. As a result, clip was removed after 17 min. The patient awoke with right hemiplegia and confusion.

A and B, T2-weighted MR images 2 days after surgery show large “infarct” in left pontomesencephalic region (arrowheads).

C and D, MR image at 2 weeks, same region. Marked diminution in extent of high-signal lesion has occurred (arrowheads). Clinically, patient had improved considerably, with new antigravity strength in right extremities and full orientation of sensorium.

small ischemic lesions in the brainstem, even immediately adjacent to the aneurysm clip, can be well demonstrated. Studies of patients after basilar aneurysm surgery have provided a unique opportunity to document the various patterns of perforator injury complicating these procedures. In large or giant aneurysms, frequently much of the aneurysm and occasionally the residual lumen can be imaged postoperatively adjacent to the clip artifact. Nonvisualization of residual lumen on MR is unreliable, and postoperative angiography is still required. Postoperative scanning of patients treated with nonmagnetic Sugita aneurysm clips is safe at a field strength of 1.5 T, and we believe of significantly greater value than postoperative CT.

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