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Gadolinium-Enhanced MR in the Evaluation of Preoperative Meningioma Embolization

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PURPOSE: To evaluate the use of postembolization gadolinium-enhanced MR imaging as a means to judge the efficacy of tumor embolization. **METHODS:** Fifteen patients with meningiomas were prospectively studied. The following data were evaluated for each tumor: the percentage of vascular supply to the tumor arising from the internal and external carotid arteries; the percentage of the tumor embolized as judged by angiography, by MR imaging, and by CT scanning; the estimated blood loss according to the surgeon; and histologic evidence of necrosis as seen by the neuropathologist. **RESULTS:** The data reveal an excellent correlation between the amount of tumor embolized as estimated by MR and both the estimated blood loss at time of surgery and the presence of histological necrosis in the specimen. **CONCLUSIONS:** Postembolization gadolinium-enhanced MR is an excellent means to evaluate the efficacy of an embolization and offers certain advantages over CT and angiography. One important advantage of this technique lies in the fact that it can be performed immediately postembolization.

Index terms: Meninges, neoplasms; Brain neoplasms, magnetic resonance; Contrast media, paramagnetic; Interventional neuroradiology

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Although many feel that preoperative embolization of meningiomas significantly reduces blood loss at time of surgery, an accurate preoperative evaluation of the efficacy of such an embolization remains difficult to obtain. Several studies have shown that postembolization angiography, computed tomography (CT), and isotopic scanning are unreliable (1, 2).

While much depends upon an educated guess by the interventional neuroradiologist as to the extent and adequacy of the procedure, we must seek means to refine the data upon which that guess is based. For those patients on whom surgery will be performed, accurate knowledge of the efficacy of embolization contributes to the

neurosurgeon's preoperative evaluation, as do such factors as size of tumor and proximity to dural sinuses. Evaluation of the risk of significant bleeding is especially important in patients with rare blood groups or when considering the risks of transfusion in the light of today's problems with blood-transmitted diseases (3).

In certain well-defined conditions, embolization may be the only therapy proposed if the blood supply can be extensively obliterated (4, 5). The assessment of the extent of embolization in these cases will determine whether or not additional treatment must be undertaken.

Magnetic resonance (MR) has become the standard imaging modality for the evaluation of intracranial tumors, and offers definite advantages over other imaging techniques. Meningiomas are a particular type of tumor that is well evaluated by MR before and after the intravenous injection of gadolinium (6–10). In this study, we have tried to determine whether MR would provide more accurate evaluation of the efficacy of the embolization of a tumor, and to determine the reliability and limitations of that evaluation.

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TABLE 1: Summary of data

Case	Age	Sex	Tumor Location ^a	Histology ^b	% ECA Supply	% Tumor Embolized on Angio	% Reduction of Enhancement on MR	Histologic Necrosis	EBL
1	52	M	R Fr Cvx	Fibroblastic	50	50	17.3	++	400 mL
2	50	M	L Fr Cvx	Fibroblastic	40	40	12.8	—	500 mL
3	40	F	R Fr	Fibroblastic	100	100	43.7	++	400 mL
4	36	F	R Fr	Fibroblastic	100	100	41.6	++	300 mL
5	53	F	R Pr Cvx	Fibroblastic [2]	95	95	90.0	—	100 mL
			R Pr Cvx	Transitional [2]				++	
			R Ps (falx)	Unknown [1]				++	
6	55	F	L Tm	Transitional	100	100	88.0	++	150 mL
7	53	M	L Pr	Transitional	5	5	6.0	—	700 mL
8	26	M	L Pr	Transitional	5	5	2.4	—	800 mL
9	48	M	L Pr	Transitional	5	5	2.9	—	700 mL
10	33	F	R Tm	Transitional	80	80	2.5	—	800 mL
11	36	F	R Tm	Transitional	80	80	3.1	—	650 mL
12	64	F	L Tm	Meningioendo	5	5	3.3	—	600 mL
13	75	F	L Fr Cvx	Meningioendo	80	80	3.3	—	600 mL
14	53	M	L Pr (falx)	Angioblastic	5	5	4.8	—	500 mL
15	45	M	R Ps (falx)	Angioblastic	10	10	3.5	—	600 mL

Note—ECA = external carotid artery; EBL = estimated blood loss; Angio = angiogram.

^a R = right; L = left; Fr = frontal; Pr = parietal; Tm = temporal; Ps = parasagittal; Cvx = convexity.

^b WHO classification of meningiomas: Meningioendo = meningioendotheliomatous meningioma.

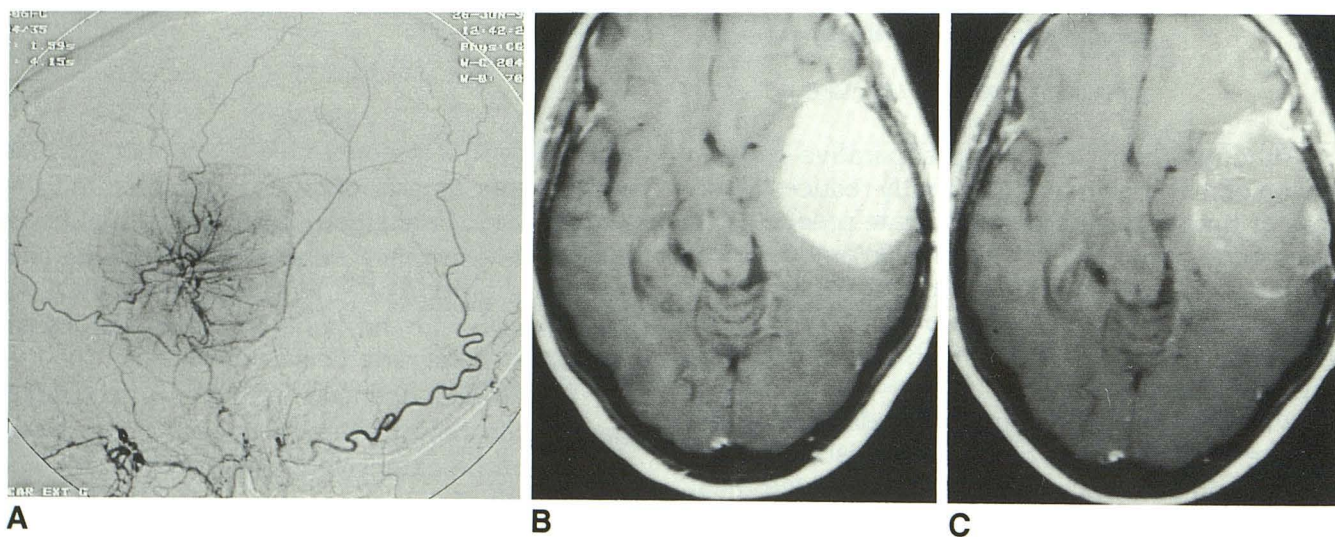


Fig. 1A. Left external carotid angiogram, case 6, lateral projection demonstrating the typical vascular pattern of a transitional cell meningioma prior to embolization.

B, Axial T1-weighted gadolinium-enhanced MR, case 6, obtained before embolization of the tumor with Gelfoam particles.

C, Axial T1-weighted gadolinium-enhanced MR, case 6, obtained 5 hours after embolization of the tumor with Gelfoam particles. Note the nonenhancing, devascularized central portion of the tumor.

Materials and Methods

Between May 1990 and December 1991, 15 patients with intracranial meningiomas underwent preoperative embolization of the blood supply to their tumors. Patients ranged from 26 to 75 years of age; 8 women and 7 men.

The initial diagnosis of intracranial tumor was made in all patients by CT scanning, MR, and selective cerebral

angiography. In eight of the cases, MR was performed on a superconductive 1.5-T system (Gyrosan S15, Philips, Eindhoven, The Netherlands), and in seven cases, on a 0.5-T system (Gyrosan T5, Philips).

All of these MR examinations included T1-weighted spin-echo images before and after intravenous injection of gadolinium-DTPA (0.1 mmol/kg body weight) in the sagittal, axial, and coronal planes. In six patients, the exami-

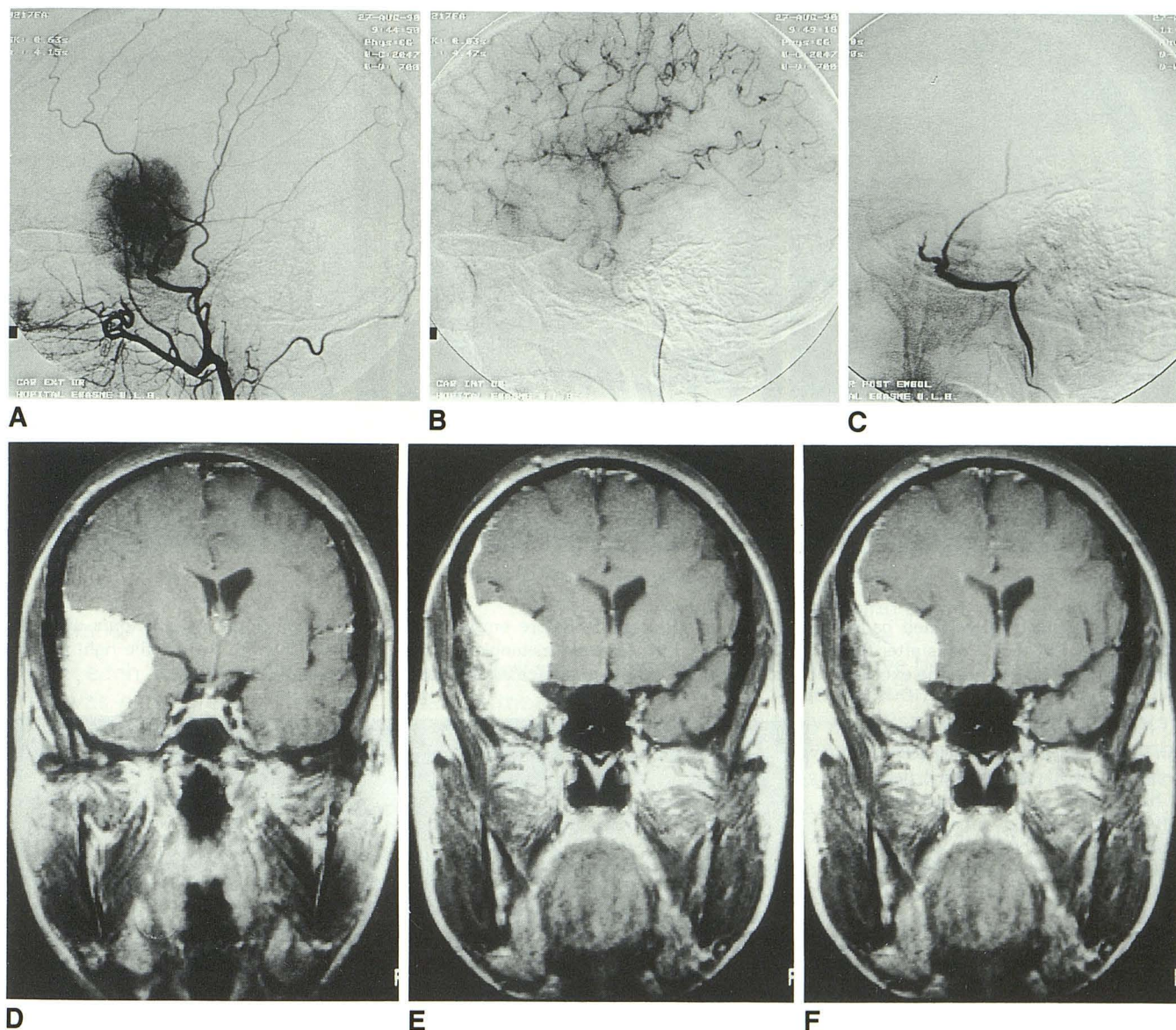


Fig. 2A. Right external carotid angiogram, case 10, lateral projection demonstrating the vascular supply to this transitional cell meningioma before embolization.

B, Right internal carotid angiogram, case 10, lateral projection, late arterial phase, demonstrating the vascular supply to the periphery of this large meningioma arising from cortical branches.

C, Right middle meningeal angiogram, case 10, lateral projection at the conclusion of the embolization, showing truncation of all branches of the middle meningeal artery.

D, Coronal T1-weighted gadolinium-enhanced MR, case 10, before embolization of the meningioma, E, 4 hours after the embolization, and F, 1½ days after the embolization. The inadequacy of the embolization was attributed to the presence of induced spasm. In this case, the postembolization MR was far more accurate than the angiogram.

nation included complementary T2-weighted spin-echo images.

Diagnostic angiography was performed using the transfemoral Seldinger technique with selective catheterization of the feeding vessels to provide complete vascular mapping of these lesions. Imaging was performed with a high-resolution (1024-line) digital subtraction angiographic system (Polytron, Siemens, Erlangen, Germany).

Embolization was performed as a separate procedure and involved the selective catheterization of the external carotid artery with a 5-F polyethylene guiding catheter and superselective catheterization of the middle meningeal artery (MMA) with a coaxial Tracker 18 (Target Therapeutics, Fremont, CA). During injection of the embolic material, the tip of Tracker catheter was positioned as far distally as practical. For six of the patients (Table 1, cases 1, 6, 8, 9,

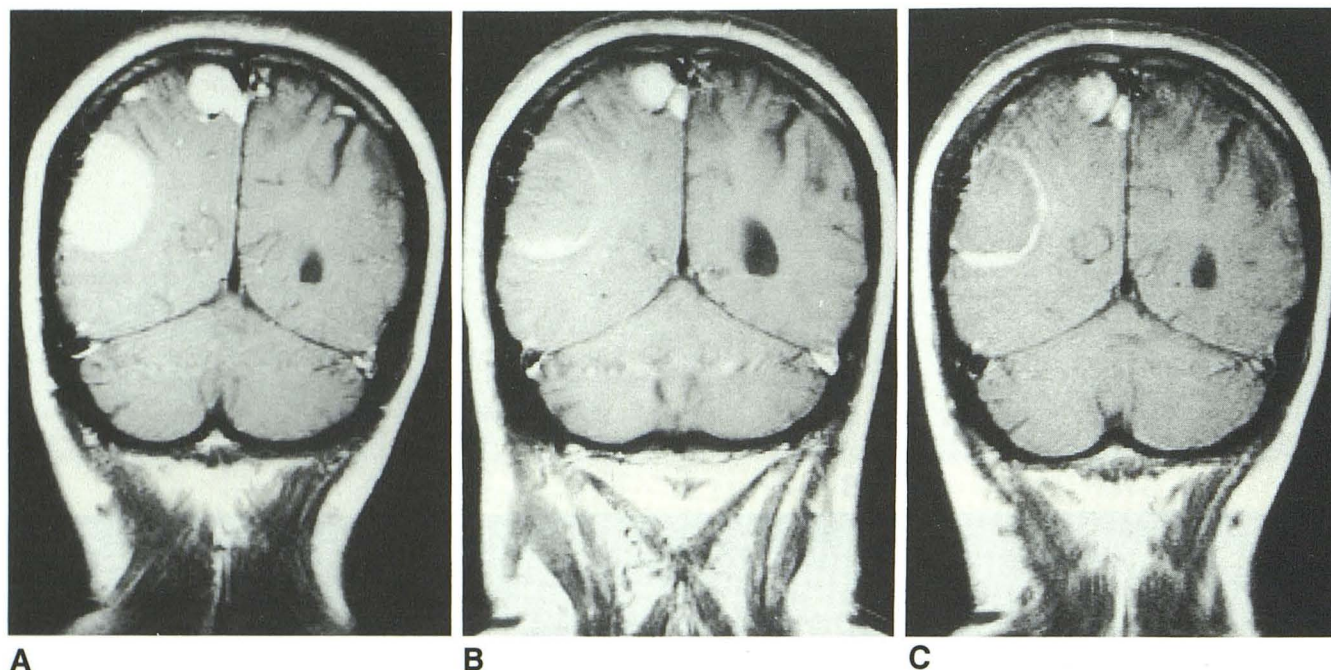
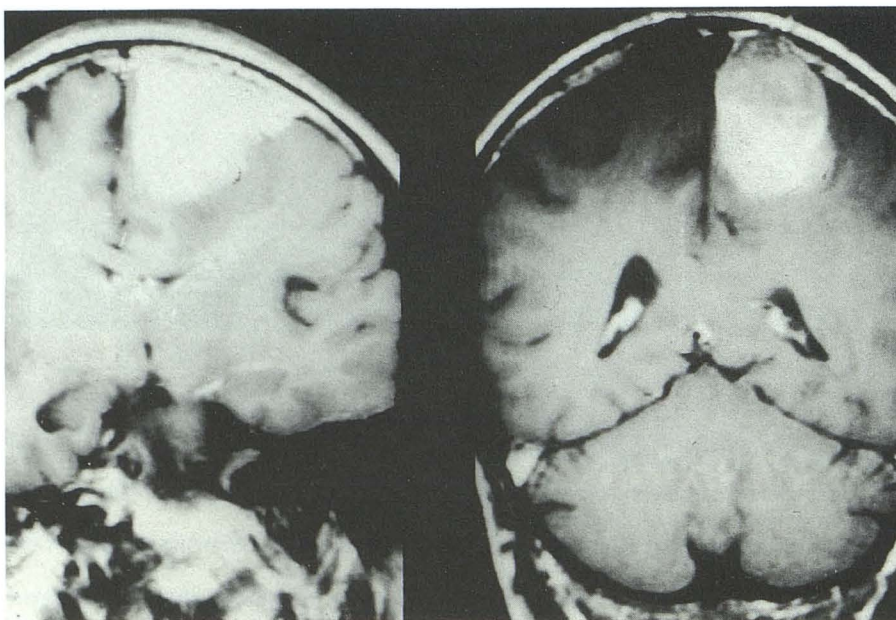


Fig. 3. Coronal T1-weighted gadolinium-enhanced MR, case 5, before embolization of the meningioma (A), 3 hours after the embolization (B), and 3 days after the embolization (C). Five separate meningiomas were present. Only the two on the right parietal convexity were embolized; the excellent occlusive effect is well documented on the postembolization MR studies.

Fig. 4. Coronal T1-weighted gadolinium-enhanced MR, case 13, before embolization of the meningioma (left), and 4 hours after embolization (right). The diffusely diminished enhancement was characteristic of cases in which spasm precluded a more complete devascularization.



10, and 14), Gelfoam particles (Upjohn, Kalamazoo, MI), free-cut at the time of treatment and suspended in contrast medium, were used as the embolic material. Particulate Ivalon (Ingenor, Paris, France) 150 to 300 microns in size was used as the embolic material in the remainder of the cases. In patients 2 and 3, the particles were rinsed with 94% ethyl alcohol before suspension in the contrast medium. Liquid embolic agents were not used because of their known potential to pass through dangerous collateral networks, occlude normal vessels, and produce unacceptable

neurologic deficits (11). At the end of each embolization, a follow-up external carotid angiogram was performed.

Three to 5 hours after embolization of these tumors, T1-weighted MR was performed before and after the intravenous injection of gadolinium-DTPA. For three of these patients, a second (delayed) MR was obtained 1 to 3 days later in the immediate preoperative period.

For each patient the pre- and postembolization MR evaluation was performed on the same imaging system (ie, same field strength), with identical imaging parameters and

identical planes of acquisition, and the images were photographed with identical windows settings.

All patients underwent surgery 1 to 4 days after embolization. The neurosurgeon's operative note was evaluated to determine the estimated blood loss from the procedure. The neuropathologist was requested to pay particular attention to the evaluation of any residual tumor vascularization and to the presence and extent of necrosis seen during histopathologic analysis of the tumor.

Estimation of the percentage of tumor supply arising from the internal or external carotid arteries, and estimation of the percentage of tumor embolized as seen on the angiogram was performed by two neuroradiologists. Using a modification of the technique described by Boyko et al (*Quantitative assessment of MR findings in PVL*, paper presented at the 29th annual meeting of the ASNR, June 1991, Washington, DC), the percentage reduction of the region of MR enhancement was calculated by two neuroradiologists using a calibrated grid and the section thickness of the images to derive a volumetric approximation of the zones of decreased enhancement within each tumor after embolization.

Results

For each tumor the extent of the embolized area was estimated by the four different means summarized in Table 1. First, the preembolization angiogram was evaluated for the percentage of tumor vascularization arising from the MMA (Table 1, "% ECA Supply"), which was compared with the percentage of tumor embolized as estimated by the postembolization angiogram. In three patients (Table 1, cases 3, 4, and 6, and Fig. 1), the arterial supply to the tumor arose from the MMA alone, allowing the potential for 100% embolization of these tumors. In four other patients (Table 1, cases 5, 10, 11, and 13), the MMA provided the dominant arterial supply to the tumors with the potential for embolization estimated at 95%, 80%, and 80%, respectively. In one patient, the MMA supply was estimated at 50% (Table 1, case 1), and in the seven other cases, it was 40% or less (Table 1, cases 2, 7, 8, 9, 12, 14, and 15).

Comparison of the values in the column labeled "% ECA Supply" with those in the "% Tumor Embolized on Angio" column shows that embolization was continued until the MMA supply to the tumor was completely occluded.

The second evaluation of the efficacy of the embolization was obtained by the comparison of the gadolinium-enhanced tumors on the T1-weighted MR postembolization with their preembolization appearance. These data are summarized in Table 1 in the column entitled "% Reduc-

tion of Enhancement on MR." In nine patients (Table 1, cases 7–15), little or no modification occurred and it was felt that less than 10% of the tumor supply had been embolized. In four patients (Table 1, cases 1–4), 12% to 50% of the tumor did not enhance. In only two patients (Table 1, cases 5 and 6) did the MR immediately postembolization reveal a decrease in the enhancing zone of approximately 90%.

In the three patients who each underwent two postembolization MR examinations (immediate and delayed), there was no modification over time of the size of the devitalized area.

Histologic evaluation of the excised tumors confirmed the pretreatment diagnosis of meningioma in each case. These tumors were subclassified according to the World Health Organization (WHO) classification (12) as eight transitional meningiomas (including one which was poorly vascularized), six fibroblastic meningiomas, two meningioendotheliomatous meningiomas, and two angioblastic meningiomas, one of which was clearly malignant. Case 5 had multiple tumors. The cases in Table 1 have been arranged to reflect the histologic classification. Necrosis was prominent histologically in seven tumors (five patients).

Although CT was an important diagnostic modality in all cases, the evaluation of the efficacy of embolization obtained by comparison of the CT appearance of the contrast-enhanced meningiomas pre- and postembolization has not been included in Table 1. This evaluation was accomplished in four cases, none of which exhibited any appreciable difference between the pre- and postembolization CT scans.

The data presented in Table 1 reveal an excellent correlation between the amount of tumor embolized as estimated by MR and both the estimated blood loss at time of surgery and the presence of histologic necrosis in the specimen. A good correlation was achieved between postembolization angiography and MR, with the exception of cases 3, 4, 10, 11, and 13, in which an apparently complete occlusion of the external carotid artery supply on the angiogram did not result in significant reduction of enhancement of the postembolization MR. In these cases, the MR accurately reflected the degree of devascularization observed at the time of surgery and in the subsequent histopathologic evaluations.

Discussion

Dean et al have shown that preoperative embolization of meningiomas can significantly re-

duce blood loss at surgery and the consequent need for transfusions (*Efficacy of endovascular treatment of meningiomas: a controlled study*, paper presented at the 30th annual meeting of the ASNR, May 1992, St. Louis, MO). Others have also suggested that embolization can decrease the likelihood of tumor recurrence by producing necrosis at the site of dural attachment (1, 2, 11). When requested by the neurosurgeon, preoperative embolization of a meningioma is done in order to facilitate surgical removal by reducing blood loss. The neurosurgeon and the neuropathologist thus become the final arbiters of the efficacy of an endovascular occlusive procedure: the efficacy is most accurately judged by the blood loss estimated by the surgical team (low blood loss and no complaints to the neuro-radiologist constituting an effective embolization) and by the evidence of necrosis seen in the specimen by the neuropathologist. Regardless of this fact, however, it is important for the surgical team to have a preoperative evaluation of the extent of embolization in order to operate under optimal conditions.

We abandoned postembolization CT scans as a means for evaluating the efficacy of embolization for two reasons. First, the CT was difficult to interpret if done in close temporal proximity to the embolization, since iodinated contrast media must be used for both procedures, and it persists for a long time, especially in the devitalized segments of the tumor. The second reason we abandoned postembolization CT was because of the poor correlation between the results predicted by this means and the observations of the surgeons and the neuropathologist.

The literature and our personal experience suggest that CT and isotope scanning are unreliable for evaluating the efficacy of an embolization (2). Manelfe et al report that when low-density areas on contrast-enhanced CT scans obtained after embolization were interpreted as necrosis and the tumors were then examined pathologically, the CT and pathologic examinations were in agreement in only one third of the cases (1).

MR has become a standard modality for the imaging of intracranial tumors. While meningiomas presented occasional problems for MR before the advent of gadolinium-containing contrast agents (10, 13), the use of these contrast agents permits a relatively conclusive diagnosis (6–9).

High-flow lesions such as arteriovenous malformations and some aneurysms readily lend themselves to evaluation with MR before and

after embolization or occlusive therapy (14–17). The flow effects upon which these determinations depend are not usually prominent enough for the evaluation of tumors postembolization, but since the iodinated contrast agent used during embolization does not significantly interfere with the gadolinium used during MR, we can readily evaluate the efficacy of embolization with this technique. As an additional advantage, since the contrast agents are different, the MR can be obtained as soon after the embolization procedure is completed as the patient can be transferred to the MR suite.

The efficacy of the tumor embolization is ordinarily dependent upon four factors: 1) the relative percentage of the vascular supply to the tumor arising from the internal and external carotid arteries; 2) the size of the embolic material used; 3) the degree of tumor vascularity; and 4) the development of spasm during the procedure (1, 5).

Usually only that portion of the arterial supply arising from the external carotid artery is treated. The greater the contribution from external carotid branches, the more extensive the embolization that can be attempted. This is well seen in cases 5 and 6, in which the meningiomas were extensively supplied by the MMA and the embolizations were highly successful as confirmed by estimated blood loss and histopathology. Cases 7–9, 12, 14, and 15, in which the blood supply to the tumors arose primarily from the *internal* carotid arteries, demonstrate the opposite aspect of this effect.

The use of smaller particles and extremely distal catheterization allows a more precise embolization with more extensive necrosis in the tumor (1), while reducing the risk of inadvertent intracerebral embolization through normal collateral channels (11). This is well seen in cases 5 and 6 (Fig. 1). In cases 2, 10, 11, and 13, however, angiography showed that 40% to 80% of the vascular supply to the meningiomas arose from the external carotid arteries, and review of the postembolization angiograms suggested complete occlusion of the feeding arteries. In one of these cases, MR demonstrated no change postembolization (Figs. 2 and 3). In the others the MR demonstrated a homogeneous diminution of enhancement following embolization (Fig. 4) that was not as striking as the focal zones of markedly diminished enhancement seen after more effective embolizations (Fig. 1). At the time of surgery, all four of these tumors remained well vascular-

ized. The discrepancy between the postembolization angiograms and the surgical findings has been attributed to spasm. It must be noted that the MR in each of these cases provided an excellent preoperative indicator of the *inadequacy* of the attempted occlusive therapy.

Conclusion

Preliminary evidence from our study shows that postembolization gadolinium-enhanced MR is an excellent modality for evaluating the efficacy of tumor embolization, especially sensitive to the disclosure of areas in which spasm produced angiographic images suggesting a more complete devascularization than was actually achieved. This is due in part to the inherent sensitivity of MR, but it is also related to the fact that images obtained before and after gadolinium can be obtained immediately postembolization and allow evaluation of any persistent vascular supply to the tumor, unaffected by the presence of iodinated contrast agent that was used during the embolization.

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Please see the Commentary by Latchaw on page 583 in this issue.