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Surgical Site after Resection of a Meningioma

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PURPOSE: Our goal was to characterize MR changes over time at the site of meningioma resection in order to determine optimal timing for detecting residual and recurrent tumor.

METHODS: **Twenty-one patients were studied with enhanced MR imaging during the first 5 postoperative days and additional studies were obtained 3 to 8 weeks after surgery (16 studies), 3 months to 1 year after surgery (17 studies), and 1 year or more after surgery (32 studies). Images were analyzed for residual tumor, membrane enhancement, parenchymal enhancement, edema, and blood collections.**

RESULTS: **Early postoperative images showed extensive, thin membrane enhancement that thickened by 3 to 8 weeks after surgery and that thinned or resolved and became less extensive by 6 months or more postoperatively. Twelve of 20 patients with long-term follow-up studies had membrane enhancement. Thin, serpiginous foci of enhancement in the surgical bed were identified only on early postoperative studies and probably represent gradual thrombosis of feeding vessels.**

CONCLUSION: **Residual foci of meningioma are best detected on studies obtained within the first 5 days after surgery because membrane thickness increases by 3 to 8 weeks after surgery and may obscure a small residual meningioma. Our study confirms the presence of prolonged membrane enhancement after surgery, although it thins with time and becomes confined to the craniotomy site.**

Meningiomas are common intracranial tumors, and surgical resection is frequently curative. When a meningioma cannot be totally resected because it involves a vital structure, other therapeutic measures, such as focused-beam radiation therapy, are frequently employed. Detection of a residual meningioma is important, but it may be difficult owing to the presence of postoperative meningeal enhancement (1, 2). To determine the optimal time of imaging for detection of residual or recurrent meningioma, we studied the postsurgical magnetic resonance (MR) images of patients after meningioma removal to identify temporal changes at the surgical site.

Methods

Consecutive patients presenting with meningioma between 1990 and 1993 were recruited for the study if they met three criteria: 1) had no contraindications to MR imaging, 2) had no contraindications to contrast material, and 3) would consent to the performance of two postoperative contrast-enhanced MR studies (one to be obtained as soon as possible after surgery and the other at 4 to 8 weeks after surgery) and to routine studies 6 months and 1 year after surgery and thereafter as deemed necessary by the neurosurgeon. Twenty-one patients met these criteria.

All surgical procedures were performed by a single neurosurgeon. MR imaging was performed on a 1.5-T MR unit and consisted of sagittal and axial short-repetition-time (TR)/short-echo-time (TE) sequences and axial long-TR/short-TE and long-TE conventional spin-echo sequences in all cases, as well as coronal sequences as necessary, depending on the location of the lesion. Short-TR/TE sequences were repeated after the administration of contrast material in doses of 0.1 mmol/kg. The enhanced images were obtained as soon as possible after contrast administration and the sequence was usually completed within 10 minutes of contrast administration. The sections were typically 5 mm in width with a 2.5-mm intersection gap. For small, parasellar lesions, interleaved coronal sections 3 mm in width were obtained.

All MR images were interpreted by a neuroradiologist and were evaluated for the presence, width, extent, and shape (linear or nodular) of enhancing membranes; parenchymal enhancement; parenchymal edema; and intra- and extraaxial blood collections. Patients' charts were reviewed to determine the extent of tumor removal and the type of meningioma encountered (benign, atypical, or malignant).

All but two patients had preoperative MR studies available for review. The timing of postoperative studies is delineated in Table 1.

Results

Histology

Histologic analyses of the meningiomas revealed 17 benign (16 typical, one epithelial), three atypical

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(with necrosis and/or bone invasion), and one malignant tumor. The locations of the lesions are listed in Table 2.

Residual Tumor

The initial postoperative images agreed with the surgical impression of complete tumor removal in 10 cases. In the nine cases in which, according to the operative report, the meningioma was incompletely resected owing to attachment to vital structures, the early MR images showed residual tumor in seven. In these patients, final imaging studies were performed 373, 384, 645, 936, 1061, 1518, and 1534 days after surgery, and none showed an increase in the size of the residual lesion. In two of these cases, the residual lesions became smaller after being stable for 228 days and 563 days. The largest residual lesion measured 3 × 2 × 2 cm and did not change between studies obtained 2 and 1518 days after surgery. Most of the residual lesions measured less than 1 cm. All these patients had benign meningiomas. The remaining two patients with a surgical residuum had no identifiable tumor on early MR studies or on the final studies, performed 215 and 395 days after surgery. One of these lesions was benign and the other malignant.

In two patients, complete tumor removal was described in the operative report, but the early MR images showed a small enhancing mass at the surgical site. Both had benign meningiomas. One lesion did not change between studies performed 3 and 1460 days after surgery while the other resolved between 27 and 381 days after surgery and may simply have been an unusual focus of postoperative enhancement.

Follow-up MR studies revealed recurrent tumor in four patients, of which three were subsequently verified surgically. The recurrences were detected on studies performed 442, 491, 787, and 1477 days after surgery. In these cases, no surgical or MR residuum was detected initially but all recurred at resection sites. Two of these lesions were benign and two were atypical meningiomas.

TABLE 1: Performance of postoperative studies

Time Intervals of Postoperative Studies	Number of Patients Studied	Range, d	Average, d
First week	21	1–5	3.2
3 weeks to 2 months*	16	21–61	36
2 to 6 months	2	103 and 154	
3 months to 1 year	15	186–281	239
1 to 1.5 years	12	371–524	439
1.5 to 2 years	8	563–731	656
2 to 3 years	6	787–1061	919
>3 years	6	1183–1534	1308

* Although the protocol called for the second postoperative study to be performed between 4 and 8 weeks after surgery, for the patients' convenience, four patients had the second postoperative study 21 to 28 days after surgery.

Membrane Enhancement

All 21 of the immediate postoperative studies revealed thin, linear enhancement between the skull and brain, parallel to the calvaria, in the usual position of the dura. It encompassed at least an entire lobe in 12 patients. The membranes measured an average of 3.2 mm (range, 1.5 to 5.5 mm) in greatest

TABLE 2: Surgical results

Case	Age, y/Sex	Type of Tumor	Location	Residuum at Surgery	Residuum at MR	Recurrence*
1	38/F	Aggressive	L frontal	0	0	···
2	32/F	Benign-typical	R petrous apex	0	+	···
3	65/F	Benign-typical	R cerebellopontine angle	0	0	···
4	51/F	Benign-typical	R frontal	0	0	···
5	70/F	Benign-typical	Tuberculum sellae	+	+	···
6	68/M	Benign-epithelial	Suprasellar	+	+	···
7	59/M	Benign-typical	L sphenoid wing	+	+	···
8	39/F	Benign-typical	R middle cranial fossa	+	+	···
9	59/M	Benign-typical	R frontotemporal	0	0	···
10	34/M	Benign-typical	Foramen magnum	0	0	···
11	43/F	Benign-typical	L temporoparietal	0	0	···
12	65/F	Benign-typical	R sphenoid wing	+	+	···
13	66/M	Benign-typical	R parietal	0	0	195
14	65/M	Benign-typical	L frontal	0	0	767
15	65/F	Benign-typical	R sphenoid wing	+	+	···
16	69/M	Benign-typical	L anterior clinoid	+	+	···
17	69/F	Malignant	R frontal	+	0	···
18	62/F	Atypical	R frontoparietal	0	0	442
19	74/M	Benign-typical	Olfactory groove	0	+	···
20	45/M	Benign-typical	L parietooccipital	+	0	···
21	39/M	Atypical	Planum sphenoidale	0	0	1477

* The figures indicate the number of days after surgery that elapsed before the recurrent tumor was detected at imaging.

width (Table 3) and the band of enhancement was smooth, uniform in width, and without nodularity. In several cases, the enhancement was discontinuous (Fig 1), but in many it formed a sheet about a lobe or hemisphere and was not confined to the craniotomy flap.

At the time of the second study, 3 to 8 weeks after surgery, 13 of the 16 patients had an increase in membrane thickness to an average of 5.2 mm (range, 2 to 7 mm; range of increase, 1 to 4 mm), but the enhancement remained smooth. Thickening of membrane enhancement at this time exaggerated the size of the residual tumor in a few cases (Fig 2). At the time of the second study, the extent of membrane enhancement had decreased in 12 of the 16 patients and was located primarily posterior to or adjacent to the craniotomy flap.

TABLE 3: Width of membrane enhancement versus time

Days after Surgery	Average Membrane Width, mm (range)
1 to 5	3.2 (1.5–5.5)
21 to 62	5.2 (2–7)
103 and 154	5.5 (5–6)
182 to 365	3.6 (2–7)
366 to 547	3.3 (2–5)
>547	2.8 (2–5)

At 6 months to 1 year after surgery, the membrane enhancement had decreased in width in seven patients and had resolved in four. In only one case did the enhancement increase in width, and a recurrent meningioma was subsequently identified at this site on a study obtained 491 days after surgery. On studies performed more than 1 year after surgery, the membrane enhancement resolved in two additional patients. Eleven patients had persistent membrane enhancement on examinations obtained 370 to 1534 days, respectively, after surgery. In one patient, the

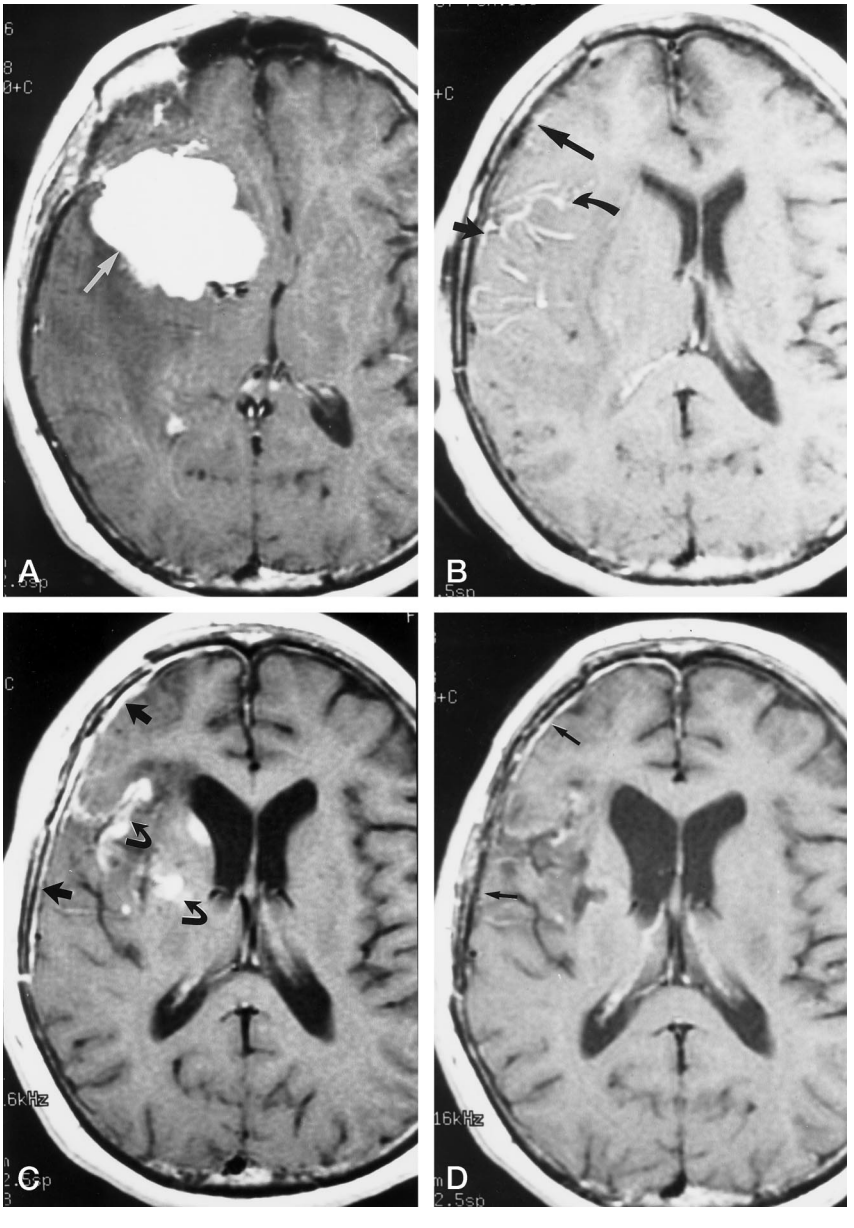

FIG 1. Changes in membrane enhancement in a 65-year-old woman with headaches. At surgery, a benign meningioma involving the right cavernous sinus and sphenoid wing was incompletely resected. All images were obtained after contrast administration.

A, Preoperative image (450/16/2) shows large right sphenoid wing meningioma (*arrow*).

B, Day 1 postoperative image (450/16/2) shows thin, intermittent, enhancing membrane (*straight arrows*) and enhancement of sylvian vessels due to infarcts (*curved arrow*).

C, Day 38 postoperative image (450/16/2) shows thickening and confluence of the membrane enhancement (*straight arrows*). Note enhancing basal ganglia and insular cortex infarcts (*curved arrows*).

D, Day 228 postoperative image (500/19/2) shows decrease in thickness of the membrane enhancement (*arrows*).

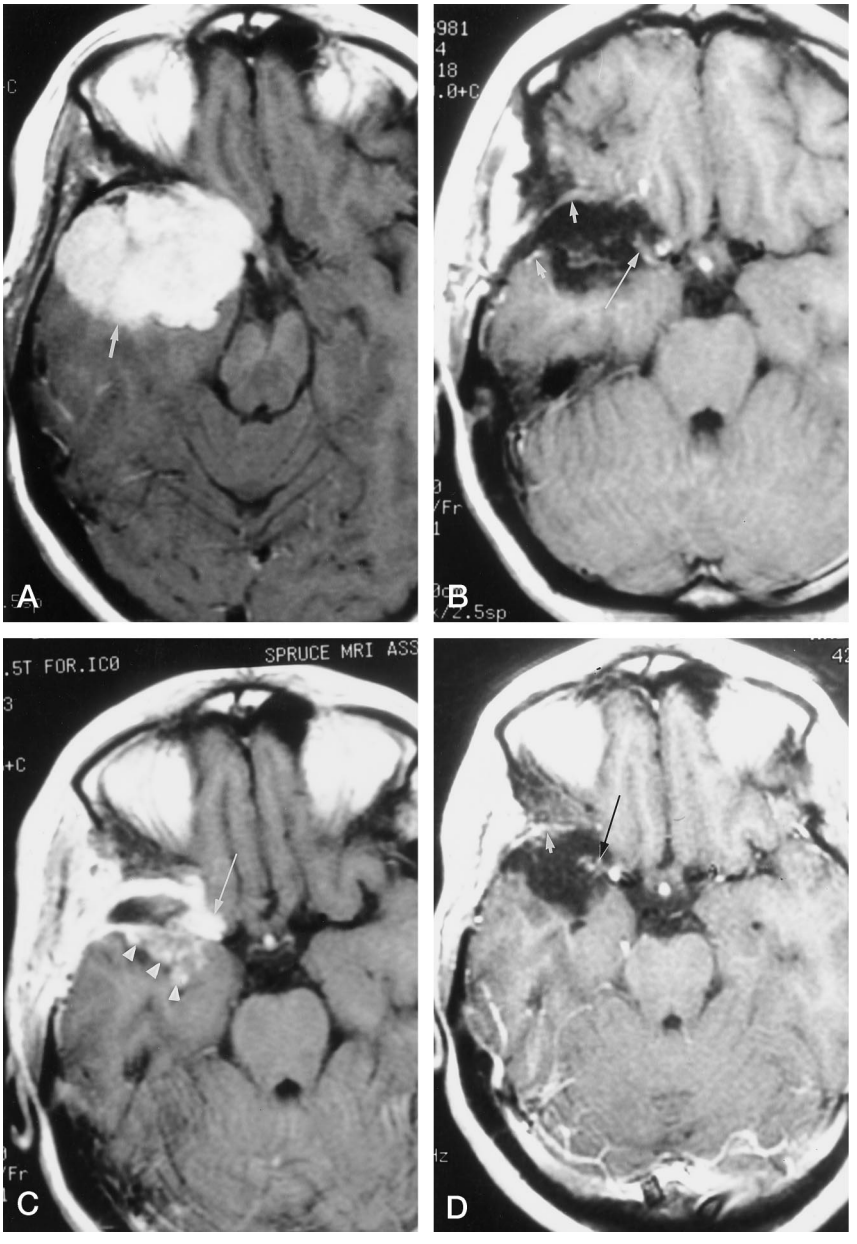

FIG 2. Membrane enhancement exaggerating residual tumor in a 39-year-old woman with headaches. At surgery, a benign sphenoid wing meningioma was removed but tumor was left adjacent to the right middle cerebral artery. All images were obtained after injection of contrast material.

A, Preoperative image (450/16/2) shows large, right-sided sphenoid wing meningioma (*arrow*).

B, Day 4 postoperative image (450/16/2) shows enhancement adjacent to the right middle cerebral artery (*long arrow*), where tumor could not be removed. Also present is thin, intermittent dural enhancement (*short arrows*).

C, Day 31 postoperative image (450/16/2) shows the dural enhancement and the enhancement at the site of the residual tumor (*arrow*) has thickened, exaggerating the apparent size of the residual tumor. Enhancement at the superior margin of the tumor bed has also appeared (*arrowheads*).

D, Day 1061 postoperative image (400/11/2) still shows thin dural enhancement (*short arrow*). Enhancement at the site of the residual tumor detected on Figure 2B has returned to its previous size; its similar appearance (*long arrow*) suggests persistence of residual meningioma.

membrane enhancement resolved between postoperative days 563 and 1061.

Dural tails were identified preoperatively in eight patients. In most cases, the sites of the tails were obscured by postoperative membrane enhancement on the first or second postoperative images (Fig 3). The tails resolved in six cases. In one patient, a linear area of enhancement remained unchanged at the prior site of the tail 444 days after surgery. In the remaining case, the presence or absence of the tail could not be determined, as osteomyelitis of the craniotomy flap developed and the bone was replaced by a metallic mesh that obscured local detail. In no case did a recurrent tumor arise in a dural tail.

Extraaxial Fluid Collections

All but one patient had extraaxial fluid collections at the surgical sites on the immediate postoperative studies. Five collections were of CSF intensity on all sequences. In nine cases, the collections appeared to be mixtures of blood and fluid, and in six cases, only blood intensity was identified. The presence of persistent membrane enhancement corresponded to the type of fluid in the extraaxial space. In the cases of CSF collections, two patients had persistent membrane enhancement and two did not. In the remaining patient, a recurrence precluded identification of a persistent membrane. In those patients who had a blood and CSF collection, six of nine had persistent membrane enhancement. In those patients with blood alone, the membrane enhancement persisted in four cases, resolved in one, and was obscured by a metallic mesh in one. In the 14 patients in whom blood was found in the fluid, 10 had persistent membrane enhancement.

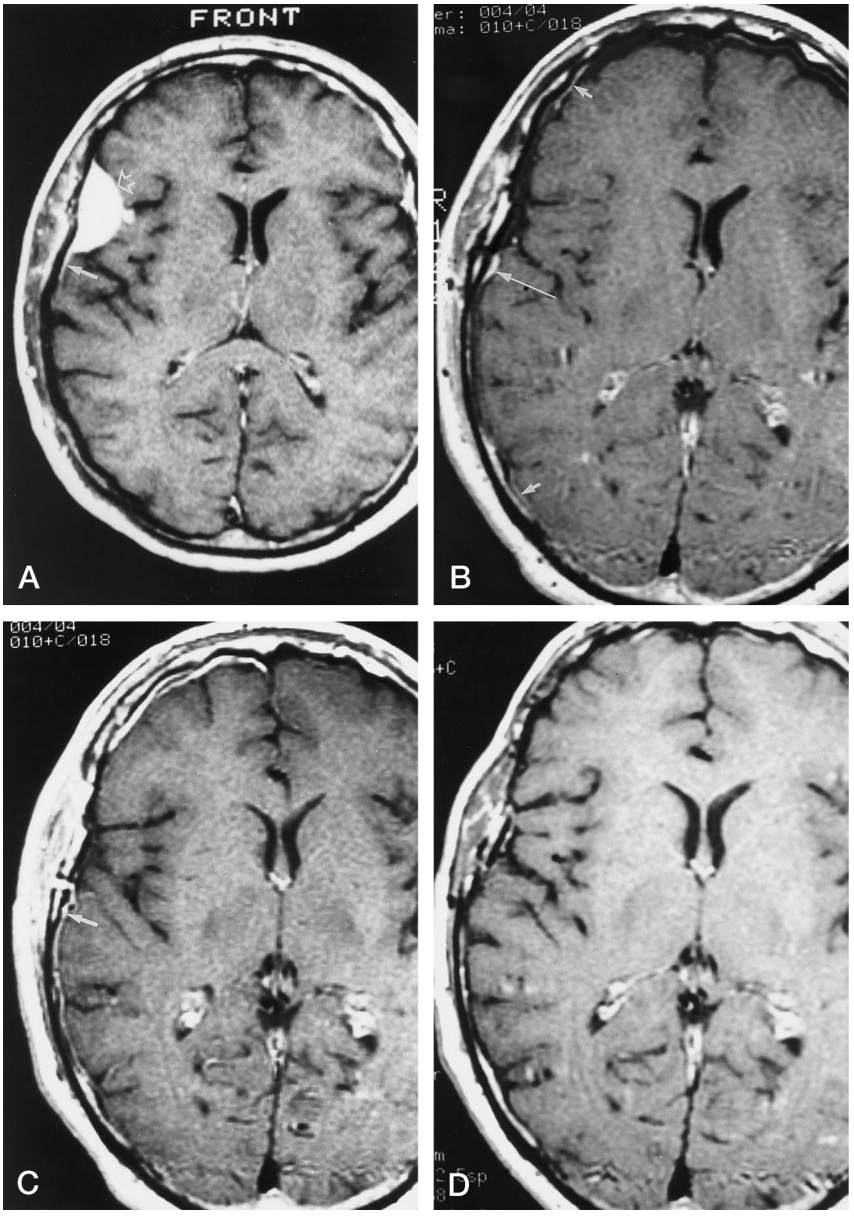

FIG 3. Dural tail in a 59-year-old man with intermittent headaches and vertigo for several years. A benign meningioma was completely resected. All images were obtained after injection of contrast material.

A, Preoperative image (600/20/1) shows right frontal parasylvian meningioma (*open arrow*) with a posterior dural tail (*solid arrow*).

B, Day 5 postoperative image (450/16/2) shows the meningioma has been resected but the dural tail (*long arrow*) persists. The postoperative membrane enhancement is thin and intermittent (*short arrows*).

C, Day 26 postoperative image (450/16/2) shows the dural tail (*arrow*) obscured by thickening of the membrane enhancement.

D, Day 231 postoperative image (450/16/2) shows the dural tail is no longer visible and the membrane enhancement has largely resolved.

Parenchymal Blood

In eight cases, foci of parenchymal blood were identified at the surgical sites. Three of these patients had persistent enhancing membranes; in three, they were not identified; and of the remaining two cases, a recurrence obscured the membrane in one and a mesh obscured it in the other.

Parenchymal Enhancement

On the immediate postoperative studies of 12 patients, thin, serpiginous structures appeared at the surgical site, in the brain parenchyma, only on the contrast-enhanced images (Fig 4). One of these patients had a gradient-echo sequence designed to demonstrate flow, but no flow was identified in the serpiginous structures. The structures had an appearance suggesting slow flow in vessels and did not have signal intensities of clotted blood on any sequence. Only two patients had persistence of the finding on subsequent imaging studies, and in these cases, the enhancement became thicker on the 3- to 8-week images and was apparently related to enhancement in areas of parenchymal damage.

In two patients, enhancing vessels, presumably related to slow flow due to the presence of a large meningioma, were seen on the preoperative studies; these decreased in size on subsequent studies, but the enhancing vessels were large and confined to a vascular distribution, unlike the small, serpiginous structures.

Eight patients had no serpiginous enhancement at the surgical site. Of the patients with such enhancement, nine had contusions, infarcts, or hematomas at the surgical site. Of those without serpiginous enhancement, only three had similar findings.

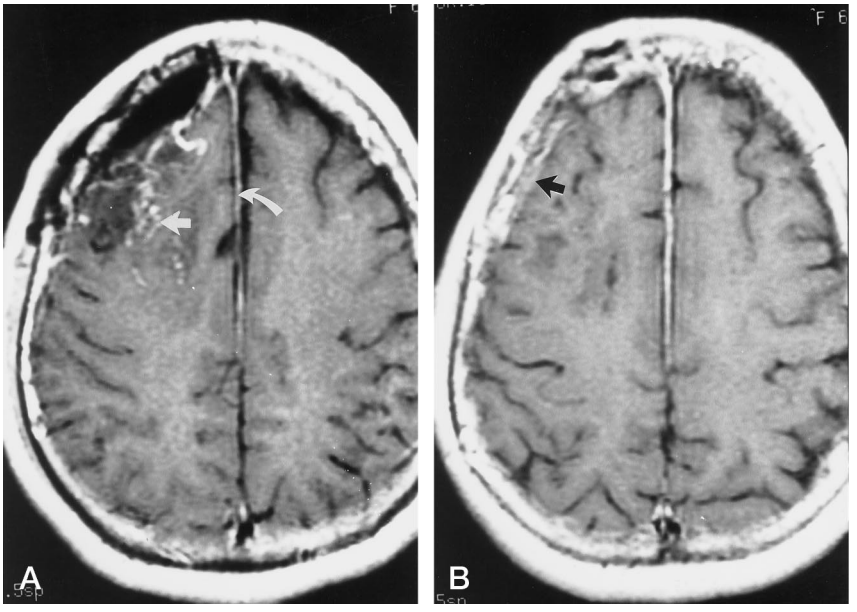

FIG 4. Persistent tumor vessels in a 69-year-old woman with headaches, memory deficits, and visual dimming. A preoperative study (not shown) revealed a 6 × 6 × 5-cm right frontal convexity meningioma. A malignant meningioma was resected, leaving only minimal tumor. All images were obtained after injection of contrast material.

A, Day 2 postoperative image (450/16/2) shows thin, serpiginous foci of enhancement in the right frontal parenchyma (*straight arrow*) beneath a craniotomy flap, and normal enhancement of the falx (*curved arrow*).

B, Day 54 postoperative image (450/16/2) shows the serpiginous foci of enhancement have resolved. The falx enhancement has thickened, and peripheral membrane enhancement has appeared (*arrow*).

Edema

Ten immediate postoperative studies showed parenchymal edema at the prior sites of edema about the meningiomas. The edema had not changed since the preoperative study in seven patients and had decreased in three. The edema subsequently resolved in three patients. In six cases, the edema decreased on subsequent studies, with most of the change in size occurring between the first postoperative study and that performed 3 to 8 weeks after surgery. In these cases, the edema evolved into an appearance consistent with gliosis. In the final case, a recurrence with surrounding edema appeared on the second postoperative study and the fate of the immediate postoperative edema could not be determined. In the nine patients without an early recurrence, four had no residual tumor at surgery. In nine cases, no edema was associated with the meningiomas on preoperative examinations despite sizes up to 6 cm. In two cases, edema could not be evaluated, as no long-TR preoperative images were available.

Discussion

Meningiomas constitute 13% to 19% of all primary intracranial tumors. They arise from arachnoid cells in the dura, pia, or arachnoid membranes but usually present with an attachment to the dura. They have a propensity to infiltrate and extend along the dura, but they remain extraaxial unless histologically atypical or malignant (3).

The meninges do not have a blood-brain barrier but are relatively avascular. They normally enhance as thin, intermittently interrupted lines (4). The enhancement is most marked about the anterior aspects of the temporal lobes and in the parasagittal region, including the falx (5). Immediately after surgical violation of the dura, the bleeding normally encountered initiates a local inflammatory response (2, 5). Biopsy samples of the enhancing material obtained within a few days after surgery show vasodilatation and reactive changes (6). In a canine model, Jeffries et al (7) found that at 1 week after surgery, the dura at the surgical site is partly covered by lysed red blood cells, neutrophils, macrophages, and fibroblasts. Such a reaction is sufficient to produce visible dural enhancement 24 hours after surgery (1, 6).

Our study is in agreement with the above findings in that meningeal enhancement was seen on the two studies of patients examined within 1 day after surgery. Early (within 5 days of surgery) enhancement is thin (2 to 6 mm in the literature and an average of 3.2 mm in our study) and frequently extends well beyond the surgical site (4, 5). Our findings show that diffuse enhancement is more likely to be identified early after surgery, probably reflecting the extent of bleeding related to the procedure.

By 3 weeks after surgery, in an animal model, dural histology shows an increase in vascular granulation tissue (7). The thickening of the dura at 3 to 8 weeks after surgery in our study most likely reflects enlargement of the granulation tissue as the reactive changes mature. We also found that the enhancement at this time becomes more focal and confined to the surgical site, suggesting resolution of reactive changes related to the presence of blood alone. The thickness of the enhancement at this time, however, is in the size range described by other authors as being suggestive of residual tumor (8, 9), although membrane enhancement due to surgery is usually uniform in thickness while residual tumor is usually nodular. We found that the thickness of the membranes at this time obscured or exaggerated the nodular shape of small foci of residual tumor.

By 6 months after surgery, the dural enhancement thins, probably as a result of replacement of vascularized granulation tissue by collagen (7). In many cases, some granulation tissue remains, which accounts for

the observation of prolonged enhancement and thickening of the dura even years after surgery (1, 2, 4, 8, 9). In our study, the persistence of membrane enhancement was more common when extraaxial blood collections were present after surgery, suggesting that the physiological changes involved in resolving a blood collection were related to development of more persistent granulation tissue. In one of our patients, membrane enhancement persisted for 2 years after surgery before resolving, suggesting that membrane enhancement may be a dynamic process for prolonged periods of time.

Several early postoperative MR studies showed residual dural tails, which resolved on examinations performed more than 1 month after surgery. The resolution of dural tails could be due to removal of the blood supply to a small focus of residual meningioma (10). Other studies have suggested that dural tails represent a reactive change (11, 12) and would be expected to resolve after resection of the meningioma. In this study, no recurrent tumor arose in a dural tail; however, no attempt was made to locate dural tails at surgery for histologic analysis.

Meningiomas are vascular lesions largely supplied by external carotid branches. The vessels supplying the lesion are occluded in the surgical bed during the procedure but are unlikely to be ligated at their origins. The thin, serpiginous, enhancing structures observed at the surgical site shortly after the procedure probably represent slow flow, with increased vascular resistance (13), in small arteries that previously fed the meningioma. The presence of these thin, short vessels does not appear to reflect permanent ischemic change because gliosis corresponding to the distribution of the enhancing structures was not observed, although there may be a relationship between some of the enhancing structures and the presence of parenchymal damage, as evidence of damage was present more frequently on studies with the serpiginous structures than on those without them. It might be speculated that the surgical necessity to occlude multiple small bleeding vessels is associated with a greater degree of brain manipulation during the procedure, resulting in the apparent parenchymal damage. Since these findings are present only on early postoperative MR studies, they do not represent residual tumor but instead might obscure a small focus of residual tumor, particularly in the case of a malignant meningioma that may have invaded the brain parenchyma.

The low signal on short-TR images that increases in intensity on long-TR images and is suggestive of edema at the surgical site after removal of a meningioma may be due to a variety of factors. In most cases in which edema surrounds a meningioma preoperatively, it will be visible unchanged or only slightly decreased in extent on early postoperative images. The edema in the brain is of uncertain origin; because meningiomas are extraaxial lesions and in most cases associated with edema, no brain invasion is identified. The edema represents an apparent response to the tumor that is not associated with symptoms and that resolves spontaneously. If the brain has been damaged during the surgical procedure, either from manipulation or infarction, then at least a portion of the detectable edema will be due to the damage and will endure beyond the 3- to 8-week postoperative period and resolve, eventually, as gliosis. The signal intensity of the edema related to the meningioma and that due to manipulative damage or infarction are similar on MR images.

Recurrent meningiomas in this series were not associated with MR-detectable residua on early postoperative images. The nidus of the recurrence, in each case, was either too small to be detected by MR imaging or it was obscured by membrane or dural sinus enhancement. Such residua may persist as nests in dura, bone, or venous sinuses (3).

The lack of growth of residual meningiomas in this series most likely reflects the slow growth of many meningiomas and the inadequate follow-up periods. The frequency of clinically detected recurrent meningiomas is 10% to 23% (3). Mirimanoff et al (14) found that after gross total resection of a benign meningioma, 7% of patients had clinically apparent recurrences after 5 years, 20% after 10 years, and 32% after 15 years, while for incompletely resected meningiomas, the recurrence rate increased to 25% after 5 years, 50% after 10 years, and 85% after 15 years. The rapidity of recurrence is also dependent on tumor type. Jaaskelainen et al (15) reported a 5-year recurrence rate of 3% for benign meningiomas, 38% for atypical meningiomas, and 78% for anaplastic lesions. The median time to recurrence decreased from 7.5 years for benign lesions to 3.5 years for malignant meningiomas. In our series, the rate of reappearance of a meningioma detected on an imaging study after an initially clear image was 19% (four patients) but this figure includes two atypical meningiomas. The detection of two recurrences of benign meningiomas in 21 patients is probably related to the small number of patients in the series and to the frequency of follow-up MR studies, which revealed recurrences before the appearance of clinical signs. Previous large series (14, 15) used clinical criteria to detect recurrences. The long-term recurrence rate in this series awaits subsequent follow-up.

Conclusion

Our study shows that residual meningiomas are optimally detected within 5 days of surgery. For the first 5 postoperative days, membrane enhancement related to the procedure remains thin, although it may be extensive. By 3 to 8 weeks after surgery, the membrane thickens and might obscure a small focus of residual tumor or might give the impression of a residual tumor where none exists, and imaging during this period is not recommended. The persistence of membrane enhancement on long-term follow-up studies appears to be related, at least in part, to the presence of blood in postoperative extraaxial fluid collections. Other factors influencing the appearance of the postoperative bed include thin, serpiginous foci

of enhancement at the surgical site, probably due to slow flow in feeding vessels, which might obscure residual meningioma that has invaded the brain, and edema on early postoperative studies that is unchanged from preoperative images, is frequently identified, and is not a predictor of residual tumor.

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