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Malignant Meningiomas: CT and Histologic Criteria, Including a New CT Sign

Paul F. J. New¹
 John R. Hesselink¹
 C. Phillip O'Carroll²
 George M. Kleinman³

Histologic features that could be correlated with malignancy were assessed by reviewing the microscopic slides of 167 meningiomas. Six tumors had shown two or more recurrences. In three having three or more recurrences, the number of mitoses counted under high power was higher than in those meningiomas showing clinically benign behavior. The radiologic and histologic features of seven meningiomas showing malignant clinical behavior and/or malignant histologic features were also evaluated and correlated. On computed tomography (CT), most of the malignant meningiomas were moderately hyperdense before contrast enhancement, but showed no or minimal calcification. Marked perifocal edema was common. Indistinct tumor margins or, occasionally, deeply extending fringes of tumor interdigitating with brain substance, marked bone destruction, or prominent low density necrosis within the tumor were present in some cases. The presence of a prominent pannus of tumor, extending well away from the globoid mass, termed "mushrooming," is described for the first time and seems to be the most useful correlate of histologic or clinical malignancy. This sign occurred in five of the seven cases and was absent in about 250 benign meningiomas reviewed. It was visible only at surgery in one additional case.

Meningiomas are common intracranial tumors. They are generally regarded as benign neoplasms, but recurrence is frequent [1-4]. The histology of malignant meningiomas has been studied extensively, without uniform agreement. Some investigators have concluded that there is no good correlation between the histologic features and aggressiveness or frankly malignant behavior of these tumors [1, 5, 6]. A majority opinion, however, is that certain microscopic features do indeed provide a useful forecast of a higher recurrence rate and malignant behavior, which may include cerebral invasion, metastasis beyond the central nervous system, and seeding through the cerebrospinal fluid pathways [7-8].

Although the common [19-23] and atypical [24-26] CT features of intracranial meningiomas have been reported extensively, there has been little attempt to identify CT correlates of meningiomas that have exhibited biologic and histologic features indicative of malignant behavior. Vassilouthis and Ambrose [23] reported the CT characteristics of 16 cases of meningioma in which the histology revealed features of aggressiveness, such as fairly frequent mitoses, focal necrosis, or invasion of the brain substance, as part of a study of 102 patients with meningiomas. Their data revealed CT appearances in certain tumor types that were indicative of aggressive characteristics.

Our report attempts, for the first time, to quantitate the frequency of mitoses in meningiomas exhibiting aggressive or frankly malignant behavior and to correlate this with the radiologic (primarily CT) features of these tumors, comparing the appearances with those of benign meningiomas. We document, also apparently for the first time, a CT sign that may be extremely useful in forecasting malignant behavior in meningiomas. Practical considerations regarding management of meningiomas exhibiting histologic and radiologic features indicative of potential malignancy are also discussed.

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¹ Department of Radiology, Harvard Medical School, Massachusetts General Hospital, Boston, MA 02114. Present address: Department of Neurology, Mayo Clinic and Foundation, Rochester, MN 55901.

² Department of Neurology, Harvard Medical School, Massachusetts General Hospital, Boston, MA 02114. Present address: Department of Neurology, Mayo Clinic and Foundation, Rochester, MN 55901.

³ Department of Pathology, Harvard School, Massachusetts General Hospital, Boston, MA 02114. Present address: Department of Pathology, Tufts-New England Medical Center, Boston, MA 02111.

Materials and Methods

Pathology

The histologic slides of 167 patients with meningothelial meningiomas were reviewed. The tumors recurred in 22 (13.2%) patients. Sixteen tumors recurred once, three recurred two or more times, and three recurred three or more times. One showed transformation to anaplastic sarcoma, and one had systemic (extra-CNS) metastases.

The supratentorial, nonbasal meningiomas, with three or more recurrences, were regarded as exemplifying clinical and biologic malignancy and their histologic features were taken to represent those most useful in determining criteria of such behavior. The histologic features of these cases were compared with those of 145 meningiomas that did not recur.

Radiology

During the 7 years, 1973–1980, that CT scanning was available, about 250 cases of nonbasal supratentorial meningioma were scanned here or elsewhere and were surgically proven at this hospital. These cases represent the background CT material of our study. There were seven cases of supratentorial nonbasal meningioma that were identified by their histopathologic characteristics as being frankly malignant or having a high potential for malignant behavior, and which had preoperative CT scans at this hospital. Two of the seven cases were also in the pathological review series (cases 4 and 6). Five cases did not qualify for inclusion in *both* series, either because there was no preoperative scan, the patient having had the original operation before CT scanning was available, or, at the time of completion of the histologic series, the patient had not developed a recurrence of tumor. In addition, the patient who had widespread extra-CNS metastases (innumerable vertebral meningioma metastases and multiple huge bilateral pulmonary metastatic meningiomas) died before the motion-degraded noncontrast cranial CT scans obtained at another hospital could be repeated.

Results

Pathology

The three frankly malignant supratentorial nonbasal meningiomas all had unusually high mitotic counts, often associated with nuclear pleomorphism, with nuclei of variable size, shape, and staining characteristics, and foci of necrosis. The slides of these meningiomas were first surveyed at low power ($\times 100$) and regions of the tumor showing the highest frequency of mitoses were then examined under high power ($\times 400$). Mitotic counts were then obtained in 50 consecutive high power fields and an average mitotic count was obtained. In these malignant tumors, mitotic indices were found to be two to three mitoses per 10 high power fields or greater. In the 145 meningiomas showing benign clinical behavior, none showed a mitotic index of greater than one to two mitoses per 10 high power fields. The large majority of the tumors showed an average of only one to two mitoses per 50 high power fields. Nuclear pleomorphism and necrosis were absent or relatively inconspicuous in the benign group, but common in the malignant tumors.

Radiology

The seven malignant meningiomas in the radiologic series included a 25-year-old man with neurofibromatosis, bilateral

acoustic neuromas, and a right parietal meningioma. He had additional small nodular intracranial tumors, presumed to be meningiomas, but without surgical proof. The other six patients were aged 59–73 years (average, 67.5 years). Three of the meningiomas were of the syncytial type and four were transitional. Three were very large, two were large, and two moderate in size. Male-to-female ratio was 4:3, a reversal of the usual ratio in meningiomas. This reversal has been noted by others reporting on malignant meningiomas [9, 12]. The duration of symptoms before diagnosis ranged from 5 to 18 months (average, 6 months).

Recurrence was documented in the three patients. Case 2 had multiple large recurrent masses 15 months after resection. Case 4 had a massive recurrent tumor at 24 months after resection and died of her tumor 30 months after the original operation. Case 6 died 5 months after tumor resection. The other four cases had no known recurrence at the time of clinical follow-up, 6–19 months after tumor resection.

High mitotic indices were documented in five cases. Mitoses were rare in case 2, but the tumor had a papillary structure, a pattern notorious for a high incidence of malignant behavior [16]. In case 5, only occasional mitoses were found, but the tumor was extensively necrotic and representative sections were probably not obtained. Data regarding recurrence and mitotic indices in the seven cases are given in table 1.

Analysis of the preoperative CT studies of the seven cases are summarized in table 2. One case had *bone destruction*. *Density on plain scan*: Six of the seven tumors were moderately hyperdense. No tumor was hypodense. *Tumor margin with contrast enhancement*: One case showed very prominent irregular fringelike extensions projecting deeply from the cerebral surface of the tumor. This was found to be due to invasion of the brain. In one other case, a less marked irregular projection of the cerebral aspect of the tumor suggested the possibility of invasion of brain, but the poor spatial resolution of the scans (case 6, 80×80 matrix) prevented satisfactory evaluation of this feature. In the other five cases, the tumor margins were relatively smooth and well defined. *Low density areas*: In four of the seven cases, relatively low density areas were present within the tumors, but this feature was striking in only one case, which showed a large central, very low density area after contrast enhancement, indicative of marked necrosis (case 5).

Calcifications: A single small calcific nodule was identified in one case and a tiny fleck of calcification in another. The other five cases showed no visible calcification. *Edema*: There was marked perifocal edema in six of the seven cases. *Mushrooming pattern*: This feature, defined as pannus extension 2.5 or more centimeters long, extending over the cerebral surface from one or more aspects of the globoid part of the tumor, was found in five of the seven cases. In one case, the entire tumor formed a very thick pannus over the cerebral surface, with no separate globoid component. This was the tumor that showed prominent deep fringe extensions (case 4). In a case of high parietal convexity meningioma with partial volume averaging of overlying bone (case 7), no mushroom extension was visible on the CT scan but a thin pannus of tumor was noted at surgery to

TABLE 1: Seven Patients with Histologically Malignant Meningiomas

Case No. (age, gender)	Presentation	Tumor Site, Size	Surgery	Histology	Mitoses	
					Per 10 High Power Fields	Recurrence
1 (73, M)	Progressive dementia, aphasia 1-2 years	Left frontal, large	Grossly total excision	Atypical transitional meningioma; frequent mitoses, foci of necrosis	3-4	0 at 19 months
2 (64, F)	2-3 months progressive irritability, left lower limb weakness and left body cortical sensory loss	Right frontal, very large	Excision very difficult due to poor plane of demarcation from brain	Syncytial meningioma, with papillary structure in some areas; moderate cellularity and nuclear and pleomorphism; rare mitoses	Rare, but papillary structures	Multiple at 15 months
3 (59, M)	Personality changes, seizures and diminishing vision over 2 months	Left frontotemporal, very large	Posterior tumor fragment adherent to middle cerebral branches not removed	Syncytial meningioma; focal pleomorphism; frequent mitoses	3	0 at 12 months
4 (72, F)*	Focal seizures in left face and arm for 6 months; left hemiparesis and later obtundation	Right frontoparietal, very large	Nearly total removal of tumor, with areas of poor demarcation from brain	Syncytial meningioma with frequent mitoses and areas of cerebral infiltration	4-5	Massive at 24 months
5 (65, M)	10 months memory loss; paranoid ideation for 2 weeks	Right frontal, moderately large	Grossly total excision of tumor, with adjacent frontal lobe	Atypical transitional meningioma, with occasional mitoses	Occasional	0 at 13 months
6 (72, F)*	Difficulty completing sentences for 2 weeks, progressing to mutism, poor memory, disorientation	Bifrontal, large	Grossly total excision. (2) operation 2 years later for large recurrence; died 5 months later	Atypical transitional meningioma, hyperchromatic nuclei	3-6	Died at 5 months, no autopsy
7 (25, M)	Neurofibromatosis, visual blurring for 1.5 months, severe papilledema, bilateral acoustic neuromas, two small left supratentorial nodules and large right parietal tumor	Right parietal, moderately large	Grossly total removal of right parietal tumor; thin layer of tumor extended beneath dura outward from bulk of tumor for 3-4 cm	Atypical transitional meningioma; very high mitotic count and large pleomorphic cells	8	0 at 6 months

* Cases included in pathology series.

extend several centimeters from the globoid mass. At the time of making this observation, the neurosurgeon had no knowledge of our study of this phenomenon.

Angiography revealed marked tumor vascularity in three cases (cases 2-4), with indistinct margins of the tumor stain. Interpretation suggested meningosarcoma in case 4. Moderate vascularity was present in case 6 and minimal vascularity in cases 1, 5, and 7. In all the tumors with marked or

moderate vascularity, the stain persisted into the venous phase. In only one case was early venous filling noted. In all seven cases, supply from both dural and cerebral vessels was evident. In cases 2, 3, and 5, cerebral vascular supply predominated. Dural sinus occlusion was noted in cases 2 and 6.

Combining our findings with those of Vassilouthis and Ambrose [23], it is evident that the most useful CT features

TABLE 2: Nonbasal Meningiomas: CT Features Suggesting Malignancy

CT Feature	Massachusetts General Hospital Study, Malignant (n = 7)	Modified from [23]	
		Malignant (n = 16)	Benign (n = 86)
Bone destruction	1	NM	NM
Moderately hyperdense (without)	6	16	52
Approximately isodense (without)	1	0	22
Irregular/indistinct margins or fronds (with)	2	9	6
Prominent necrotic center (with)	1
Low density areas (with)	4	5	6
Tiny calcifications	2
No visible calcification	5	16	62
Marked perifocal edema	6	12	44
Mushrooming pattern:			
From globoid mass	5	NM	NM
With no globoid mass	1	NM	NM
Visible only at surgery	1	NM	NM

Note.—With = with contrast material; without = without contrast material, NM = not mentioned.

in predicting malignant histology and potentially malignant behavior of a meningioma are irregular or indistinct tumor margins, particularly if associated with deeply penetrating fringes of tumor, and a mushrooming pattern of tumor growth (table 2). The latter sign appears to be the more useful, being visible on CT in five of our seven cases and absent in the approximately 250 benign meningiomas reviewed, whereas the former sign is less often observed and may be seen in benign meningiomas, albeit rather infrequently. Case 4 exhibited a large lentiform mass, without a globoid component. This pattern, very similar to a case illustrated by Vassilouthis and Ambrose [23], could be regarded as the ultimate form of "mushrooming."

Low density areas *within* the tumor, particularly when they involve relatively small parts of the tumor, may be seen in benign meningiomas [22, 26], but when striking and extensive should suggest malignant potential. Although the presence of marked perifocal edema seems to be correlated well with aggressive meningiomas, it has been noted that this is commonly seen with benign meningiomas [22, 23, 26]. Features that seem to be strongly correlated with *benignity* are hypodensity on plain scan and the presence of more than minimal tumor calcification.

Obvious lytic or predominately lytic associated bone change, although seldom seen, should raise suspicion of a biologically aggressive tumor [14, 27, 28].

Representative Case Reports

Case 1

A 73-year-old man was admitted with a 1–2 year history of progressive dementia and aphasia. Examination revealed right-left confusion, expressive-receptive aphasia, perseveration, echolalia, and right hyperreflexia. CT scans and angiography revealed a large left frontal mass (fig. 1). A left frontotemporoparietal craniotomy was performed with a grossly total removal of the meningioma. An unusual configuration of tumor was confirmed, with a globoid part bulging deeply into the brain and with a mushrooming extension overlying the cortex. A biopsy from the central part of the mass was

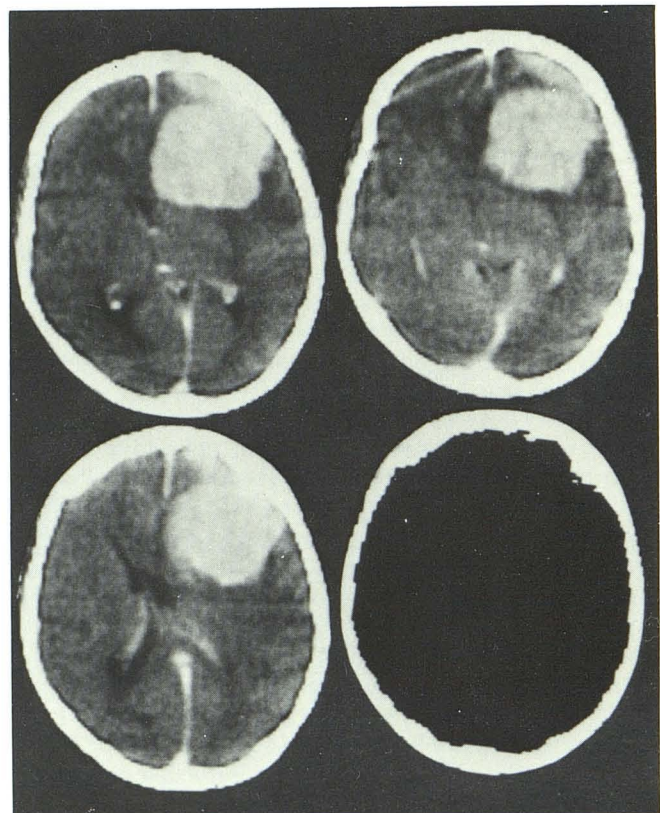
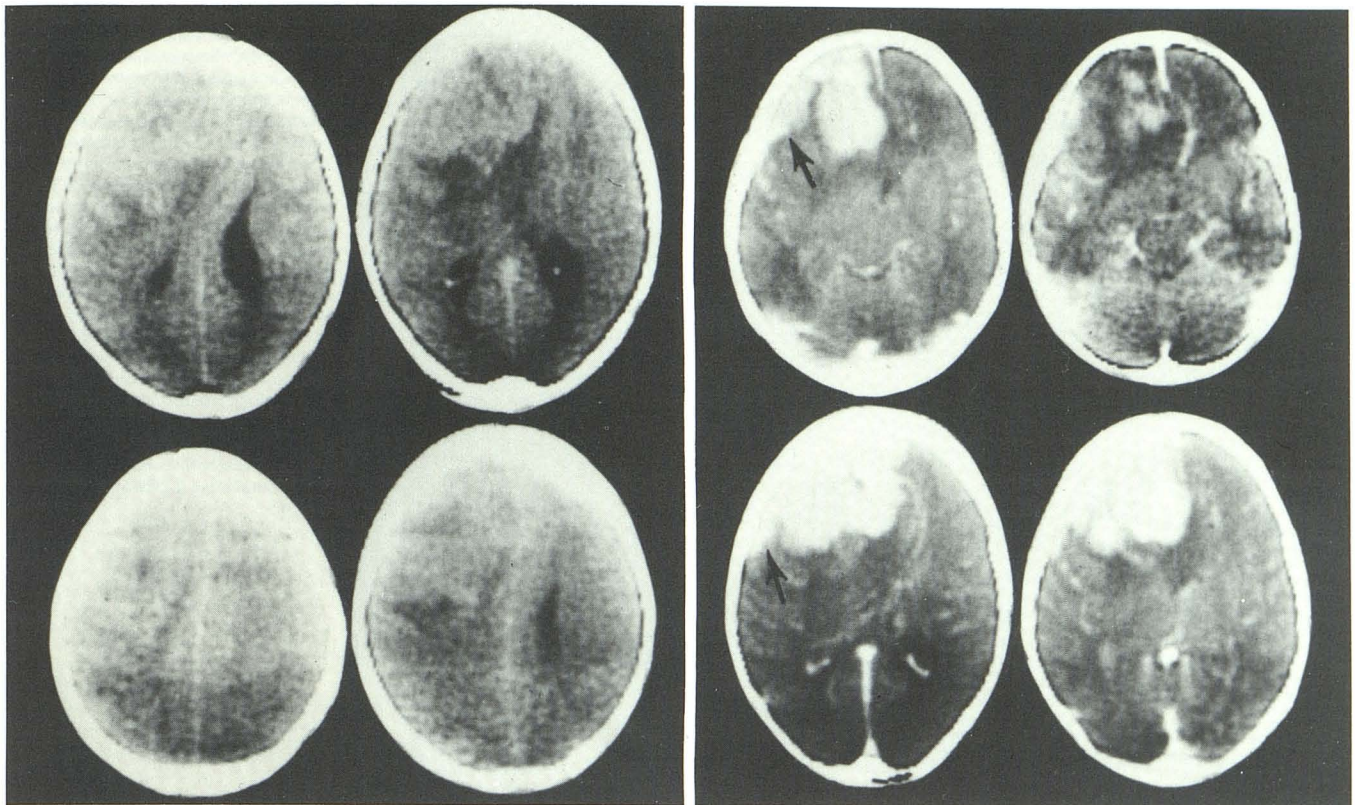


Fig. 1.—Case 1. Malignant frontal meningioma. Contrast-enhanced scan shows moderately dense and quite homogeneous enhancement of tumor; margins slightly lobulated and quite sharply defined. Thick pannus of tumor extends anteriorly over frontal pole almost to midline. Extensive generalized white matter edema in left hemisphere and some edema in anterior part of right frontal lobe. Skull films did not demonstrate bone changes. Bone window settings revealed minor left frontal hyperostosis and tiny subadjacent fleck of calcification. CT diagnosis was meningioma.

interpreted as benign transitional meningioma. A second biopsy of the anterolateral extension of the tumor, where it appeared to infiltrate the brain, was interpreted as atypical meningioma.

Pathology. Atypical transitional meningioma, with frequent mi-



A

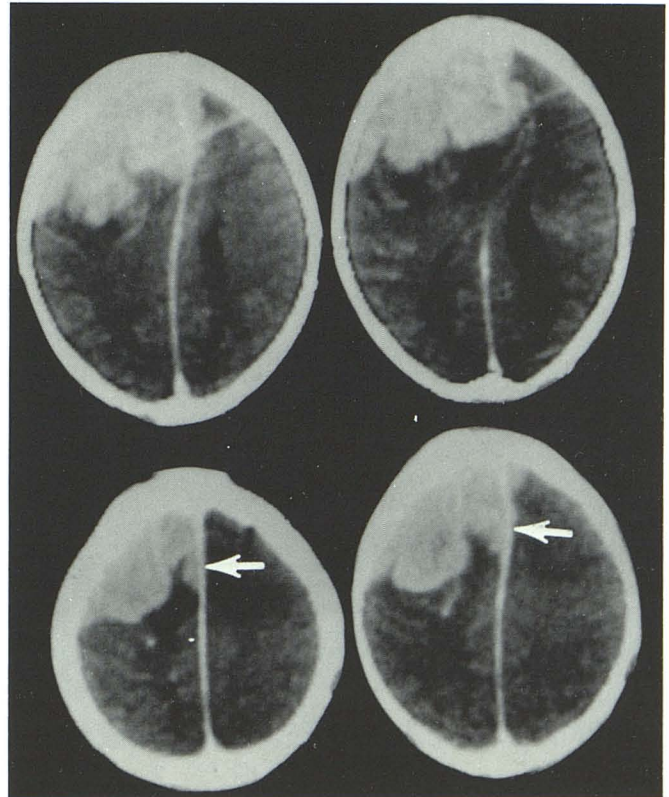
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Fig. 2.—Case 2. Very large malignant meningioma of right frontal convexity, extending through falx to medial left frontal region. **A**, Plain scan. Very large, generally hyperdense mass, containing small hypo- and isodense areas. **B** and **C**, Contrast-enhanced scans. Irregular lobulated but smoothly margined and moderately enhancing tumor. Almost homogeneous enhancement. Mushrooming pattern of tumor growth extends away from globoid mass over cerebral surface at lateral convexity and also along right side of falx (arrows). Very extensive white matter edema in right hemisphere and in left frontal lobe. Bone window setting showed extensive destruction of bone over tumor. Lytic changes were visible but were less striking on plain films. CT diagnosis was meningioma.

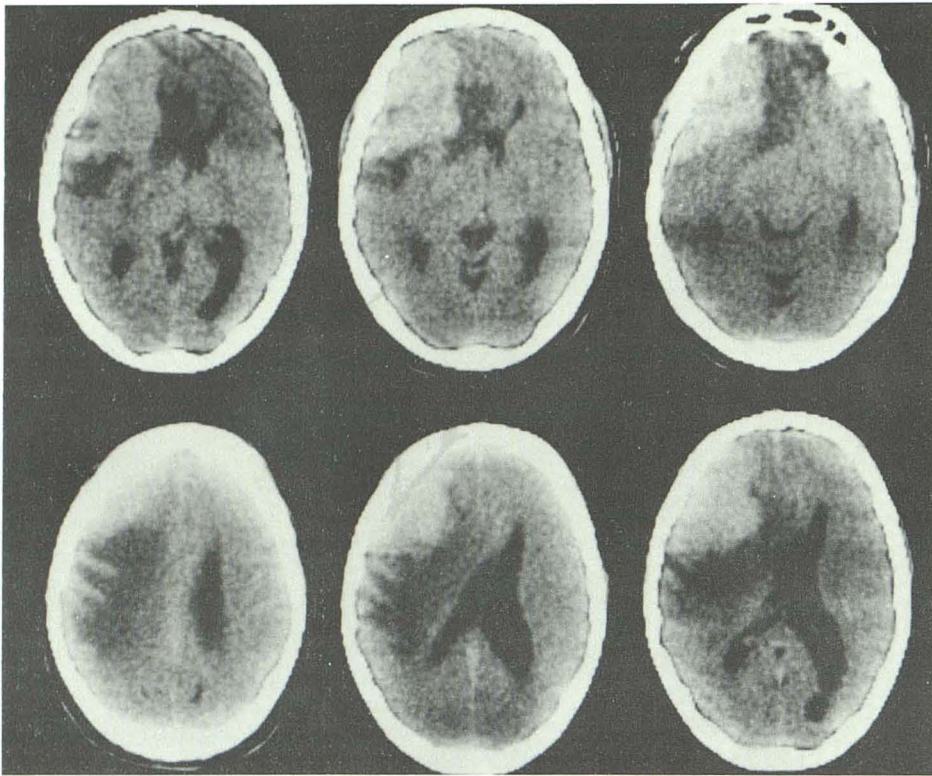
tos, averaging three to four per 10 high power fields. Scattered foci of recent necrosis through the tumor. Lobules of tumor extend into and compress cerebral cortex, which is gliotic and edematous. The frequent mitoses suggest potential for aggressive growth. Follow-up examination 19 months after operation revealed no evidence of tumor recurrence.

Case 2

A 64-year-old woman was admitted because of increasing irritability, confusion, and a tendency to drag the left leg for the previous 3–4 months. Examination showed a left inferior quadrantanopsia, left hemiparesis, left seventh nerve palsy, and cortical sensory loss over the left side of the body. CT and angiography revealed a very large right frontal mass (fig. 2). A right frontoparietal craniotomy revealed a huge, moderately encapsulated, nodular tumor, presenting a very irregular inner surface, with areas of brain invagin-



C



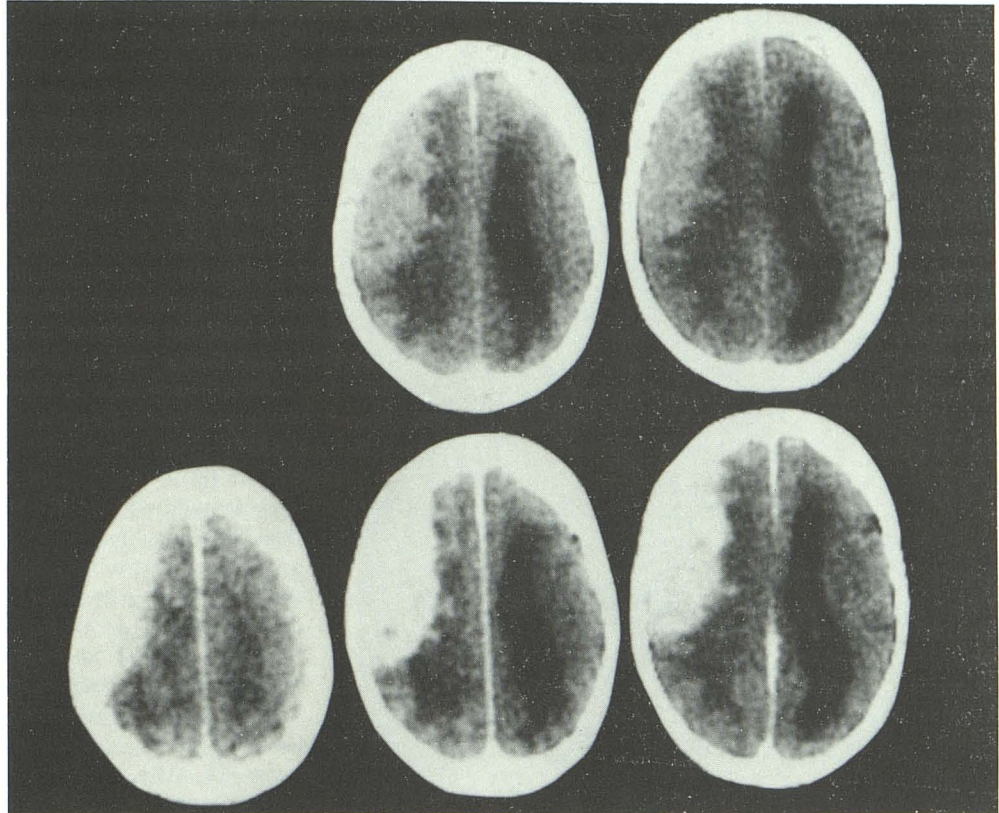
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Fig. 3.—Case 3. Very large, frontal, low-convexity malignant meningioma. **A**, Plain scan. Hyperdense mass (28 H mean density), with peak density of 48 H except at very small nodular calcification near inner table in lateral part of mass. Anterior to this focal calcification is suggestion of minor hyperostosis. **B**, After contrast enhancement. Marked nonhomogeneous increase in density (mean 42 H), with scattered moderate-sized and small areas of lower density within mass, consistent with areas of necrosis. Margins of mass were lobulated, but quite sharply demarcated. Serpiginous area of markedly increased density extends from posterior part of mass, corresponding with large draining vein. Tumor mushrooms over surface of temporal lobe in lower sections. Moderately extensive cerebral edema in left hemisphere extends into medial part of right frontal lobe. CT diagnosis was meningioma.

Fig. 4.—Case 4. Very large frontal and parietal convexity malignant meningioma. **Top row**, Plain scan. Moderately hyperdense mass spreading extensively over frontal and anterior parietal cerebral convexity with three small areas of lesser density. **Bottom row**, Marked, rather generalized contrast enhancement of mass. Small areas of lower density still visible, but not clearly shown at window level of illustration, chosen to bring out internal marginal irregularity of lesion, which showed number of fronds of enhancing tissue extending into outer part of markedly compressed hemisphere. Widespread white matter edema of right cerebral hemisphere. CT (and angiographic) features of this case, particularly appearance of fronds of tumor tissue extending into brain, suggested diagnosis of meningeal sarcoma. At surgery, plane between tumor and brain was unusually difficult to follow in some areas.



ating into the tumor, which projected into the cortex. There was no discrete plane of demarcation, which made removal very difficult.

Pathology. Meningotheliomatous (syncytial) meningioma. Tumor heavily infiltrated by histiocytes and foam cells. In some areas, tumor cells formed papillary structures around fibrovascular stalks. The tumor is moderately cellular and the nuclei moderately pleomorphic, but only rare mitoses are identified. The presence of papillary structures suggests potential for aggressive behavior. Fifteen months after the grossly total tumor removal, CT showed tumor recurrence in the right parietal, parasagittal, and frontal regions. The rapid recurrences strongly suggested malignancy. These tumors were excised and no further tumor recurrence was identified 5 months after the second operation.

Cases 3 and 4

See figures 3 and 4.

Case 5

A 65-year-old man was admitted with a 10 month history of memory loss and paranoid ideation for 2 weeks. No focal neurologic abnormality was identified on examination. CT and angiography demonstrated a moderately large mass in the right frontal region (fig. 5). At right frontal craniotomy, the tumor and adjacent part of the frontal lobe were excised. The tumor was semiencapsulated and loosely adherent to the dura. The tumor and adherent adjacent part of the frontal lobe were excised, leaving surrounding gliotic cerebral tissue.

Pathology. Atypical transitional meningioma with occasional mitoses, suggesting aggressive behavior. There was extensive tumor

necrosis. There was no evidence of recurrent tumor on CT 13 months later.

Case 7

A 25-year-old man was admitted with neurofibromatosis. He had developed episodes of visual blurring for 1½ months. Examination revealed severe bilateral papilledema. CT demonstrated moderate-sized bilateral acoustic neuromas and two very small superficial left frontal nodular masses. In addition, there was a moderate-sized right superior parietal mass (fig. 6). Angiography showed a right parietal mass effect and a slightly vascular tumor. A right parietooccipital craniotomy was performed. Slight hyperostosis involving the inner table was noted at surgery (not visible on radiologic studies). The tumor involved the lateral wall of the sagittal sinus. A grossly total removal was obtained. A thin layer of tumor extended beneath the dura outward from the bulk of the tumor for 3–4 cm. This was not visible on CT, probably due to the thinness of the mushrooming component and volume averaging with bone. No coronal sections were obtained.

Pathology. Atypical transitional meningioma. Frequent mitoses in all sections, with an average count of eight mitoses per 10 high power fields. This suggests the tumor is aggressive or malignant. Follow-up: no evidence of recurrence at 6 months.

Discussion

Recurrence of meningiomas as a group is well known and has been estimated to occur in 21% of cases [1], irrespective of microscopic or other biologic features. In most in-

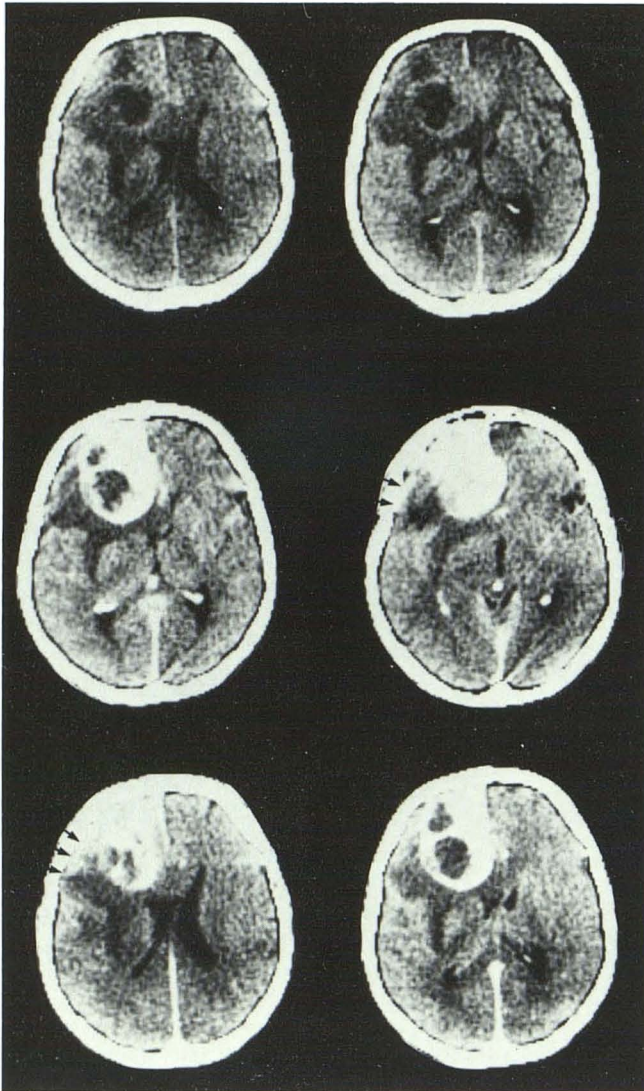


Fig. 5.—Case 5. Large frontal-convexity malignant meningioma, also involving falx. **Top row**, Plain scan. Rounded area of hypodensity with attenuation values similar to cerebrospinal fluid. Irregular thin ring of approximately isodense tissue between this low density region and surrounding low density tissue, which includes region of white matter edema. Suggestion of slightly hyperdense tissue just beneath inner table in anterolateral frontal region. **Middle and bottom rows**, Marked enhancement of mass, which contains quite large areas of sharply demarcated but somewhat irregularly contoured regions of low density. Mass extends to falx anteriorly and bulges for short distance left of midline, apparently beneath free margin of falx. Tongue of tumor mushrooms posteriorly over lateral surface of frontal lobe, away from globoid part of mass (arrows). CT features suggested diagnosis of malignant glioma.

stances, recurrence seems to depend primarily on the incompleteness of tumor excision and has varied from 9% in tumors apparently completely excised to 34% for those partially removed [1, 17]. Thus recurrence alone is not a firm criterion of malignancy. Also, local invasion of dura, venous sinuses, and over lying bone is characteristic of meningioma. These features are usually associated with a benign cellular appearance [14, 15] and therefore in themselves are not criteria of malignancy.

Malignant meningiomas are said to be quite rare, with a

reported incidence of 2% [29] to 10% [7, 10]. Males predominated over females with a 3:2 ratio, a reversal of the usual gender predilection of meningioma. According to Smith [9], less than 10% of meningiomas have malignant features and high rates of recurrence. Simpson [1] reported recurrences in 21% of surgical cases, of which one-half occurred after excision was believed to be complete. According to Rubinstein [15], the more frankly invasive examples of malignant meningioma may be termed sarcomatous and those cannot easily be distinguished from the rare primary meningeal sarcomas. Despite the problems that may exist in some cases in making this distinction, there seems to exist a group of meningiomas that possesses appropriate gross features but has somewhat atypical cytologic features, recurs rapidly, and, in very rare instances, can give rise to metastases beyond the central nervous system [7-9, 12, 16].

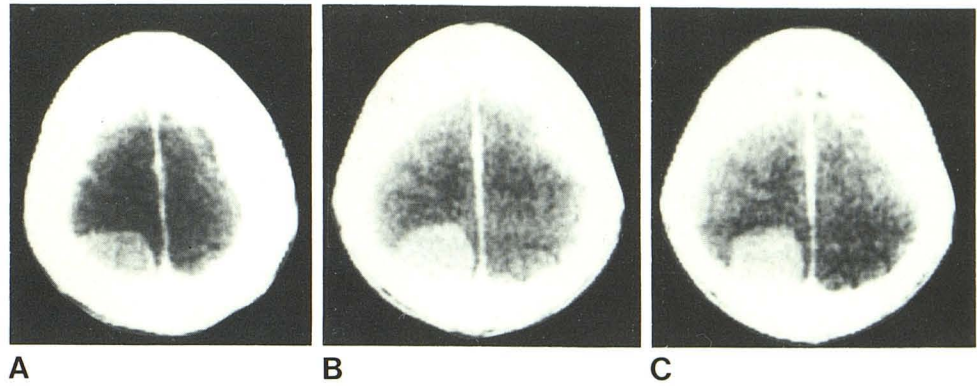
Metastatic seeding of meningiomas, often but not invariably histologically malignant, through the cerebrospinal fluid pathways is extremely rare and only a few cases have been described [15, 17]. Meningioma metastases tend to occur after surgery [15], but in about 25% of cases, metastases have occurred without surgery [12]. Forty acceptable metastatic cases were reported by Shuangshoti et al. [12]. The most common sites of extracranial hematogenous metastases are lung, liver, pleura, lymph nodes, bones, and kidneys [12, 15]. It has been reported that the histologic appearance of both the primary neoplasm and its metastases may be either quite benign or atypical [14]. Aggressive atypical meningiomas, which tend to recur rapidly and/or to metastasize, tend also to show a more pleomorphic cell pattern than the classic type, in association with generally poor whorl formation, but with preservation of the lobular architecture in some places. Mitotic figures are exceptional in typical meningiomas and the presence of considerable numbers of mitotic figures is taken to be indicative of aggressive growth, with a tendency for early tumor recurrence [2, 15]. Any of the histologic types of meningioma may have or may develop such typical and malignant features, but the angioblastic and syncytial types are said to be particularly likely to do so [15].

Angioblastic meningiomas are reported to constitute 4% of meningiomas as a whole [13] but account for about 15% of all metastatic meningiomas and are considered to display more aggressive biologic behavior than other histologic variants. Mitotic figures in the absence of other atypical cytologic features are a common finding in angioblastic meningiomas, in contrast to their paucity in meningiomas in general [13].

In one of four cases of malignant meningiomas reviewed by Tytus et al. [10], a large, purely osteolytic area was present in the skull and three cases involved the parasagittal region. All four tumors had invaded the brain, with an accompanying intense glial reaction at the sites of invasion. One tumor showed areas of less differentiation, one mild pleomorphism, and two showed marked pleomorphism with multinucleate giant cells, mitoses, and loss of architecture.

Papillary architecture in meningiomas represents a variant in the histologic spectrum of meningiomas, is invariably associated with other features of malignancy, and this type

Fig. 6.—Case 7. Malignant meningioma of moderate size involves high right parietal convexity in patient with neurofibromatosis. Enhanced scan. Typical features of benign meningioma; moderate homogeneous enhancement of mass with extensive meningeal base and smooth, quite sharply demarcated margins. Mass was slightly hyperdense without contrast medium. No calcific levels of density or bone changes were identified. There were bilateral moderate-sized acoustic neuromas and at least two other supratentorial nodular lesions adjacent to inner table, measuring only few millimeters in diameter, thought to represent small meningiomas, though histology was not confirmed. CT diagnosis was meningioma.



often displays aggressive clinical behavior marked by a high local recurrence rate and distant metastases. Occasionally, papillary structures are present only in the metastases [29]. Progression of a typical cytologic pattern to that of a papillary structure, spindle cell sarcoma, or increasing anaplasia has also been described [14].

Ludwin et al. [16] reported 17 meningiomas (six syncytial, five angioblastic, and four transitional) with a papillary pattern. All showed additional histologic features suggesting malignancy, such as brain invasion or numerous mitotic figures. The papillary pattern usually occurs in only a part of otherwise unmistakable meningioma, but occasionally constitutes the dominant histologic pattern.

Mitoses were found in "significant numbers" in 13 cases. Eight of the 17 showed histologic evidence of brain invasion and eight arose in childhood, with onset at 3–13 years. Ten had local recurrence of tumor at 4 months to 16 years after the first operation, usually at 2–4 years. Five cases developed distant metastases, three via cerebrospinal pathways, and two metastasized outside the central nervous system. Seven cases died with residual tumor within 1–16 years of the first operation.

The histologic features then, that have been correlated with aggressive or frankly malignant behavior of meningiomas, include: "frequent" mitoses, cellular pleomorphism, prominent tumor necrosis, and infiltration of tumor into brain (i.e., invasion of the brain rather than merely growth of tumor into sulci and/or Virchow-Robin spaces). The more prominent these features, the greater the probability of recurrence [2, 4, 15]. It is held that the probability of recurrence and malignant change is considerably greater in parasagittal meningiomas than those in other locations [1, 10], and in those exhibiting a papillary architecture.

Meningiomas are correctly predicted by CT in the region of 90% [19, 22, 26]. Russell et al. [26] studied the CT appearance and pathologic findings in a consecutive series of 131 previously untreated patients with meningioma, excluding cases with clinically evident malignant meningiomas. Of these cases, 93% were correctly diagnosed preoperatively as meningioma using CT data alone. Of the latter cases, 85% were entirely typical in CT appearance; 8% had segmentally aberrant CT features, but the overall pattern was considered diagnostic of meningioma; 7% were misdi-

agnosed by CT as other varieties of malignant neoplasm. All of the latter nine cases were also atypical on pathologic grounds, and correlation between CT findings and histologic features was excellent. The predominant atypical feature seen on CT was extensive low density within the tumor, associated with a cystic appearance due to peripheral enhancement, nonhomogeneous enhancement, or enhancement of only a small nodule within the low density region. These patterns correlated with extensive necrosis within the tumor. Two of the cases were angioblastic meningiomas and one was syncytial with angioblastic elements. Two cases showed greater than usual cellularity and a poor plane of separation from brain at surgery suggested malignancy. Each of these tumors was, however, classified as benign meningioma. A "mushrooming" pattern of tumor growth was not mentioned in this study nor in the report by Vassilouthis and Ambrose [23].

The CT appearances of 16 malignant meningiomas reported by Vassilouthis and Ambrose [23] summarized in table 2 and compared with their incidence in histologically benign meningiomas. They did not mention bone changes or a mushroom pattern. One of their cases of malignant meningioma, illustrated in their figure 5, showed a nongloboid configuration. The poorly defined deep margin and the irregular fringes of tumor received comment, but not the absence of a typical globoid configuration. This case resembles our case 4. All of their malignant meningiomas were moderately hyperdense before contrast enhancement. However, this appearance also occurred in 60.5% of benign meningiomas in their series. Two cases had poorly defined margins, seven irregular margins, and two irregular fringes. Eight percent of their benign meningiomas showed poorly defined or irregular fringelike margins. None of the 16 cases had visible calcification, compared with the presence of moderate calcification in 28% of the benign tumors. Moderate edema was seen in three and marked edema in 12 cases, compared with 40% and 51%, respectively, in the benign tumors. The incidence of these and other features in our seven cases is listed in table 2. Of these features, the mushrooming pattern seems to represent the most reliable in predicting malignant characteristics.

A purely or predominately osteolytic reaction has been mentioned by a number of authors as a feature that may be

helpful in predicting malignancy of meningiomas [27, 28]. This feature was identified preoperatively in only one of our cases; it was moderately extensive and better shown on CT than skull films. One case had minor hyperostosis, also better seen on CT. Calcification was noted in two cases, a single fleck in one and a tiny nodule in another case.

If, as now seems possible, radiologic studies can provide an early warning of the presence of a meningioma with malignant potential, certain practical considerations arise. Alerted to the situation, the surgeon would be well advised to obtain an increased number of biopsies for examination by frozen section, particularly from the peripheral parts of the meningioma, where the most actively growing area of the tumor may be identified. A mushrooming segment of the tumor should receive particular scrutiny. If the histologic features at this stage support the suspicion of malignant meningioma, maximal surgical effort toward total tumor removal, including laser sterilization of the tumor bed, would be advisable. If final histologic slides confirm the malignant potential of the tumor, earlier and more frequent follow-up studies than usual, particularly by CT, should be undertaken, and consideration given to postoperative radiation therapy, keeping in mind that the aggressiveness of meningiomas and also the difficulty of surgical extirpation may increase with time.

In summary, CT of supratentorial nonbasal meningiomas showing one or more of the following features suggests malignant histology and clinical behavior: extensive bone lysis, irregular indistinct tumor-brain margins, deeply penetrating fronds, extensive necrosis, absent or minimal calcifications, and a mushrooming pannus of tumor extending over the cerebral surface to a considerable distance from the globoid part of the tumor. The neurosurgeon, alerted to the possibility or probability of a malignant meningioma, may wish to modify biopsy and extirpative procedures. Regardless of apparent completeness of extirpation, the high recurrence rate of meningiomas with unusually high mitotic indices indicates the need for earlier and more frequent follow-up CT studies.

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