ENINGIOMAS are usually considered encapsulated tumors that are easily resectable. Nevertheless, surgical procedures are frequently followed by postoperative complications and neurological deficits, especially when tumors are located in eloquent cortical areas. Even in patients with uneventful postoperative courses, systematic early postoperative follow-up review with CT scanning often reveals small, punctuated hemorrhages within the parenchyma underlying the tumor bed. These hemorrhages are related to (most often small) ischemic and/or venous infarcts caused by impairment of cortical pial vessels that are adherent to or even incorporated into the tumor capsule. Therefore, we can question whether a high number, if not all, of the intracranial meningiomas are usually cleavable from the underlying parenchyma. Some authors of publications have stressed the usefulness of preoperative CT scanning, MR imaging, and arteriography in predicting resectability and outcome. This study was conducted to determine the value of preoperative imaging investigations in predicting an extra-pial surgical plane of cleavage of the tumor mass from the underlying cerebral cortex in a series of a 100 consecutive patients with meningioma.

Steps of the study included investigation of the following factors: 1) the importance of the size of the tumor to its surgical management; 2) whether a well-delineated interface between tumor and cortex, as seen on MR imaging, is a predictor of ease in finding an extra-pial plane of dissection; 3) whether the presence of edema in the surrounding brain parenchyma on CT or MR imaging studies (and if so, its degree of importance) is predictive of the need to pass into a subpial plane to dissect the tumor from the underlying parenchyma after the discovery of an extra-pial interface; 4) the usefulness of performing preoperative selective angiography; and 5) the correlation between the characteristics of the plane of cleavage (extra-pial or subpial) and outcome, especially for the meningiomas located in eloquent areas.

Clinical Material and Methods

Characteristics of Tumors in the Series

This prospective study was conducted between January 1998 and January 2001. The series was composed of 100 consecutive cases of intracranial meningioma.
consecutive supratentorial meningiomas that were all resected by the senior author (M.S.) by using the same microsurgical techniques; the patients were followed postoperatively for a minimum of 1 year. Meningiomas of the posterior fossa and of the central skull base (especially those arising from the cavernous sinus) were not included in this study because they generally do not have a large interface between the tumor capsule and surface (that is, pia mater) of the brain. Intraventricular meningiomas were also excluded. Tumors were located as shown in Table 1. Of 100 tumors, the size was less than 3 cm in diameter in 26, from 3 to 6 cm in 62, and more than 6 cm in 12; the mean tumor size was 4 ± 1.8 cm (mean ± SD).

**Patient Population**

There were 25 men and 75 women included in the study (ratio 1:3). The patients ranged in age from 20 to 80 years; the mean patient age (mean ± SD) was 56 ± 11.7 years when surgery was performed (Fig. 1). All patients underwent a preoperative assessment of their neurological and functional status, the latter with the KPS and three imaging studies (CT scanning, MR imaging, and transfemoral angiography). The operative record mentioned, in addition to the location and size of the tumor, the surgical plane of cleavage (extrapial/subpial) from the underlying cerebral cortex, as well as the quality of the gross removal, which was calculated using the Simpson score. The appearance of the brain cortex at the end of surgery was also noted.

Before leaving the intensive care unit, postoperative CT scans were obtained in all patients on the 1st or 2nd day after surgery. In all patients a postoperative clinical evaluation of their functional status was performed, including the KPS, on postoperative Day 10, at 2 months, and at the last follow-up (that is, at 1 year at least, and 3 years at most).

Histopathological subtyping was performed by a neuropathologist who was blinded to the clinical and neuroimaging findings. Tumors were categorized according to the WHO classification as follows: 46 transitional or mixed, 30 fibroblastic, 11 meningotheelial, six atypical, three angiomatosus, two psammomatous, one secretory, and one clear cell meningioma (Table 2). Seven cases (the clear cell and the atypical subtypes) were classified as having more aggressive behavior. No tumor in this series was anaplastic or malignant.

**Study Design**

**Prediction of Surgical Plane of Cleavage on Preoperative Imaging.** To predict whether the surgical plane of cleavage was extrapial, this study was focused on the following imaging features: 1) tumor size; 2) space between the tumor capsule and the underlying cortex on MR imaging; 3) the presence of peritumoral edema on CT and MR imaging; and 4) the supply from dural arteries on the side of dural insertion and from corticopial arteries on the side of the brain cortex.

Tumor Size. The tumor size was defined as its largest diameter, which was noted on the T1-weighted MR imaging sequences; this measurement was recorded based on the centimeter scale printed on the images. The overall series was divided into three groups according to the size of the tumor: less than 3 cm (small), 3 to 6 cm (medium), and greater than 6 cm (large).

Tumor–Cortex Interface. The tumor capsule–cortex interface was determined based on T2-weighted MR imaging sequences obtained using a Magneton 63 sp 1.5-tesla system (Siemens, Erlangen, Germany). The T2-weighted images studied were obtained with a TR of 2200 to 3000 msec and a TE of 80 or 100 msec.

The tumor–cortex interface was classified as follows: 1) marked interspace—a clearcut marked space (> 1 mm wide) on more than 50% of the surface between the tumor and the surrounding cortical surface; 2) regular border—no evidence of interspace or irregular border between the tumor and the underlying cortical surface, but a regular deli-

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**TABLE 1**

<table>
<thead>
<tr>
<th>Tumor Location</th>
<th>No. of Lesions</th>
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<tr>
<td>convexity</td>
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<td>sphenoid ridge</td>
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<tr>
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</tr>
<tr>
<td>tuberculum sellae</td>
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</tr>
<tr>
<td>temporal fossa</td>
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**TABLE 2**

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<th>Plane of Cleavage</th>
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eation between them on more than 50% of the surface; and 3) irregular border—an absence of clearcut tumor–cortex delineation on more than 50% of the surface (Fig. 2).

Peritumoral Edema. Quantification of peritumoral edema was determined from both CT scans obtained with iodine contrast agent and T2-weighted MR imaging sequences. Peritumoral edema was diagnosed when a low-density area around the tumor (7–25 HU) on CT scans (Fig. 3) and a corresponding peritumoral hyperintense signal on T2-weighted MR imaging sequences (Fig. 4) were observed. If present, the extent of edema was defined according to its thickness; the centimeter scale printed on the images was used to measure edema width. The outer edge of the tumor on the axial slice showing the largest cross section of the lesion was measured.

Edema was graded as follows: 1) absent, no evidence of peritumoral hypodensity on CT scans and hyperintensity on T2-weighted MR imaging sequences; 2) focalized, peritumoral hypodensity on CT scans and hyperintensity 3 cm or less in width on T2-weighted images; and 3) lobar or hemispherical, peritumoral hypodensity on CT scans and hyperintensity more than 3 cm in width, occupying an entire lobe or even a complete hemisphere on MR images.

Arterial Supply. Angiography was performed through the transfemoral route and consisted of selective ECA and internal carotid and vertebral artery injections. According to the respective participation of pial–cortical and dural–meningeal arteries (Fig. 5), the vascular supply was classified as follows: pial predominance meant that pial–cortical participation was 75% or more of the overall arterial supply; mixed meant that pial–cortical supply was greater than 25% and less than 75%; and dural predominance was assigned when dural–meningeal participation was 75% or more of the overall arterial supply.

The various CT or MR imaging and angiographic classifications, grading, and statistical analyses were established by an independent observer (J.A.), who was blinded to the anatomical surgical findings and postoperative outcome.

Characterization of the Surgical Plane of Cleavage

Resections were performed in all cases by the senior surgeon, who used current microsurgical dissection procedures (operating microscope, bipolar coagulation, microscissors, microsuction, ultrasonic aspiration, and so forth). The operative steps can be succinctly described as follows: 1) separation of the tumor base from its dural implantation by
using bipolar coagulation forceps; 2) intratumoral volume reduction (either by piecemeal removal with bipolar microcoagulation, microscissors, and microsuction, or by means of an ultrasonic aspirator); and 3) sharp dissection of the tumor from the underlying cerebral cortex under high magnification.

A gross-total resection was attempted in most patients. Intraoperative evaluation of tumor removal in 100 meningiomas was quantified according to the Simpson classification. The type and characteristics of the cleavage plane(s) found were carefully noted in all operative reports.

The dissection plane was considered to be extrapial (Type I) if a clear surgical plane of cleavage existed between the tumor capsule and cortical brain surface outside the pia mater layer (regardless of whether an arachnoidal membrane could be clearly identified) in more than two thirds of the overall interface between tumor and cortex; mixed (Type II) if the plane of cleavage as described earlier was more than one third and less than two thirds of the overall interface; or subpial (Type III) if the surgeon was required to pass underneath the pia mater layer because of its incorporation into the tumor capsule on a surface of more than two thirds of the overall tumor–cortex interface.

**Correlative Studies**

Correlative studies were made between the imaging data and the three different types of planes of cleavage encountered during surgery. First, tumor size on neuroimaging was correlated with the surgical plane and the corresponding outcome; second, the tumor–cortex interface on T2-weighted MR imaging sequences, peritumoral hypodensity on CT scanning, and hyperintense signal on T2-weighted MR imaging sequences were also correlated with the operative findings; and third, the role of the plane of cleavage in the postoperative clinical outcome at the 1-year follow-up review was evaluated using the KPS.

**Statistical Analysis**

Statistical analyses were performed using a software package available for free downloading (BiostaTGV version 1999, http://faculty.vassar.edu/lowry/webtext.html; Richard Lowry, Department of Psychology, Vassar College, Poughkeepsie, NY). For continuous numerical data, the analyses were conducted as follows. The analysis of variance test was used to study the differences in the KPS scores between the three surgical groups. The t-test was used to study the differences in preoperative and postoperative KPS scores within each particular group. The mean values were presented with a 95% confidence interval.

For nominal data the analyses were conducted as follows. The chi-square test was used to study the correlation between the preoperative CT, MR imaging, and angiographic findings in the three surgical groups. The Fisher exact test was used to study the differences in postoperative CT scans when only two groups were evaluated. Finally, the factors for which probability values were less than 0.05 were defined as significant.

**Results**

**Overall Surgical Results**

Gross tumor removal was complete in 92% of cases:
excision of dural attachment (Simpson Grade I) was performed in 49 patients, and excision with coagulation of the zone of attachment in 43 patients (Simpson Grade II). Resection was subtotal (Simpson Grade III) in 7% of the cases, and partial (Simpson Grade IV) in one case (Fig. 6).

A cleavage plane between the tumor and the underlying cortex could be achieved by passing in the extrapial plane over more than two thirds of the total brain–tumor interface in 43 patients. A subpial plane over more than two thirds of the dissection was found in 46 patients. In the 11 remaining cases, the plane of cleavage was classified as mixed.

In terms of mortality and morbidity, one patient died postoperatively of septicemia due to uncontrolled subdural empyema. Morbidity in the 99 surviving patients consisted mainly of wound infection: an extradural empyema was evacuated with a good outcome in three patients and a bone flap infection required surgical removal in two patients. A postoperative subdural hematoma occurred in one patient and was successfully removed surgically.

The quality of survival was evaluated according to the KPS. Postoperative scores ranged from 70 to 100, with a mean score of 96 ± 10, whereas the preoperative scores ranged from 40 to 100 with a mean of 92 ± 13 (mean ± SD).

**Correlations Between Tumor Size and Surgical Plane**

Twenty-two (85%) of the 26 tumors smaller than 3 cm could be removed via an extrapial plane, whereas one case (4%) involved a mixed plane and the other three (11%) a subpial plane. For the 62 medium-sized tumors (3–6 cm) the surgical plane was extrapial in 20 cases (32%), mixed in 10 (16%), and subpial in 32 (52%). For the tumors larger than 6 cm, 11 (92%) of the 12 were removed passing in the subpial plane, and only one (8%) was extrapial. Thus, in the overall series the larger the tumor size the more difficult it was to find an extrapial plane of cleavage (p < 0.00001, chi-square test; see Fig. 7).

**Correlations Between Preoperative Neuroimaging and Surgical Plane**

In the group of 62 patients with medium-sized (3–6 cm) meningiomas, preoperative neuroimaging results were correlated with the plane of cleavage. This group was chosen because 85% of tumors smaller than 3 cm had an extrapial plane of cleavage and 92% of those larger than 6 cm had a subpial plane. Therefore, we decided to focus the correlational study of the predictive value of the neuroimaging features on the group of tumors that were between 3 and 6 cm in size.

**Tumor–Cortex Interface.** The tumor–cortex interface was examined on the T1-weighted MR imaging sequence.

In the series of 62 patients whose tumors were 3 to 6 cm in size, a clearcut limit between tumor and cortex was found in 56 (90%) of the 62 cases studied, an irregular tumor–cortex interface was found in three cases (5%), and a marked interspace between the tumor and the cortex surface was identified in three other cases (5%).

Of the three cases with a marked interspace, two had an extrapial plane, but the other one had a mixed plane. In 18 (90%) of the 20 cases with a surgical extrapial plane of cleavage, MR images demonstrated a clearcut tumor–cortex interface. All three patients classified as having an irregular tumor–cortex interface had a subpial plane of cleavage at surgery, although 29 (90%) of 32 patients with the same subpial surgical plane were classified as having a clearcut tumor–cortex interface on the T1-weighted MR images. Thus, the type of tumor–cortex interface on T1-weighted MR imaging did not predict plane of cleavage (p > 0.1, chi-square test); interestingly, similar data were observed for the entire series of 100 cases, as shown in Fig. 8.

**Peritumoral Edema.** Based on CT scans obtained in 62 patients, there were 30 cases (48%) without peritumoral hypodensity, 19 (31%) with a focalized hypodensity around the tumor, and 13 (21%) with lobar or hemispherical peritumoral hypodensity (Fig. 9). All 13 cases with lobar or hemispherical peritumoral hypodensity were positively correlated with a subpial or mixed plane of cleavage; 17 (89%) of the 19 cases with focalized peritumoral hypodensity had positive correlations with a subpial or mixed plane of cleavage; and 18 (60%) of the 30 cases without hypodensity
Preoperative neuroimaging as a predictor of plane of cleavage

were correlated with an extrapial plane of cleavage. In other words, in 22 (69%) of the 32 cases in the subpial group there was either lobar or focalized peritumoral hypodensity. Thus, positive correlations between absence or presence (and also degree) of peritumoral hypodensity on CT scans and the surgical plane of cleavage were statistically significant in this series (p < 0.0001, chi-square test).

On T₂-weighted MR images obtained in the 62 patients with medium-sized meningiomas, there were 26 lesions (42%) without peritumoral high-intensity signal, 13 (21%) with a focalized high-intensity signal around the tumor, and 23 (37%) with a lobar or hemispherical hyperintense signal. The T₂-weighted images were correlated with the surgical plane of cleavage (Fig. 10). All 23 cases with lobar or hemispherical peritumoral hyperintensity were reported as having a subpial or mixed plane of cleavage; 11 (85%) of the 13 cases with focalized peritumoral hyperintensity had a subpial or mixed plane of cleavage; and 18 (69%) of the 26 cases without hyperintensity had an extrapial plane of cleavage.

Alternatively, 18 (90%) of the 20 cases reported as having an extrapial plane of cleavage demonstrated no peritumoral hyperintensity changes on T₂-weighted MR imaging, and 34 (80%) of the 42 cases with a mixed or a subpial plane of cleavage showed peritumoral hyperintensity changes, with 14 (33%) with lobar and 20 (48%) with focalized peritumoral hyperintensity.

**Fig. 8.** Left: Bar graph showing the correlation between the tumor–cortex interface observed on T₂-weighted MR imaging (T₂-MRI) and the surgical plane of cleavage in the group of tumors that ranged from 3 to 6 cm in size. Right: The results in the overall series are illustrated.

**Fig. 9.** Left: Bar graph showing the correlation between the peritumoral hypodensity on CT scans and the surgical plane of cleavage in the group of tumors that ranged from 3 to 6 cm. Right: The results in the overall series are shown. Hem = hemispherical.
plane of cleavage demonstrated either a focalized or lobar/hemispherical peritumoral hyperintensity. Thus, correlations between the peritumoral hyperintensity on T2-weighted MR imaging and the surgical plane of cleavage were positive in this series (p < 0.00001, chi-square test).

Tumor Arterial Supply. Based on selective angiography performed in the 62 patients, four (6%) had a predominantly pial vascular supply to the tumor, 23 (38%) had mixed vascularization, and 35 (56%) had a predominantly dural–meningeal supply. The vascular supply observed on selective angiography was correlated with the surgical plane of cleavage (Fig. 11), with the following results. In 20 (57%) of the 35 cases classified with predominantly dural–meningeal supply on angiography there was an extrapial plane of cleavage. Of the 23 patients with mixed vascularization, 17 (74%) were reported as having a subpial plane and six (26%) had a mixed plane of cleavage; no patient had an extrapial plane in this subgroup.

When angiography demonstrated a predominantly pial supply, all four cases were correlated with a subpial plane of dissection. In other words, when vascularization was classified as mixed or subpial, the surgical plane of cleavage was never extrapial; thus, the correlation between the vascular supply of the tumor and the surgical plane of cleavage was statistically significant in this series (p < 0.0001, chi-square test).

Outcome and Plane of Cleavage

In 26 tumors smaller than 3 cm, the mean preoperative KPS score was 98 ± 4.9, whereas the mean postoperative KPS score was 98.8 ± 3.2 (mean ± SD). Although there was an increase of 0.76 in the postoperative score, the difference was not statistically significant (p > 0.5, Student t-test). In the 12 tumors larger than 6 cm, the KPS mean value was 83.3 ± 14.9 preoperatively and 85.8 ± 25.3 (mean ± SD) postoperatively. Although there was an increase of 2.5 in the score, the difference was not statistically significant (p > 0.5, Student t-test).

Outcome and Tumor Size in the Meningioma Series

In 26 tumors smaller than 3 cm, the mean preoperative KPS score was 98 ± 4.9, whereas the mean postoperative KPS score was 98.8 ± 3.2 (mean ± SD). Although there was an increase of 0.76 in the postoperative score, the difference was not statistically significant (p > 0.5, Student t-test). In the 62 tumors from 3 to 6 cm, the KPS mean value was 97.1 ± 14.3 and the postoperative one was 95.96 ± 7.56 (mean ± SD). The improvement of 4.19 in the postoperative KPS score was statistically significant (p = 0.01, Student t-test). In the 12 tumors larger than 6 cm, the KPS mean value was 83.3 ± 14.9 preoperatively and 85.8 ± 25.3 (mean ± SD) postoperatively. Although there was an increase of 2.5 in the score, the difference was not statistically significant (p > 0.5, Student t-test).

Outcome and Plane of Cleavage

Overall Series (100 cases). Follow-up evaluations were performed after 1 year to establish whether outcome differences existed related to the surgical plane of cleavage. At 1 year postoperatively, the KPS mean value was 98 ± 4 in the extrapial as well as in the mixed group and 92 ± 15 (mean ± SD) in the subpial group. Although the KPS score was “worst” in the subpial group, the differences between the various groups were not statistically significant (p > 0.05, analysis of variance test).

Eloquent Areas Group (40 cases). A subgroup analysis was conducted in 40 patients in whom the tumor was located in eloquent areas. To simplify the study, the population was divided into two subgroups: one corresponded to the extrapial plane of cleavage (15 patients) and the other to a group termed “nonextrapial plane” (25 patients with a mixed or subpial surgical plane). The mean value of the KPS score 1 year postoperatively was 99 ± 2 in the extrapial subgroup and 95 ± 8 (mean ± SD) in the nonextrapial subgroup. This difference was statistically significant (p = 0.03, Student t-test).

To identify the anatomical and pathological cause(s) of the differences in the postoperative functional status between the two subgroups (extrapial compared with nonextrapial planes of cleavage), the early (within postoperative Day 2) CT scan was considered. Images revealing ischemia and/or hemorrhagic infarctions located in the cortical and the underlying subcortical areas corresponding to the tumor bed were viewed as representing adverse consequences of the surgical removal of the tumor. There were no such
The results of this study clearly show that the larger the tumor size the higher the likelihood of a subpial plane of dissection. The probable explanation is that the larger the tumor the more important the pial participation to its vascularization, as observed on the preoperative angiogram (p < 0.005, chi-square test).

These data provide strong arguments in defense of the policy of early operation on tumors while they are still small, especially when they are located in eloquent areas, even if they are asymptomatic, given the fact that at this stage there is a good possibility of finding a predominantly extrapial plane of dissection. The significant role of the size of the tumor in cleavability is in contrast to the absence of a role for the histopathological nature of the meningioma, at least in our series. As a matter of fact, we found no significant correlation between the surgical plane of cleavage and the histological subtype (p > 0.05), even for the seven tumors with a histological behavior more aggressive than normal. Nevertheless, it must be noted that there were neither malignant nor anaplastic tumor types in this series.

**Prediction of the Surgical Plane of Dissection on Neuroimages**

In this study we show a statistically positive correlation between the difficulty in finding a safe (that is, extrapial) surgical plane of cleavage and the presence of peritumoral edema as represented on CT scans by a peritumoral hypodensity and on T2-weighted MR images by a peritumoral hyperintensity. Surprisingly, the appearance of the brain–tumor interface on MR imaging did not have a statistically significant value as a predictor of the surgical plane in our series.

This study corroborates the findings reported in previous publications of a strong correlation between the predominance of a pial–cortical arterial supply to the tumor and the greater difficulty in finding an extrapial plane of cleavage.9,13,15,16

**Functional Outcome**

When the overall series was considered, the differences in functional outcome evaluated using the KPS scoring system were not significant between the three surgical groups (extrapial, subpial, and mixed). Nevertheless, when the group of meningiomas located in eloquent areas was analyzed and separated into two subgroups (extrapial plane compared with the nonextrapial plane), the differences were statistically significant at the 1-year postoperative follow-up review (p = 0.03). Therefore, the tumors located in eloquent areas have to be considered as a special surgical subgroup, especially when neuroimaging findings indicate a plane of cleavage that is predominantly subpial. In those cases, patients and their relatives have to be informed of the higher risk of postoperative deficits and persistent sequelae.
Conclusions

When considering intracranial meningiomas for surgery, namely, while assessing the ability to find a safe surgical plane of dissection from the underlying cortex, neuroimages have to be carefully analyzed to identify the presence of peritumoral hypodensity on CT scans and peritumoral hyperintensity on T2-weighted MR images that obscures the invasion by the tumor of the underlying pia mater.

In most meningiomas smaller than 3 cm the tumor can be removed using a dissection plane outside the pia mater. On the contrary, meningiomas larger than 6 cm are more likely to be resected along a subpial plane. For meningiomas of medium size (that is, between 3 and 6 cm), the presence of peritumoral edema on CT or MR imaging studies is a valuable indicator. Also, tumor pial vascularization as seen on selective angiography gives accurate information about the surgical plane of pial penetration by the tumor. The tumor–cortex interface (on T2-weighted MR images) does not allow reliable predictions of the plane of cleavage that will be found at surgery.

Although our study shows that CT scans or MR images are sufficient to give evidence of pial inclusion within the tumor capsule, we believe selective angiography is important to define the best strategy and design the most appropriate surgical planning for safe removal of the tumor by providing very precise information about its vascularization.

Because the smaller the tumor it is to find an extrapial plane of cleavage, we advocate that meningiomas be surgically removed at an early stage, especially those located in eloquent areas, even if they are asymptomatic. Our anatomical and imaging observations, as well as the surgical results obtained in this series, plead for such a therapeutic attitude.

References

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Address reprint requests to: Marc P. Sindou, M.D., Department of Neurosurgery, Hôpital Neurologique Pierre Wertheimer, 59 Boulevard Pinel, 69003 Lyon, France. email: marc.sindou@chu-lyon.fr.