Results of attempted radical tumor removal and venous repair in 100 consecutive meningiomas involving the major dural sinuses

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Object. Radical removal of meningiomas involving the major dural sinuses remains controversial. In particular, whether the fragment invading the sinus must be resected and whether the venous system must be reconstructed continue to be issues of debate. In this paper the authors studied the effects, in terms of tumor recurrence rate as well as morbidity and mortality rates, of complete lesion removal including the invaded portion of the sinus and the consequences of restoring or not restoring the venous circulation.

Methods. The study consisted of 100 consecutive patients who had undergone surgery for meningiomas originating at the superior sagittal sinus in 92, the transverse sinus in five, and the confluence of sinuses in three. A simplified classification scheme based on the degree of sinus involvement was applied: Type I, lesion attachment to the outer surface of the sinus wall; Type II, tumor fragment inside the lateral recess; Type III, invasion of the ipsilateral wall; Type IV, invasion of the lateral wall and roof; and Types V and VI, complete sinus occlusion with or without one wall free, respectively. Lesions with Type I invasion were treated by peeling the outer layer of the sinus wall. In cases of sinus invasion Types II to VI, two strategies were used: a nonreconstructive (coagulation of the residual fragment or global resection) and a reconstructive one (suture, patch, or bypass). Gross-total tumor removal was achieved in 93% of cases, and sinus reconstruction was attempted in 45 (65%) of the 69 cases with wall and lumen invasion. The recurrence rate in the study overall was 4%, with a follow-up period from 3 to 23 years (mean 8 years). The mortality rate was 3%, all cases due to brain swelling after en bloc resection of a Type VI meningioma without venous restoration. Eight patients—seven of whom harbored a lesion in the middle third portion of the superior sagittal sinus—had permanent neurological aggravation, likely due to local venous infarction. Six of these patients had not undergone a venous repair procedure.

Conclusions. The relatively low recurrence rate in the present study (4%) favors attempts at complete tumor removal, including the portion invading the sinus. The subgroup of patients without venous reconstruction displayed statistically significant clinical deterioration after surgery compared with the other subgroups (p = 0.02). According to this result, venous flow restoration seems justified when not too risky.

KEY WORDS • meningioma • parasagittal meningioma • dural sinus • venous reconstruction • tumor recurrence

Surgical treatment of meningiomas involving the major dural sinuses poses a dilemma to the surgeon: leave a fragment of the invasive lesion and have a higher rate of recurrence, or attempt a total removal and put the venous circulation at risk. The current tendency is to resect the tumor mass outside the sinus wall(s) and coagulate the remnant, followed if needed by en bloc removal of the residual fragment when complete sinus occlusion occurs. Note that a commonly accepted belief is the decreased likelihood of a recurrence with less residual tumor. In fact, Simpson reported that complete removal of a meningioma with excision of its dural attachment leads to a lower rate of recurrence (6%) compared with the rates following complete removal with coagulation (16%) or without treatment of the dural attachment (29%).

In the event of sinus invasion with preserved sinus circulation, resection of the invaded wall(s) requires patching of the defect to maintain flow. In the event of a totally occluded sinus, the surgeon must decide whether to restore venous circulation by performing a bypass once the occluded sinus is resected or simply to remove the invaded portion without venous reconstruction. Because collateral venous pathways will likely develop in such a scenario, conventional knowledge assumes that complete removal of the invaded sinus is not very dangerous and needs no venous flow restoration. This assumption may not always be true, however. When considering sinus surgery, the benefits must be carefully weighed against the risks. For example, the risks of radical lesion removal must be juxtaposed with

Abbreviations used in this paper: CT = computed tomography; DS = digital subtraction; GKS = Gamma Knife surgery; KPS = Karnofsky Performance Scale; MR = magnetic resonance; SRT = stereotactic radiotherapy; WHO = World Health Organization.
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the capacities and limits of radiotherapy. Although the application of radiation treatment has been traditionally considered effective for any tumor remnant attached to the dural sinus, the recurrence rate after such treatment has been reported to be 18 to 22%.\textsuperscript{55} Note, however, that current refined stereotactic radiosurgical techniques increasingly play a role in the treatment of meningiomas in risky locations.\textsuperscript{18,31,48}

After some preliminary experimental work on the venous system\textsuperscript{62,63} and in an effort to reduce the risk of recurrence, postoperative morbidity and mortality rates as well as neurological aggravation, we attempted gross-total removal of meningiomas including the intrasinusional portion.\textsuperscript{56,59,60} In the present paper we summarize the results of this experience, with particular attention to recurrence and morbidity and mortality rates.

Clinical Material and Methods

Study Design and Definitions of Terms

Four questions prompted this clinical study: 1) Is the recurrence rate of meningiomas with dural sinus invasion reduced by attempting radical surgery? 2) Does the nature of the radical surgery compel the surgeon to deal with reconstruction of the venous flow? 3) Is the venous dural flow restoration a safe procedure? 4) Does the restoration procedure work?

Total removal was defined as a resection equivalent to Simpson Grade I or II.\textsuperscript{5} Overall removal with the exception of a (small) coagulated remnant was defined as Simpson Grade III. In these three grade groups the consistent absence of residual tumor on postoperative CT or MR imaging with contrast medium by the 3rd postoperative month indicated tumor control. All patients were followed up via mail or telephone inquiry in August 2004 to verify that no new clinical manifestations existed.

Neurological morbidity was described as the aggravation of a previous neurological deficit or the appearance of a new deficit that persisted beyond the 3rd postoperative month. Functional status was evaluated using the KPS. Any deaths within the first 3-month period after surgery were considered to be procedure related.

Patient Population and Tumor Characteristics

This study included 100 consecutive patients who had been referred to the senior author (M.P.S.) for surgery between 1980 and 2001 and were followed up for more than 3 to 23 years (mean 8 years). Thirty-one patients were male and 69 were female, with ages ranging from 15 to 81 years (mean ± standard deviation 57 ± 12.9 years). In addition to a neurological assessment, the KPS was used to determine the patient’s functional status. All patients underwent CT scanning, MR imaging, and DS angiography via the transfemoral arterial route to determine the degree of dural sinus and lumen invasion.

Meningiomas included in the study were those positioned on the confluence of sinuses or the sagittal or transverse sinus. The following varieties were excluded: 1) a meningioma located on the falx or paramedian convexity even if it was adjacent to the sinus and not invading its wall, as well as any tumor potentially detachable from the lateral wall without requiring resection of at least its outer layer; 2) a meningioma involving the sagittal sinus anterior to the precentral veins; and 3) a meningioma involving the lateral sinus at its sole sigmoid portion.

Ninety-two of the tumors were located in the superior sagittal sinus: 28 in the anterior third in close relation to the precentral veins, 48 in the middle third in relation to the postcentral veins, and 16 in the posterior third. Three lesions were positioned on the confluence of sinuses and five on the transverse portion of the lateral sinus. The tumor location included the falx in 15 cases and the tentorium in five. Histopathological subtypes of the meningiomas were defined according to the WHO classification (Table 1). The surgical record documented not only the location and size of the meningioma, but also the extent of removal based on the Simpson classification and the degree of sinus invasion. Meningiomas were categorized using a sinus invasion classification scheme created by the senior author (M.P.S.)\textsuperscript{56,58} and based on a simplification of those described by Krause (as detailed in Merrem\textsuperscript{8}) and by Bonnal and Brotchi\textsuperscript{8} (Fig. 1). The categories developed for a parasagittal lesion were also applied to meningiomas involving the confluence of sinuses or transverse sinus. Thirty-one cases had Type I invasion; eight, Type II; 11, Type III; 13, Type IV; five, Type V; and 32, Type VI.

Surgical Procedure

Surgical Strategy Based on Sinus Invasion. Three main surgical strategies were established based on the type of sinus invasion and the particularities of a case (such as the degree of preoperative deficits and age of the patient). The first involved simple resection of the outer dural layer and coagulation of the inner layer at the site of tumor attachment. The second strategy entailed resection of the invaded sinus wall(s) and its repair by using one of three methods: resecting the intraluminal fragment in the recess and suturing the recess edges, resecting the invaded wall(s) and repairing the sinus with an autologous patch, or resecting the occluded portion and creating a bypass with either an autologous vein or a Gore-Tex tube graft. The third strategy included no venous reconstruction and technically corresponded to a coagulation of the residual fragment or global resection of the involved sinus portion without any venous flow restoration.

Principles of Tumor Removal, Venous Reconstruction, and Control of Patency. Because the techniques have been detailed in previous publications,\textsuperscript{56,58,60,64} only the basic principles will be addressed here. All patients were placed in the semisitting position for sagittal sinus meningiomas and the sitting position for lesions in the confluence of sinuses or transverse sinus to allow good venous return. The skin flap and craniotomy extended across the midline to allow visualization of both sides of the sinus and approximately 3 cm proximally and distally to the margins of the occluded sinus. Particular care was taken to preserve the venous anastomotic pathways that had developed throughout the scalp, the pericranium, and the diploic venous channels, which had been previously identified on venous-phase DS angiograms and plain x-ray films of the skull (Fig. 2). Because there were frequent discrepancies between imaging data and anatomical findings regarding (eventual) intrasinusal fragments, the sinus was constantly explored through a small incision of 5 to 10 mm.

Venous bleeding from the sinus as well as from the af-
Different veins was temporarily controlled by packing small pledgets of hemostatic material (Surgicel; Johnson Medical, Viroflay, France) into the lumen and inside the ostia of its affluents (Fig. 3). Inflated balloons were not used because we had found that they generally do not pass easily through the sinus lumen because of septations, especially in the middle third portion. We also avoided using vascular clamps and aneurysm clips because of their propensity to crush the sinus walls. Venous reconstruction was performed using patches or bypasses, with two hemirunning sutures (Prolene 8-0; laboratoire ETHNOR, Neuilly/Seine, France). A piece of dura mater, pericranium, fascia lata, or fascia temporalis, depending on the case, was used for patching. For a totally occluded sinus, autologous vein grafts were harvested from the internal saphenous vein for long bypasses (that is, longer than 6 cm) or from the external jugular vein for shorter bypasses. A Gore-Tex tube was also used in some cases.

Surgery was accomplished in one stage in 69 patients and in two stages in 31 patients in whom it had been predicted that long operations might not be well tolerated. The two-stage group included all 12 patients who had undergone an autologous bypass and the 19 in whom patching had been performed; all six bypasses with the Gore-Tex tube were performed in one stage. Heparin therapy was administered as soon as the morning after surgery and for 3 weeks thereafter at dosages to double the clotting time. Coumadin was then administered for the next 3 months until the hypothetical end of sinus reendothelization.

A postoperative CT scan was obtained in all patients within the 2nd postoperative day before they left the intensive care unit. A control imaging study with and without contrast medium was performed at the first outpatient visit at 3 months postsurgery to look for a tumor remnant and at 3 years postsurgery to look for a recurrence. Therapeutically, only a clinical follow-up evaluation was performed, and an imaging study was undertaken only in the presence of new clinical manifestations. Patency of the venous repair was verified on DS angiography before the patient was discharged, approximately 2 weeks after surgery. Only 40 of 46 patients who had had venous reconstruction underwent DS angiography after surgery to check patency.

**Correlative Studies and Statistical Analysis**

Postoperative outcome, surgical morbidity and mortality rates, and tumor recurrence rate were studied in relation to surgical strategies and types of tumor presentation.

Statistical analyses were performed using BiostaTGV software (version 1999; Richard Lowry, Vassar College, Poughkeepsie, NY; http://faculty.vassar.edu/lowry/webtext.html). For continuous numerical data, the analysis of variance test was used to study the differences in KPS scores among the surgical groups. The Student t-test was used to evaluate the differences in pre- and postoperative KPS scores within each particular surgical group or between a maximum of two groups. The mean values are presented with a 95% confidence interval. For nominal data, the Fisher exact and chi-square tests were used to analyze the recurrence rate and mortality rate differences when two or three groups were evaluated. The factors for which probability values were less than 0.05 were defined as significant.

**Results**

**Degree of Resection**

Gross-total removal of the mass outside the sinus was complete in all 100 cases. Thirty-one cases had outer layer peeling associated with coagulation of the inner layer.
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(which was not invaded), thus reflecting a Simpson Grade II (if not Grade I) resection. Sixty-two cases involved total resection of the tumorous fragments invading the sinus (Simpson Grade I). The remaining seven cases involved only coagulation of the remnant (Simpson Grade III).

Surgical Modality According to the Type of Sinus Invasion

All 31 cases (100%) classified as having Type I sinus invasion entailed a peeling; all eight (100%) with Type II invasion required extraction of the tumor fragment located within the lateral recess, followed by resuture (Fig. 4). In eight (73%) of the 11 cases with Type III invasion, the invaded wall was resected and then patched (Fig. 5). In one (9%) of the remaining cases of Type III invasion, which involved a middle-third location, the fragment invading the wall was simply coagulated; in the other two cases (18%), both located in the anterior third, a global resection of the

Fig. 2. Representative parasagittal meningioma with Type VI invasion in the posterior third of the sinus. Left: Plain x-ray film, lateral view, showing a major intraosseous collateral venous pathway (ICVP). Right: Venous-phase DS angiogram, lateral view, demonstrating the collateral venous circulation from the superior sagittal sinus (SSS) to the sigmoid sinus (SS). Note complete occlusion (asterisk) of the posterior third of the SSS by the meningioma (M).

Fig. 3. Illustrations of parasagittal meningioma with Type IV sinus invasion showing steps in the patching technique. A: Exploration of the sinus lumen through a 3-cm-long opening, which allows identification of the intrasinusal tumor fragment. B: Control of venous bleeding using pledgets of Surgicel. C: Venous reconstruction performed using an autologous patch (Fascia temporalis in this case). F = falx cerebri; LW = lateral wall of SSS; P = patch; R = roof of SSS; S = Surgicel.
invaded portion of the sinus was performed without reconstruction. In six (46%) of the 13 cases of Type IV invasion, a resection of the two invaded walls plus patching was performed; in five cases (38%), a resection of the invaded portion plus a bypass was performed; and in two cases (15%), a simple coagulation of the residual fragment was deemed appropriate. All five cases (100%) of Type V invasion were treated with a resection of the two invaded walls plus a restoration of the venous flow with a patch. In 13 (41%) of the 32 cases of Type VI sinus invasion, the invaded sinus portion was resected and a bypass was performed (Fig. 6). Another four cases (13%) were treated with simple coagulation of the residual fragment. The remaining 15 cases (47%) involved a global resection of the invaded sinus without any reconstruction.

Postoperative Complications

Air embolism occurred in one case (1%) but was un-
A hematoma—one subdural (subacute) and two extradural—developed in three patients (3%); all patients had a favorable outcome after evacuation of the lesion. Note that in just one case with venous reconstruction did the complication of a hematoma occur among those in the anticoagulated subgroup. Six patients (6%) had sepsis: three due to a bone flap infection, two due to a cerebral abscess, and one due to an extradural empyema. All had a favorable outcome after the administration of antibiotic agents. All six of these patients belonged to the one-stage surgery group. A postoperative infection rate of 0% was associated with the two-stage surgery group.

The overall mortality rate was 3%; all deaths involved brain swelling. All three patients in these cases had Type VI sinus invasion and the entire invaded portion was resected without venous flow reconstruction (p = 0.002, chi-square test). Eight patients (8%) suffered permanent aggravation of their neurological deficit; three had undergone venous repair and five had not. The deficit was linked to focal cerebral infarction with a venous origin and was related to impairment of afferent bridging veins. Significantly, the location of the meningioma was in the middle-third portion of the sagittal sinus in seven patients and in the anterior third in one patient.

Functional Outcome

Overall, the mean preoperative KPS score was 92.7 ± 1.8, and the mean postoperative score was 90.7 ± 18; the differences between the scores were not statistically significant (p = 0.2, Student t-test). In cases of Type I sinus invasion, the mean preoperative KPS score was 92 ± 4 and the mean postoperative score was 96 ± 2.5; this increase of four points in the postoperative score was statistically significant (p = 0.02, Student t-test). Similarly, in cases of Type II invasion, improvement in the KPS score after surgery was significant: 85 ± 8 compared with 97 ± 4, respectively (p = 0.02, Student t-test). Among cases of Types III, IV, and V invasion, despite a slight decrease in the postoperative KPS score, differences in outcome were not significant: 94 ± 4 and 91 ± 8 for Type III, 94 ± 5 and 92 ± 6 for Type IV, and 98 ± 5 and 90 ± 2 for Type V. There was significant worsening in the postoperative KPS score among patients with Type VI invasion: 94 ± 3 compared with 84 ± 28 (p = 0.03, Student t-test).

Recurrence Rate

Four patients (4%) had a tumor recurrence. All recurrent lesions were located in the middle-third portion of the superior sagittal sinus. One patient, with Type IV sinus invasion, had been treated with resection of the invaded walls plus a patch; although the lesion had been classified as atypical at the first operation, it was deemed to be anaplastic at the second. Another patient, with Type II invasion, had undergone resection of the intraluminal fragment, through the lateral recess, plus resuturing; the recurrent lesion was categorized as a WHO Grade I. A third patient, with Type IV invasion, had undergone a two-stage surgery including a bypass with a saphenous vein; results of a pathological examination showed...
showed an angiofiblastic meningioma but with atypical signs (WHO Grade II). The fourth patient, who had undergone surgery elsewhere 2 years previously and had been referred to our institution for tumor recurrence, had Type VI invasion. An en bloc resection was performed, and the results of a pathological examination revealed a fibroblastic meningioma. Recopeation led to successful tumor removal in all four cases without any neurological aggravation. Adjunctive radiotherapy was indicated for the anaplastic meningioma.

Angiographic Results

Only 40 of the 45 patients who had undergone venous reconstruction had DS angiography data, which was obtained during the first 2 weeks after surgery. All eight patients (100%) who had undergone removal of a lesion fragment within the lateral recess together with simple resuture had sinus patency. Thirteen (87%) of the 15 patched cases and eight (72.7%) of the 11 autologous bypasses were patent, according to angiography studies (Figs. 5 and 6). All six patients in whom a Gore-Tex tube graft had been used were found to have thrombosis. One of them suffered acute intracranial hypertension, which was successfully reversed after intensive care management; the other five had asymptomatic thrombosis. When a saphenous venous graft was used, seven (70%) of the 10 controlled bypasses were patent. The one with the external jugular vein was patent as well.

Correlative Studies

To make the analysis of our results easier, the study population was divided into three groups. Group 1 (31 cases) consisted of cases in which the tumor did not invade the sinus lumen but only the outer layer of one wall; this group actually corresponded to cases with Type I sinus invasion. Group 2 (45 cases) included those cases with wall and lumen invasion (from Type II to VI invasion) that had involved venous reconstruction of any kind. Group 3 (24 cases) corresponded to those cases with the same wall and lumen invasion as in the second group but without any venous reconstruction; invaded wall(s) were coagulated and the occluded portion was globally resected without any flow restoration.

Postoperative Complications. The postoperative complications were compared according to surgical strategy. Group 1, in which a simple peeling of the outer layer had been performed, included one case of extradural hematoma, one case of intracerebral abscess, and one case of pulmonary embolism. Two of these three cases involved a tumor located in the anterior-third portion of the sinus, and one case involved the middle-third portion. In Group 2, two patients with Type VI invasion (the middle and posterior thirds) had a hematoma postoperatively. Complications also occurred in two other patients in Group 2: one patient with Type VI invasion in the region of the confluence of sinuses and transverse sinus who had undergone patch reconstruction had a frontal abscess at the site of a temporary external ventricular catheter, and one patient with Type II invasion in the middle-third portion of the sinus treated by opening and resuturing the lateral recess had an extradural empyema. In Group 3, there were three cases of bone flap infection; all of these patients had Type VI sinus invasion—two in the middle-third portion and one in the anterior third.

Functional Status. The preoperative KPS scores in patients in surgical Groups 1, 2, and 3 were 92 ± 4, 92 ± 3, and 96 ± 3, respectively. There were no significant differences among these scores (p = 0.5, analysis of variance). The differences between pre- and postoperative KPS scores were significant in Group 1 (92 ± 4 compared with 96 ± 2, respectively; p = 0.02, Student t-test) and Group 3 (95 ± 3 compared with 81 ± 3, respectively; p = 0.02, Student t-test), but not in Group 2 (92 ± 3 compared with 93 ± 9, respectively; p = 0.04, Student t-test). This result means that there was significant improvement in Group 1 and significant worsening in Group 3, in which no reconstruction was performed. Furthermore, differences in outcome between Group 2 (with reconstruction) and Group 3 (without reconstruction) were highly significant (p = 0.009, Student t-test; postoperative KPS Scores 93 ± 9 and 81 ± 3, respectively). Results are presented in a simplified form in Fig. 7.

Functional Outcome Based on Sinus Invasion and Reconstruction. In patients with Type II sinus invasion, the KPS score was significantly improved after surgery (85 ± 8 compared with 97 ± 4, p = 0.02, Student t-test; Table 2). In patients with Types III, IV, and V sinus invasion, all grouped together, reconstruction did not significantly worsen the postoperative KPS score (94.2 ± 8 compared with 92.5 ± 10, p = 0.4, Student t-test). On the contrary, patients who did not undergo a reconstruction had significantly worse postoperative KPS scores (96 ± 5 compared with 82 ± 13, p = 0.01, Student t-test). The change in the KPS score after surgery (Δ = 12.34) between reconstruction and nonreconstruction strategies significantly favors reconstruction (p = 0.02, Student t-test). In meningiomas with Type VI invasion, similar significant results based on surgical strategies were found. When reconstruction was performed, the KPS score did not change significantly after surgery (93 ± 8 compared with 92 ± 9, p = 0.4, Student t-test); in patients who did not undergo a bypass procedure, the postoperative KPS score worsened after resection (94 ± 8 compared with 78 ± 35, p = 0.03, Student t-test). Despite the discrepancy of 14 points in the postoperative KPS score in favor of the reconstructive strategy, statistical differences were not significant (p = 0.07, Student t-test; Table 2).

Discussion

Tumor Recurrence

In the current series of patients, the tumor recurrence rate was 4%, with a follow up ranging from 3 to 23 years (mean 8 years). This percentage was expected according to Simpson’s general classification of Grade I resections, or excisions of dural attachments. This relatively low rate seems due not only to the small number (only three) of atypical meningiomas encountered at the first surgery, but also to our policy of attempting radical resection, including the intrasinus portion, in most cases. Note that all four of these recurrent lesions were located in the middle third of the sagittal sinus, which is known to receive numerous and important afferent veins of the central group, and thus making surgery more difficult and risky. In the literature, the recurrence rate varies from 6% as in Hoessly and Olivecrona’s study, in which most patients underwent an en bloc resection, to 24% in the study by Mirimanoff and colleagues, with intermediate percentages being reported.
Discrepancies and associates in a reported tumor progression in seven cases, two reported different results in a series of evaluated the roles of microsurgery and GKS in conducted a retrospective study of 128 pa-

radiosurgery, respectively. In the surgical group, a Simpson diameter; 136 and 62 cases had been treated with surgery or 198 adults with benign meningiomas more than 35 mm in parasagittal location. In fact, Black and colleagues, not contain results specifically regarding meningiomas of institutional or hospital care (KPS Score or bad, patient unable to care for self and requires equivalent of in-

live at home and care for most personal needs (KPS Score 50–70); fair, patient unable to work but able to work at home and care for most personal needs (KPS Score 80–100); good, patient able to carry on normal working ac-

plished in all cases. In Types II to VI, the different modalities used according to types of tumor invasion and surgical modalities. In Type I, outer layer invasion by the tumor, a simple peeling was accom-

in any of the cases involving a Simpson Grade I or II resec-

ence or progression was more frequent in the surgical group than in the radiosurgical group, with complications occurring in 22% after surgery and in 10% after radiosurgery. In a series of 219 meningiomas diagnosed based on imaging criteria and treated with GKS alone, Flickinger and colleagues reported tumor progression in seven cases, two involving lesions other than meningiomas, after a median follow-up period of 29 months. Note that they also reported that there was a 2.3 ± 1.4% chance of an incorrect diagno-

sis. A tumor control rate of 93.2 ± 2.7% and the risk of a postradiosurgical injury reaction of 8.8 ± 3% at both 5 and 10 years were observed. Considering linear accelerator–based radiosurgery for the treatment of such lesions, Torres and colleagues conducted a retrospective study of 128 pa-

or hospital care (KPS Score < 40).

in other studies (Table 3). Most studies published thus far do not contain results specifically regarding meningiomas of the parasagittal location. In fact, Black and colleagues, in a study of 100 consecutive cases of skull base meningiomas followed up for a mean period of 5 years, showed a 7% morbidity rate in the 72 patients who had undergone resec-

ion of more than 50% of the tumor volume. Conversely, no complications were found in the group that had received radiotherapy (13 cases), although one case of tumor progress-

was reported. No tumor progression occurred in the 15 cases that were just monitored. In a study of 74 cases followed up for a mean period of 21.5 months, Linskey and associ-

ates evaluated the roles of microsurgery and GKS in 38 and 35 patients, respectively. There were no recurrences in any of the cases involving a Simpson Grade I or II resec-

ion (27 cases), and tumor control was 96.8% in the patients who underwent GKS. Although no differences in morbidi-

ty and mortality rates were found, symptoms improved in 48.4% of the patients who had undergone microsurgery and in 16.7% in those who had undergone GKS. However, Pol-

lock and associates reported different results in a series of 198 adults with benign meningiomas more than 35 mm in diameter; 136 and 62 cases had been treated with surgery or radiosurgery, respectively. In the surgical group, a Simpson Grade I resection was performed in 42%, a Simpson Grade II in another 42%, and Simpson Grade III or IV in 16%. After a mean follow-up period of 64 months, tumor recur-

rence or progression was more frequent in the surgical group than in the radiosurgical group, with complications occurring in 22% after surgery and in 10% after radiosurgery.

TABLE 2 Differences in pre- and postoperative KPS scores overall, according to the type of sinus invasion and the surgical strategy used

<table>
<thead>
<tr>
<th>Type of Invasion &amp; Surgical Strategy</th>
<th>Preop</th>
<th>Postop</th>
<th>Δ</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I peeling (31)</td>
<td>92 ± 4</td>
<td>96 ± 2</td>
<td>0.02*</td>
<td></td>
</tr>
<tr>
<td>Type II reconstruction (8)</td>
<td>85 ± 8</td>
<td>97 ± 4</td>
<td>0.02*</td>
<td></td>
</tr>
<tr>
<td>Types III–VI† reconstruction (24)</td>
<td>94.2 ± 8</td>
<td>92.5 ± 10</td>
<td>−1.66</td>
<td>0.4</td>
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<tr>
<td>no reconstruction (5)</td>
<td>96 ± 5</td>
<td>82 ± 13</td>
<td>−14</td>
<td>0.01*</td>
</tr>
<tr>
<td>Type VII‡ reconstruction (13)</td>
<td>93 ± 8</td>
<td>92 ± 9</td>
<td>−0.76</td>
<td>0.4</td>
</tr>
<tr>
<td>no reconstruction (19)</td>
<td>94 ± 8</td>
<td>78 ± 35</td>
<td>−15.78</td>
<td>0.03*</td>
</tr>
</tbody>
</table>

* Significant difference.
† Difference between scores after surgery with and those after surgery without reconstruction was −12.54 (p = 0.02).
‡ Difference between scores after surgery with and those after surgery without reconstruction was −14.02 (p = 0.02).

TABLE 3 Literature review of studies of meningiomas involving the major dural sinuses and reconstruction procedures

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases</th>
<th>Recurrence Rate (%)</th>
<th>Median Follow Up (yrs)</th>
<th>Overall Mortality (%)</th>
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<tbody>
<tr>
<td>Hoessly &amp; Olivecrona, 1955</td>
<td>196</td>
<td>6</td>
<td>5</td>
<td>12.3</td>
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<tr>
<td>Simpson, 1957</td>
<td>107</td>
<td>19</td>
<td>5</td>
<td>—</td>
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<tr>
<td>Logue, 1975</td>
<td>91</td>
<td>11</td>
<td>—</td>
<td>4.4</td>
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<tr>
<td>Bonnal &amp; Brothi, 1978</td>
<td>21</td>
<td>14</td>
<td>—</td>
<td>4.7</td>
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<tr>
<td>Kropp, et al., 1978</td>
<td>96</td>
<td>16.6</td>
<td>7</td>
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<tr>
<td>Yamashita, et al., 1980</td>
<td>80</td>
<td>14.6</td>
<td>5</td>
<td>—</td>
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<tr>
<td>Chan &amp; Thompson, 1984</td>
<td>16</td>
<td>13</td>
<td>—</td>
<td>—</td>
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<td>Giombini, et al., 1984</td>
<td>243</td>
<td>17.7</td>
<td>5</td>
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<td>Mirimanoff, et al., 1985</td>
<td>38</td>
<td>24</td>
<td>10</td>
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<td>Jaaskelevainen, 1986</td>
<td>136</td>
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<td>Philippon, et al., 1986</td>
<td>153</td>
<td>14.4</td>
<td>10</td>
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<td>Baird &amp; Gallagher, 1989</td>
<td>46</td>
<td>23.9</td>
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<td>—</td>
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<td>Di Meco, et al., 2004</td>
<td>108</td>
<td>13.9</td>
<td>13</td>
<td>2</td>
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<tr>
<td>present study</td>
<td>100</td>
<td>4</td>
<td>8</td>
<td>3</td>
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* = not available.
follow-up period of 32.5 months. These authors studied the results of SRT as a primary treatment and as a complementary therapy after microsurgical resection in 44 and 84 patients, respectively. Stereotactic radiosurgery to treat 79 lesions and fractionated SRT to treat 77 were evaluated over a mean period of 40 and 24 months, respectively. A 90% tumor control rate was achieved in the SRT-treated group of meningiomas and a 97.2% rate in the SRT-treated lesions. Additionally, 5 and 5.2% respective complication rates were reported.

Very few authors have detailed the effects of radiosurgery for a specific parasagittal location. In a study of 203 patients with histologically benign parasagittal meningiomas, Kondziolka and colleagues showed that the 5-year tumor control rate was 60 ± 10% in patients who had undergone radiosurgery after a previous surgery and 93 ± 4% in those who had undergone radiosurgery as the primary therapy. No treatment failures—that is, tumor growth needing additional therapy—occurred in patients harboring tumors smaller than 7.5 cm³ (41 patients). Because of the presence of symptomatic edema in 16% of the patients, predominantly in the larger meningiomas, the authors advised radiosurgery alone for tumors smaller than 3 cm in diameter and with an adjacent patent sinus, as long as the patient did not present with a rapidly progressive neurological deficit. Other authors have also reported postradiosurgical edema. Singh and associates studied a series of 77 intracranial meningiomas, 50 classified as basal and 27 as nonbasal (23 of which were parasagittal), that had been treated with GKS. They reported a 22% incidence of edema in the nonbasal (all of them parasagittal) group that was manifested as a temporary worsening of the neurological deficit in two thirds of the cases, compared with only 6% in the basal group and with manifestations in just one third. Similar results were reported by Chang, et al., in a study of 194 tumors treated with GKS and followed up over a period of 37.3 months. A 9.3% rate of transient symptomatic imaging-demonstrated changes were seen mostly in cases of convexity, parasagittal, and falx meningiomas.

In summary, authors of a fair number of retrospective studies have suggested that radiotherapy can decrease the rate of local treatment failure or tumor progression 5 years after subtotal surgery of meningiomas to less than 20%. Unfortunately, there has never been any randomized trial in which radiosurgery has been compared with surgery for the treatment of these tumors. Simple observation and radiotherapy at recurrence could be appropriate. Note, however, that the following randomized trial is starting (European Organisation for Research and Treatment of Cancer protocol 260201-22021): Observation versus conventionally fractioned radiotherapy or radiosurgery after non-radical surgery in benign intracranial meningioma. It will certainly help in the near future to elucidate the real role of these therapies.

**Surgical Venous Damages**

All authors dealing with parasagittal meningiomas agree on the importance of preserving the afferent (bridging) veins to the sinus, especially the ones of the central group in the middle-third portion of the sagittal sinus as well as those located at the transverse sinus and corresponding to the inferior cerebral veins of Labbé.

Avoiding the interruption of a partially occluded sagittal sinus is also a matter of strong consensus. On the contrary, the safety of resecting a totally occluded portion of a sinus, although traditionally accepted, remains disputable; brain swelling, venous infarction, and subcutaneous cerebrospinal fluid collection may occur when venous collateral circulation is impaired. In the study by Hoessly and Olivecrona, which included 196 parasagittal meningiomas treated without venous reconstruction, morbidity amounted to 12.3%; half of the cases involved venous damages. The 10% mortality rate corresponded to 14 (12.8%) of the 109 tumors located in the middle-third portion of the sinus, three (9.7%) of the 31 lesions in the posterior third, and three (5.3%) of the 56 lesions in the anterior third. In Bonnal and Brotchi’s study including 21 cases, one patient (4.8%) died after an en bloc tumor resection without venous restoration. In a recent article documenting the cooperative experience of eight surgeons and the grouping of 108 cases, Di Meco and colleagues mentioned the occurrence of severe brain swelling in three of the cases (10%) treated with en bloc resection without venous reconstruction. Also, persistent subgaleal fluid collection, likely corresponding to a default in cerebrospinal fluid resorption and/or persistent high intracranial pressure from a venous origin, was observed in 11 patients (10%). In the present study, morbidity and mortality rates related to venous damage and/or absence of venous flow reconstruction were estimated at 8 and 3%, respectively. Perhaps these patients would have had a better outcome if they had undergone venous repair, or perhaps shaving of the tumor outside the sinus with secondary SRT would have been less harmless. We really do not know.

**Dural Sinus Reconstruction**

Reconstructions in the venous system are not new. Different techniques of dural sinus repair were reported long ago and encouraging results of anastomosing cortical veins to the sinus were described more recently. Only studies of meningiomas involving the major dural sinuses with reconstruction are mentioned in our Table 3. First Bonnal and Brotchi and then Hakuba and colleagues reported satisfactory experiences with patches of pieces of dura or autologous venous graft. In the present study, 13 (86.6%) of the 15 repairs with dura or fascia, confirmed angiographically, were patent. Harvesting autologous veins, theoretically the best material for patching the venous system, actually seemed too excessive for patching. According to our experience, the most appropriate material is the thin and glossy fascia temporalis. For performing bypasses, the internal saphenous vein for a long graft and the external jugular vein for a short graft were used in 12 patients. Eight (72.7%) of the 11 angiographically controlled bypasses were patent. When a synthetic graft (namely, a Gore-Tex tube) was used (six cases), none were patent despite the use of anticoagulation, and thus we do not recommend using synthetic grafts on the venous system. When temporary occlusion of the sinus is required, the use of small pledges of Surgicel within the lumen and at the ostia of the tributary afferent veins makes the process simple. This technique has been found much more preferable than using aneurysm clips or balloons. In fact,
Treatment of meningiomas involving the major dural sinuses

The aim of this study was not to pretend that all tumors invading the major dural sinuses must be radically resected and the sinus systematically repaired. Before deciding to perform such a procedure, especially for those located in the middle-third portion of the sinus, other alternatives should be discussed: 1) primary surgery to shave the tumor from the sinus and, if the tumor grows, adjuvant radiosurgery or radiotherapy; and 2) radiosurgery for a small meningioma, with secondary surgery if the tumor is not controlled. A randomized trial to determine long-term tumor control and complication rates after radiosurgery as either a primary or a complementary treatment is needed.

Conclusions

The low recurrence rate in our study supports resecting not only the tumor portion outside the sinus but also the fragment invading the sinus. Ultimately, a decision must be made after weighing the benefits and risks. When we attempt radical removal, we consider venous reconstruction mandatory when the sinus is incompletely occluded and find it potentially useful even in cases of complete occlusion to restore flow that might be compromised by impaired collateral venous channels. Achieving radical removal requires opening the sinus, exploring its lumen, and (temporarily) interrupting its circulation; this process can be easily performed with pledges of Surgicel. Resected walls should be repaired with patching; a graft harvested from adjacent dura, fascia lata, or preferably the fascia temporalis appears adequate. For performing bypasses, only autologous grafts should be utilized: the external jugular vein for short grafts and the internal saphenous vein for longer ones. Patching or bypassing to restore venous flow did not increase the morbidity rate in our study. We consider postoperative anticoagulation mandatory for at least 3 months, until reendothelialization occurs; this strategy does not increase hemorrhagic complications.

The aim of this study was not to pretend that all tumors invading the major dural sinuses must be radically resected and the sinus systematically repaired. Before deciding to perform such a procedure, especially for those located in the middle-third portion of the sinus, other alternatives should be discussed: 1) primary surgery to shave the tumor from the sinus and, if the tumor grows, adjuvant radiosurgery or radiotherapy; and 2) radiosurgery for a small meningioma, with secondary surgery if the tumor is not controlled. A randomized trial to determine long-term tumor control and complication rates after radiosurgery as either a primary or a complementary treatment is needed.

References

22. Hakuba A, Huh CW, Tsuchijawa S, Nishimura S: Total removal of a parasagittal meningioma of the posterior third of the sagittal


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