Planum Sphenoidale and Tuberculum Sellae Meningiomas: Operative Nuances of a Modern Surgical Technique with Outcome and Proposal of a New Classification System

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BACKGROUND: The resection of planum sphenoidale and tuberculum sellae meningiomas is challenging. A universally accepted classification system predicting surgical risk and outcome is still lacking.

OBJECTIVES: We report a modern surgical technique specific for planum sphenoidale and tuberculum sellae meningiomas with associated outcome. A new classification system that can guide the surgical approach and may predict surgical risk is proposed.

METHODS: We conducted a retrospective review of the patients who between 2005 and March 2015 underwent a craniotomy or endoscopic surgery for the resection of meningiomas involving the suprasellar region. Operative nuances of a modified frontotemporal craniotomy and orbital osteotomy technique for meningioma removal and reconstruction are described.

RESULTS: Twenty-seven patients were found to have tumors arising mainly from the planum sphenoidale or the tuberculum sellae; 25 underwent frontotemporal craniotomy and tumor removal with orbital osteotomy and bilateral optic canal decompression, and 2 patients underwent endonasal transsphenoidal resection. The most common presenting symptom was visual disturbance (77%). Vision improved in 90% of those who presented with visual decline, and there was no permanent visual deterioration. Cerebrospinal fluid leak occurred in one of the 25 cranial cases (4%) and in 1 of 2 transsphenoidal cases (50%), and in both cases it resolved with treatment. There was no surgical mortality.

CONCLUSION: An orbitotomy and early decompression of the involved optic canal are important for achieving gross total resection, maximizing visual improvement, and avoiding recurrence. The visual outcomes were excellent. A new classification system that can allow the comparison of different series and approaches and indicate cases that are more suitable for an endoscopic transsphenoidal approach is presented.

INTRODUCTION

Meningiomas account for approximately 36% of all primary central nervous system tumors, representing the most frequently diagnosed primary brain tumor.
Twenty-five percent of all meningiomas consist of skull base meningiomas. Suprasellar meningiomas account for 5%–10% of all meningiomas, a term first used by Cushing and Eisenhardt in 1929 to describe tumors arising from the tuberulum sellae. In 1916, Cushing was the first to successfully resect such a tumor. Following Cushing’s description, authors included meningiomas of sellar and juxtasellar regions under the category of suprasellar meningioma. With time, clearer terminology evolved, as most neurosurgeons recognize the importance of anatomic origin in surgical planning. Al-Mefty subclassified the term suprasellar meningiomas to those arising from the planum sphenoidale (PS), tuberculum sellae (TS), diaphragma sellae (DS), and anterior clinoid (AC) process. De Divitiis distinguished clinical meningiomas from other suprasellar meningiomas.

PS and TS meningiomas can extend into adjacent areas such as the DS, sella turcica, posterior clinoid, and superior wall of the cavernous sinus. The sellar and juxtasellar regions are anatomically complex and critical. Elongate structures such as the optic nerves, internal carotid arteries (ICAs), anterior cerebral arteries (ACA), cavernous sinuses, pituitary stalk, and hypothalamus surround the area. Complete meningioma resection including vascular supply and the involved dura and bone may be difficult due to their intimate involvement with these nearby structures. Moreover, closeness of the sphenoid sinus and a surgical corridor through the sinus also predisposes these patients to postoperative cerebrospinal fluid (CSF) leak.

In this study, we present our 10-year retrospective, single-institutional experience with modern technique and its nuances aimed at resecting PS and TS meningiomas operated by the same technique. The purposes of this study are to report the outcomes for modern skull base techniques for resecting this group of meningiomas and describe a classification system allowing comparison of different series and approaches that may also be predictive of complication and outcome.

MATERIALS AND METHODS

Approval to review patients’ data retrospectively was obtained from the University of Washington Institutional Review Board. A retrospective analysis of all patients who underwent cranietomy for resection of meningiomas involving the suprasellar region, between 2005 and 2015 at the UW-Harborview Medical Center (HMC), Seattle, Washington, was performed.

Twenty-seven consecutive patients with previously unoperated suprasellar meningiomas operated between 2005 and March 2015 (by LNS and MJF) at HMC are included in the study. One had previous surgery at another institution from a large olfactory groove meningioma, resulting in blindness, and 10 years later she developed an unrelated suprasellar meningioma and underwent an endoscopic resection in our hospital. Overall, 2 patients underwent an endonasal transphenoidal endoscopic tumor removal. There were 5 giant tumors that either extended into the PS/TS area from the olfactory groove or the clinoidal area or from these expanded into the olfactory groove (Table 1). The resection approaches used for these giant tumors were frontotemporal with orbital osteotomy (1 patient). The 22 patients with small- to large-sized tumors (Table 2) underwent a frontotemporal craniotomy, orbital osteotomy, and optic canal decompression in all cases with the exception of 2 who underwent an endoscopic approach and 1 who underwent a fronto-temporal orbitozygomatic approach. Preoperative magnetic resonance imaging (MRI) was performed in all patients to determine tumor location, size, and surrounding neurovascular structure involvement, as well as signs of brain invasion. All patients received perioperative antibiotics, dexmethasone, and mannitol.

MRI examination was done postoperatively as well in the follow-up to assess the degree of resection. Computed tomography was performed instead of MRI if the patient could not have it for medical or financial reasons. Detailed histologic analysis of resected specimens was used to verify pathologic diagnosis and grading of the meningioma.

Tumor size was obtained as the average of measurements in 3 dimensions in any plane on MRI, calculated by tumor equivalent diameter, \( d = (D1 \times D2 \times D3)^{1/3} \).

All statistical comparisons were performed by a statistician (KJB) on IBM SPSS version 19 (IBM Corp., Armonk, New York, USA) using Fisher’s exact tests, \( t \)-tests, and Kaplan-Meier survival estimation as appropriate.

RESULTS

Patient Population

Of the 27 patients, 20 (74%) were female and 7 (26%) were male. The female-to-male ratio was 2.85:1. The mean age was 55.40 years (range 28–81 years, SD 13.10).

Clinical Findings

Visual disturbance was present in 21 (77%) patients, ranging from slight decrease of vision and partial field cut to complete loss of vision. Other symptoms, in order of frequency, included seizure (5 patients, 18%), headache (4 patients, 15%), anosmia (2 patients, 7%), cognitive deficit (2 patients, 7%), diplopia (1 patient, 4%), and dizziness, proptosis, and loss of balance (1 patient each, 4%) (Table 3). Anosmia and cognitive defects were mainly present in tumors of giant sizes, extending into multiple regions, and in tumors invading the brain.

Radiologic Findings

Preoperative MRI with and without contrast and magnetic resonance angiography were used to determine tumor location, size, and involvement of surrounding structures. These structures mainly included the ICA, ACA, optic canal and nerves, and surrounding brain tissue. For tumors encasing the ICA and ACA, a catheter intra-arterial digital subtraction angiogram was also performed.

Tumors originated from both PS and TS in 10 (37%) patients, TS in 5 (18.5%) patients, PS in 4 (15%) patients, PS and OG in 4 (15%) patients, TS and AC in 1 (3.7%) patient, PS and AC in 1 (3.7%) patient, and TS and dorsum sellae in 1 (3.7%) patient, and TS and OG in 1 patient (3.7%).

The tumor size ranged from 15–50 mm (mean 28.84 mm). Tumor invasion into the optic canals was found in 15 (55.5%) patients. Of these, 5 (33.3%) had 1 canal involved and 10 (66.6%)
<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Location</th>
<th>Presenting Symptoms*</th>
<th>Tumor Size (mm)</th>
<th>Preop KPS</th>
<th>Preop Snellen Test</th>
<th>Extent of Resection</th>
<th>LOS (Days)</th>
<th>Length of Follow-up (Months)</th>
<th>WHO Tumor Grade</th>
<th>Postop Radiation</th>
<th>Postop KPS</th>
<th>Recurrence</th>
<th>Postop Vision Snellen Test</th>
<th>Visual Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>F</td>
<td>TS/DS/Upper Clivus</td>
<td>Decreased vision, seizure, anosmia, cognitive deficit</td>
<td>45</td>
<td>80</td>
<td>R NLP L20/70</td>
<td>FT + OZ</td>
<td>GTR</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>R NLP L20/100</td>
<td>Worse in the immediate postoperative weeks, improved later to preop levels</td>
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<tr>
<td>2</td>
<td>63</td>
<td>M</td>
<td>PS</td>
<td>Progressive vision loss on the left eye</td>
<td>36</td>
<td>80</td>
<td>RNLP L15/50</td>
<td>FT + OO</td>
<td>NTR</td>
<td>9</td>
<td>2</td>
<td>GK</td>
<td>90</td>
<td>No regrowth</td>
<td>RNLP L20/25</td>
<td>Improved</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>F</td>
<td>PS</td>
<td>Persistent headaches, dizziness, visual cloudiness, seizure</td>
<td>53</td>
<td>80</td>
<td>R NLP L20/40</td>
<td>FT + OO</td>
<td>GTR</td>
<td>5</td>
<td>2</td>
<td>PB</td>
<td>90</td>
<td>-</td>
<td>R NLP L20/20</td>
<td>Left improved, right NLP</td>
</tr>
<tr>
<td>4</td>
<td>44</td>
<td>F</td>
<td>TS/OG</td>
<td>Progressive visual loss Anosmia, cognitive deficit</td>
<td>59</td>
<td>60</td>
<td>R20/50 L LP</td>
<td>BF + BOO</td>
<td>GTR</td>
<td>21</td>
<td>2</td>
<td>GK</td>
<td>80</td>
<td>-</td>
<td>R 20/100 L/4/200</td>
<td>Right worse Left slight improvement</td>
</tr>
<tr>
<td>5</td>
<td>53</td>
<td>M</td>
<td>PS/TS</td>
<td>Headaches, visual cloudiness</td>
<td>57</td>
<td>90</td>
<td>R 20/20 L20/25</td>
<td>BF + T + OO</td>
<td>GTR</td>
<td>10</td>
<td>1</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>R 20/20 L20/25</td>
<td>Unchanged</td>
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</table>

*LOS, length of hospital stay; WHO, World Health Organization; KPS, Karnofsky Performance Score; DS, dorsum sellae; NLP, no light perception; FT, frontotemporal approach; OZ, orbitozygomatic osteotomy; GTR, gross total resection; BF, bifrontal approach; T, temporal craniotomy; BOO, biorbital osteotomy; OO, orbital osteotomy; LP, light perception; GK, Gamma knife; PB, proton beam; GTR, gross total resection; NTR, near total resection.

*All nonvisual presenting symptoms resolved postoperatively.
Table 2. Patients with Small- and Medium-Sized Meningiomas Extending or Originating in the Planum Sphenoidale (PS)/Tuberculum Sellae (TS) Area

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Location</th>
<th>Presenting Symptoms*</th>
<th>Tumor Size (mm)</th>
<th>Preop KPS</th>
<th>Preop Vision Snellen Test</th>
<th>Surgery</th>
<th>Extent of Resection</th>
<th>LOS (Days)</th>
<th>Length of Follow-up (Months)</th>
<th>WHO Tumor Grade</th>
<th>Postop Radiation</th>
<th>Postop KPS</th>
<th>Postop Vision Snellen Test</th>
<th>Visual Outcome</th>
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<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>F</td>
<td>PS/TS</td>
<td>Decreased vision, diplopia</td>
<td>20</td>
<td>80</td>
<td>R20/30 + 2 L20/20</td>
<td>FT + OO</td>
<td>GTR</td>
<td>5</td>
<td>99.9</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>—</td>
<td>R20/25 L20/20</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>F</td>
<td>TS</td>
<td>Blurred vision, diplopia, headaches</td>
<td>17</td>
<td>80</td>
<td>R20/25 L20/40</td>
<td>FT + OO</td>
<td>GTR</td>
<td>13</td>
<td>99.6</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>R20/25 L20/30</td>
<td>Improved</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>F</td>
<td>TS</td>
<td>Progressive visual loss</td>
<td>15</td>
<td>80</td>
<td>RNLP L20/50</td>
<td>FT + OO</td>
<td>GTR</td>
<td>4</td>
<td>93.8</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>RNLP L20/40</td>
<td>Improved</td>
</tr>
<tr>
<td>4</td>
<td>62</td>
<td>M</td>
<td>PS/OG</td>
<td>Seizures</td>
<td>28</td>
<td>90</td>
<td>—</td>
<td>FT + OO</td>
<td>GTR</td>
<td>2</td>
<td>71.1</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>—</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>F</td>
<td>PS/TS</td>
<td>Blurred vision</td>
<td>19</td>
<td>80</td>
<td>R20/20 L20/25 + 1</td>
<td>FT + OO</td>
<td>GTR</td>
<td>11</td>
<td>64.1</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>R20/20 L20/20</td>
<td>Improved</td>
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<tr>
<td>6</td>
<td>81</td>
<td>F</td>
<td>PS/OG</td>
<td>Incidental</td>
<td>31</td>
<td>80</td>
<td>—</td>
<td>FT + OO</td>
<td>GTR</td>
<td>9</td>
<td>63.1</td>
<td>1</td>
<td>—</td>
<td>100</td>
<td>—</td>
<td>NA</td>
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<tr>
<td>7</td>
<td>58</td>
<td>F</td>
<td>PS/OG</td>
<td>Seizures</td>
<td>24</td>
<td>80</td>
<td>—</td>
<td>FT + OO</td>
<td>GTR</td>
<td>4</td>
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<td>1</td>
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<td>90</td>
<td>—</td>
<td>NA</td>
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<tr>
<td>8</td>
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<td>F</td>
<td>PS/OG</td>
<td>Seizures</td>
<td>35</td>
<td>80</td>
<td>—</td>
<td>FT + OO</td>
<td>GTR</td>
<td>11</td>
<td>55.9</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>—</td>
<td>NA</td>
</tr>
<tr>
<td>9</td>
<td>51</td>
<td>M</td>
<td>TS</td>
<td>Visual cloudiness</td>
<td>16</td>
<td>80</td>
<td>R20/20 L15/20</td>
<td>FT + OO</td>
<td>GTR</td>
<td>15</td>
<td>56.2</td>
<td>1</td>
<td>—</td>
<td>80</td>
<td>R20/20 L20/20</td>
<td>Improved</td>
</tr>
<tr>
<td>10</td>
<td>35</td>
<td>M</td>
<td>TS</td>
<td>Headaches, blurred vision</td>
<td>21</td>
<td>80</td>
<td>R20/10 L20/20</td>
<td>FT + OO</td>
<td>GTR</td>
<td>5</td>
<td>49.4</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>R20/60 L20/20</td>
<td>Improved</td>
</tr>
<tr>
<td>11</td>
<td>48</td>
<td>F</td>
<td>PS/TS</td>
<td>Blurred vision</td>
<td>29</td>
<td>80</td>
<td>R20/40 L20/25</td>
<td>FT + OO</td>
<td>GTR</td>
<td>4</td>
<td>40.8</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>R20/25 L20/25</td>
<td>Improved</td>
</tr>
<tr>
<td>12</td>
<td>69</td>
<td>F</td>
<td>PS/TS</td>
<td>Progressive visual loss, diplopia</td>
<td>22</td>
<td>80</td>
<td>R20/60 L CF at 3</td>
<td>FT + OO</td>
<td>GTR</td>
<td>11</td>
<td>38.6</td>
<td>2</td>
<td>GK</td>
<td>90</td>
<td>R20/20 HM</td>
<td>Improved</td>
</tr>
<tr>
<td>13</td>
<td>51</td>
<td>F</td>
<td>TS/AC</td>
<td>Progressive visual loss diplopia</td>
<td>27</td>
<td>80</td>
<td>R20/25 L LP</td>
<td>FT + OO</td>
<td>GTR</td>
<td>3</td>
<td>37.6</td>
<td>1</td>
<td>—</td>
<td>80</td>
<td>R20/20-1 L HM peripherally</td>
<td>Improved</td>
</tr>
<tr>
<td>14</td>
<td>53</td>
<td>F</td>
<td>PS/TS</td>
<td>Blurred vision</td>
<td>27</td>
<td>80</td>
<td>R20/20 L20/200</td>
<td>FT + OO</td>
<td>GTR</td>
<td>8</td>
<td>27.7</td>
<td>1</td>
<td>—</td>
<td>100</td>
<td>R20/20 L20/40</td>
<td>Improved</td>
</tr>
<tr>
<td>15</td>
<td>54</td>
<td>F</td>
<td>PS/TS</td>
<td>Progressive visual loss</td>
<td>33</td>
<td>80</td>
<td>R15/20 L20/40</td>
<td>FT + OO</td>
<td>GTR</td>
<td>7</td>
<td>20.8</td>
<td>1</td>
<td>—</td>
<td>90</td>
<td>R20/25 + 1 L20/25 - 3</td>
<td>Improved</td>
</tr>
</tbody>
</table>

KPS, Karnofsky Performance Score; LOS, length of hospital stay; WHO, World Health Organization; BF, bifrontal approach; FT, frontotemporal approach; T, temporal craniotomy; BOO, biorbital osteotomy; OO, orbital osteotomy; OZ, orbitozygomatic osteotomy; GTR, gross total resection; LP, light perception; NLP, no light perception; GK, Gamma knife; PB, proton beam; GTR, gross total resection; NTR, near total resection; NA, not applicable.

*All nonvisual presenting symptoms resolved postoperatively.
| Pt | Age (years) | Gender | Location | Presenting Symptoms* | Tumor Size (mm) | Preop KPS | Preop Snellen Test | Surgery | Extent of Resection | LOS (Days) | Length of Follow-up (Months) | WHO Tumor Grade | Postop Radiation | Postop KPS | Postop Vision Snellen Test | Visual Outcome |
| 16 | 31 | F | PS | Patient blind from previous surgery in a other institution complained about headaches | 31 | 40 | -- | Endoscopic approach | GTR | 3 | 15.8 | 1 | -- | 50 | -- | -- | NA |
| 17 | 60 | F | TS | Blurred vision | 18 | 90 | R20/20 L20/240 | FT + OO | NTR | 3 | 13.9 | 1 | -- | 90 | -- | R20/20 L20/50 | Improved |
| 18 | 80 | F | PS/TS | Headaches, occasionally visual cloudiness | 27 | 90 | R20/25 L20/30 | FT + OO | GTR | 6 | 13.9 | 1 | -- | 90 | -- | R20/25 L20/30 | Unchanged |
| 19 | 47 | F | PS | Proptosis, visual cloudiness | 15 | 100 | R 20/20 L20/25+1 | FT + OZ | GTR | 2 | 7.5 | 1 | -- | 100 | -- | R20/20 L20/20 | Improved |
| 20 | 58 | F | PS/TS | Visual cloudiness | 20 | 100 | R 20/25 -2 L20/25 | FT + OO | GTR | 5 | 5 | 1 | -- | 100 | -- | R 20/20-2 L20/20 | Improved |
| 21 | 66 | F | PS/TS | Blurred vision | 31 | 90 | R20/25+2 L20/20 | FT + OO | GTR | 13 | 1.9 | 1 | -- | 100 | -- | R20/25 L20/20 | Improved |
| 22 | 62 | F | PS | Incidental after work-up for head trauma | 15 | 100 | R 20/20 L20/20 | Endoscopic approach | GTR | 7 | 1.9 | 1 | -- | 100 | -- | R 20/20 L20/20 | Unchanged |

KPS, Karnofsky Performance Score; LOS, length of hospital stay; WHO, World Health Organization; BF, bifrontal approach; FT, frontotemporal approach; T, temporal craniotomy; BOO, biorbital osteotomy; OO, orbital osteotomy; OZ, orbitozygomatic osteotomy; GTR, gross total resection; LP, light perception; NLP, no light perception; GK, Gamma knife; PB, proton beam; GTR, gross total resection; NTR, near total resection; NA, not applicable.

*All nonvisual presenting symptoms resolved postoperatively.
had both canals involved. Of the patients with optic canal involvement, 3 patients (20%) had unilateral or bilateral almost complete canal occlusion. Two of these had their tumors arising from PS and 1 from TS.

Vascular encasement was defined as an artery surrounded by tumor and was measured by the extent of tumor-vessel contact. For practical reasons, we divided encasement into 2 groups: more or less than 180% of the circumference of the involved artery.8

For practical reasons, we divided encasement into 2 groups: more or less than 180% of the circumference of the involved artery.8 ICAs were encased in 21 patients (77.7%); of the patients who had ICA encasement, 5 (23%) had unilateral ICA involved and 16 of them (76%) had bilateral ICAs involved. ACAs were encased in 12 (44%) patients; of this group of patients, three (25%) had unilateral ACA involved and 9 (75%) had bilateral ACAs involved. Of the 27 patients in this series, 3 patients (11%) had no arteries encased, 5 patients (18.5%) had 1 artery encased, 4 patients (14%) had 2 arteries encased, 3 patients (11%) had 3 arteries encased, and 9 patients (33%) had 4 arteries encased.

Surrounding brain tissue involvement was assessed indirectly by fluid-attenuated inversion recovery (FLAIR) magnetic resonance angiography imaging. The findings were then divided into 2 types based on the level of FLAIR enhancement: mild and significant. As mild FLAIR might be seen without actual brain invasion, only significant FLAIR-imaging was considered as probable evidence of pial brain invasion.

Significant FLAIR-signal was found in 2 patients (8%). Both cases originated from PS.

Surgical Procedure and Length of Hospitalization

Twenty-five of the 27 meningiomas were resected through a frontotemporal craniotomy with orbital osteotomy and early optic canal decompression. One patient had an additional zygomatic osteotomy due to a larger surgical corridor needed for access to an extensive sellar and hypothalamic involvement, and 2 patients were resected by an endonasal transsphenoidal approach.

Gross total resection (GTR) was defined as no residual based on an independent neuroradiology report on the immediate postoperative MRI scan. Near-total resection (NTR) was described as any minor tumor residual (at least 95% resection on volumetric assessment) based on a similar independent neuroradiology report. GTR was accomplished in 25 patients (92.5%), and the remaining 2 patients (7.5%) had NTR. Of the NTR patients, the preoperative tumor size was 18 in one and 36 mm in the other. The tumor residuals were minimal adherent tumor residual left in the left optic canal, and in the other case around the right ICA.

The length of hospitalization ranged from 2–21 days (mean 7.68 days).

Operative Technique with Nuances: Frontotemporal Craniotomy with Orbital Osteotomy and Early Optic Canal Decompression

The side of vascular encasement is chosen as the craniotomy side, regardless of the side of optic canal involvement. A standard frontotemporal craniotomy is followed by a lateral orbital osteotomy. As much of the PS as possible is removed extradurally. The superior orbital fissure is decompressed by additional bone removal. Extradural decompression of the ipsilateral optic nerve and removal of the ipsilateral anterior clinoid process using the ultrasonic bone curette (Sonopet, Striker Co, Kalamazoo, Michigan, USA) are then performed, followed by the optic nerve decompression with a rough or smooth diamond drill. We avoid using the ultrasonic bone curette at this stage because of concern for visual loss due to heat or ultrasonic vibrations.

The ipsilateral Sylvian fissure is opened. Care is taken to preserve the olfactory tract; if necessary, it is dissected away from the frontal lobe. Brain retractor use is avoided or minimized. The ipsilateral optic nerve is decompressed farther intradurally by opening the falxform ligament and the dural sheath widely before any tumor resection, in order to avoid excessive traction on the optic nerve. This will allow the optic nerve to spring away from the tumor and be gently manipulated. The tumor is debulked between the 2 optic nerves and through the ipsilateral optico-carotid triangle. The tumor is then dissected away from the ipsilateral optic nerve, chiasm, ICA, and ACA, maintaining the arachnoid plane. Special attention should be given to perforators from the ACA and the bilateral superior hypophyseal arteries, which should be preserved. The dura of the PS/TS region is resected, and if necessary hyperostotic bone is drilled away to access tumor within the sella. The ipsilateral anterior clinoid process is removed completely intradurally, if the ICA is encased. The contralateral optic canal is usually decompressed intradurally as well so that the tumor can be removed in that location.

The important initial step of tumor removal is to create a central cavity that is free of tumor and bring the remaining tumor piece by piece into this cavity to remove it. Tumor debulking is performed away from the optic nerve and chiasm, in a piecemeal fashion. Encased arteries can generally be dissected using the arachnoid plane or an epidural adventitial plane.

The dural defect is covered by a free pericranial graft, and if there is a wide opening in the sphenoid sinus, the superior portion of the sinus is packed with a fat graft in addition to the pericranial graft. (See Supplemental Video 1, Right Frontotemporal Craniotomy with Posterolateral Orbitotomy for

**Table 3. Presenting Symptoms in 27 Patients with Planum Sphenoidale Meningiomas**

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Number of Patients</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual disturbance*</td>
<td>21</td>
<td>77</td>
</tr>
<tr>
<td>Seizure</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Headache</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Cognitive deficit</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Anosmia</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Diplopia</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Dizziness/loss of balance</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Proptosis</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

*Twenty-one of 27 patients had visual symptoms on admission. Of these, 15 had discernible unilateral or bilateral optic canal invasion on preoperative magnetic resonance imaging. Of 21 patients with preoperative visual decline, 19 of them (90%) improved, 1 had no change (10%), and none had worsening of visual deficits.

**Video available at WORLDEUROSURGERY.org**

**Supplemental Video 1** Right Frontotemporal Craniotomy with Posterolateral Orbitotomy for...
Resection of Planum Sphenoidale and Tuberculum Sellae Meningioma. A lumbar drain is only used if CSF leak is observed postoperatively.

**Histopathology**

The pathologic slides were carefully reviewed for number of mitoses per 10 high-power fields, hyperchromasia, hypercellularity, and brain invasion. These parameters were found in 9 patients (33.3%), 2 patients (7%), 2 patients (7%), and 2 patients (7%), respectively. Twenty-four (89%) cases were classified as World Health Organization (WHO) grade I, and three (11%) were classified as WHO grade II tumors. There were no WHO grade III tumors.

**Postoperative Radiotherapy**

Four patients had postoperative radiotherapy. The 3 patients (11%) with WHO grade II tumors received postoperative radiation; 2 had undergone GTR, and 1 had undergone NTR. The NTR patient had a WHO grade I meningioma and received postoperative radiotherapy because of the encasement of four vessels, bilateral optic nerves, and the oculomotor nerve. Gamma knife (GK) radiation treatment was given to 3 patients, and 1 received proton beam radiotherapy (Figure 1). One patient with NTR and WHO grade I tumor was not irradiated due to the proximity of the optic canal.

**Follow-up and Outcomes**

**Clinical Follow-up and Visual Outcome.** Duration of clinical follow-up ranged from 2 to 100 months (mean 40.1 months).

<table>
<thead>
<tr>
<th>Approach</th>
<th>Sekhar–Mortazavi Tumor Classification</th>
<th>Tumor Resection</th>
<th>WHO Tumor Classification</th>
<th>Postoperative RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS and TS meningiomas</td>
<td>Sekhar–Mortazavi Class I and Class II</td>
<td>N = 20</td>
<td>WHO Grade I N = 18 / WHO Grade II N = 1</td>
<td>RT in WHO Grade II patient</td>
</tr>
<tr>
<td>Intracranial Approach N = 25</td>
<td>PS and TS meningiomas</td>
<td>N = 27</td>
<td>WHO Grade I N = 1</td>
<td>No RT</td>
</tr>
<tr>
<td>PS and TS meningiomas</td>
<td>Sekhar–Mortazavi Class III N = 5</td>
<td>GTR N = 2</td>
<td>WHO Grade II N = 2</td>
<td>RT in WHO Grade II patients</td>
</tr>
<tr>
<td>Endoscopic Approach N = 2</td>
<td>PS and TS meningiomas</td>
<td>N = 2</td>
<td>WHO Grade I N = 1</td>
<td>RT in NTR WHO Grade II patient</td>
</tr>
</tbody>
</table>

Of the 21 patients with preoperative visual disturbance, 19 of them (90%) had varying degrees of improvement and 2 of them (10%) had no change. No patient experienced permanent worsening of vision at 3 months postoperatively or developed new permanent postoperative visual deficit (see Table 3).

Five patients with preoperative seizure improved after surgery. Four (80%) stopped antiepileptic medications during follow-up, and one (20%) was still on medications with no more seizure episodes. Preoperative anosmia persisted in both patients postoperatively. All other presenting symptoms completely resolved after surgery.

**Postoperative Nonvisual Complications**

**Cranial nerves.** Immediate postoperative cranial nerve (CN) complications were found in 8 patients (30%). These include partial oculomotor (third) nerve paresis (4 patients, 14.8%), partial abducens (sixth) nerve paresis (1 patient, 4%), and partial frontalis nerve paresis (2 patients, 8%). A complete olfactory, first nerve paresis (anosmia), was preoperatively present in 2 patients (8%) and remained unchanged postoperatively.

**Cranial nerves.** However, most of these CN complications were transient and resolved at 6-months of follow-up. Among the 23 patients (85%) with at least 6 months of follow-up, we observed that 4 with postoperative partial oculomotor (third) nerve paresis had completely recovered (see Table 4).

**Cranial nerves.** Other: Immediate postoperative complications included CSF leak (2 patients, 7%); headache (2 patients, 3.7%); diabetes insipidus (DI, 1 patient, 3.7%); atypical facial pain.
(1 patient, 3.7%); dysconjugate gaze (1 patient, 3.7%); pseudomeningocele (1 patient, 3.7%); decreased taste for salt (1 patient, 3.7%); and late wound erosion on a titanium plate requiring revision (1 patient, 3.7%) (see Table 4). Early in our series, CSF leak was observed in 1 patient after intracranial approach (4%); the leak was managed by a transnasal transsphenoidal approach using a septal vascularized flap and fat graft. It also occurred in 1 patient after an endoscopic transsphenoidal operation, this leak being managed by endonasal endoscopic re-exploration and herniated abdominal fascia reconstruction using additional AlloDerm (LifeCell Corporation, Branchburg, New Jersey, USA) and Duraseal (Covidien, Minneapolis, Minnesota, USA) dural sealant.

Intraoperative ICA injury occurred in 1 patient (3.7%), during the removal of a WHO grade II tumor encasing and invading the ICA. The ICA was injured during resection and repaired intraoperatively with sutures with no persistent complications. During the follow-up period, all of the postoperative complications had resolved.

**Imaging Follow-up and Recurrence.** The duration of imaging (MRI or computed tomography) follow-up ranged from 6–94 months (mean 17.1 months). We set a minimum of 12 months of follow-up to determine the presence or absence of tumor recurrence. This is based on clinical experience and is not validated due to the rarity of this tumor group. Of the 23 patients (85%) with at least 12 months of follow-up, none has shown any tumor recurrence. The WHO II tumors that received postoperative radiation so far have not recurred (see Figure 1).

**Functional Outcome**
Preoperative functional evaluation was measured according to Karnofsky performance score (KPS). Two patients had a lower KPS: One patient presented a KPS of 40 and another of 60. One patient had a KPS of 70, sixteen had KPS of 80, five had KPS of 90, and 3 of 100. The mean preoperative KPS was 81.1.

Postoperatively, 5 patients had a KPS of 80, 15 had a KPS of 90, and 8 had a KPS of 100. In total, 20 patients (74%) had improved KPS and 7 (27%) were unchanged. However, the 2 patients with the lower KPS had improvements of their scores: from 40–50 and from 60–80. Among those without KPS changes were the patients who had preoperative scores of 100, 3 who had preoperative scores of 90, and 3 of 80. The mean postoperative KPS was 90.8. The mean KPS improvement was 9.7.

**PROPOSED CLASSIFICATION**
On the basis of our experience with the current series, we propose a new score-based classification system. In this classification, 6 parameters are tested using preoperative MRI and previous treatment. Points are assigned to each parameter.

**Tumor Size**
Larger tumors usually cause stretching of the surrounding neurovascular structures and extend into multiple areas and, therefore, are more difficult to resect completely. Moreover, larger tumors are harder to completely resect through transsphenoidal approach, and craniotomy is usually necessary.

Advances in modern imaging allow accurate and detailed measurement of tumor size. In the literature, a generally preferred size measure is the tumor’s greatest diameter in any plane on MRI.9,10 Although the tumor volume might be a more accurate measure, it does not have a practical utility in clinical practice and surgeon-surgeon or surgeon-radiologist communication. In most studies, tumor size is described according to Yasargil’s classification, where tumors are divided as <2 cm, 2–4 cm, and >4 cm.
We have maintained 0–1.9 cm, 2–3.9 cm, and ≥4 cm of the tumor equivalent diameter to derive the points (0, 1, or 2).

**Optic Canal Involvement**
The degree of tumor invasion into the optic canal can alter the route of access and help determine the clinical outcome and recurrence. If slight invasion is present, a transsphenoidal approach is an option, but if extensive invasion is present, a craniotomy approach is necessary to decompres the optic nerve completely and remove the entire tumor. Recurrences will often occur due to insufficient tumor resection from the optic canal. We assign 0, 1, or 2 points for optic canal invasion (Table 5).

**Vascular Encasement**
The absence of arachnoid plane between the tumor and the surrounding encased vessels predicts more difficult resection and more risk of vascular injury. The most commonly involved vessels are the ICA, ACA, and their branches. Vascular encasement was graded as none, <180°, ≥180°, and ≥2 arteries involved. The points assigned were, respectively, 0, 1, 2, 3, and 4 (see Table 5).

**Brain Invasion**
Tumor invasion into the surrounding brain tissue can be suspected preoperatively using FLAIR imaging on MRI scans. Such invasion is usually associated with larger tumor size. Mild FLAIR signal might be due to local compression of the tumor and therefore does not indicate brain invasion. Patients with brain invasion tend to have a higher incidence of perioperative seizures, mental and behavioral alterations, and memory deficits. Risk of intraoperative CN injury during tumor resection is also higher in these patients. Therefore degree of brain invasion, determined by the level of surrounding neural tissue enhancement, warrants the need for better and larger view during the surgery to achieve a more radical and less traumatic resection. We assigned 1 point when a significant FLAIR signal was present (see Table 5).

**Previous Surgery and Radiation**
The other 2 factors to determine preoperatively are prior surgery and radiation. Although none of the patients in this series had prior surgery or radiation, on the basis of the senior author’s long-term experience, previous surgery or exposure to radiation makes surgery more difficult due to scarring and should be considered preoperatively.

**Summary of Scoring**
On the basis of these factors, points were given as follows (see Table 5):

1. Tumor size: 0 points for <2 cm, 1 point for 2–4 cm and 2 points for >4 cm.
2. Optic canal invasion: 0 points for invasion <5 mm, 1 point for >5 mm, and 2 points for complete occlusion. A maximum of 2 points is given for any combination of optic canal invasion.
3. Vascular encasement (2 ICAs, 2 ACAs): 0 points for no vascular encasement, 1 point for encasement <180°, and 2 points for encasement >180°. A maximum of 4 points for any combination of vascular encasement, even if the sum is more than 4.
4. Brain invasion (by FLAIR): 0 points for no or mild FLAIR signal and 1 point for significant FLAIR signal.
5. Previous surgery: 0 points for no and 1 point for previous surgery.
6. Previous radiation: 0 points for no and 1 point for previous radiation.

**Classification System**
A class is given according to the sum of total points for each tumor (total score ranges from 0–11): class I: 0–3 points, class II: 4–7 points, and class III: 8–11 points (see Figure 2, A-C) After applying this classification on our series, 11 patients (44%) were in class I, 9 patients (36%) were in class II, and 5 patients (20%) were in class III (see Table 5).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>0  1  2  4</td>
</tr>
<tr>
<td>&lt;2 cm</td>
<td>2.4 cm</td>
</tr>
<tr>
<td>&gt;5 mm</td>
<td>Complete</td>
</tr>
<tr>
<td>Vascular invasion (ICA, ACA)</td>
<td>No  &lt;180°</td>
</tr>
<tr>
<td>No</td>
<td>&gt;180°</td>
</tr>
<tr>
<td>Brain invasion on MRI</td>
<td>No or mild FLAIR signal</td>
</tr>
<tr>
<td>Yes</td>
<td>Significant FLAIR signal</td>
</tr>
<tr>
<td>Previous surgery</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Previous radiation</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5. Proposed Score-Based Classification System for Planum Sphenoidale and Tuberculum Sellae Meningiomas**

Scores: 0-3 = Class I; 4-7 = Class II; 8-11 = Class III.
Study sample (n = 27): Class I (n = 13), Class II (n = 9), Class III (n = 5).
ICA, internal carotid artery; ACA, anterior cerebral artery; MRI, magnetic resonance imaging; FLAIR, fluid attenuated inversion recovery.
*A maximum of 2 points is given for any combination of optic canal invasion.
To assess the predictive efficacy of the proposed classification, outcomes of surgical resection of both low-class (Class I) and high-class (Classes II and III) tumors were compared (Table 6). High-class tumors had higher rates of intraoperative vascular injury (6% vs. 0%). The need for postoperative radiation of high-class tumors was higher (25% vs. 0%), but this was probably secondary to the fact that these 3 cases were WHO grade 2 tumors that always receive postoperative radiation per our protocol. As there was no tumor recurrence, no accumulative recurrence rate could be calculated.

Visual improvement was higher in the low-class tumors (100% vs. 90%).

**Predictive Value**

Figure 2. Illustrations showing examples of our proposed classification for PS and TS meningiomas. (A) (Class I): showing a <2-cm tumor, with no extension into the optic canal and no ICA or ACA encasement. (B) (Class II): showing a >4-cm tumor, with >5-mm extension into the right optic canal, and >180° encasement of the right ICA. (C) (Class III): Showing a >4-cm tumor, with >5-mm extension into both optic canals, >180° encasement of bilateral ICAs or ACAs, and bone invasion with extension into the sphenoid sinus.
Case 2 — ICA cases were encased by progressive visual loss due to a 27-mm tumor arising from the TS tumor recurrence at 73-months with no diplopia, and she had no more seizures. There was no tumor was graded pathologically as WHO I. Her vision improved orbital osteotomy was performed, and GTR was achieved. The and therefore was Class I. A frontotemporal craniotomy with Per our classi

Table 6. Predictive Value of the Proposed Classification System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total (N = 27)</th>
<th>Class I (N = 11)</th>
<th>Class II–III (N = 16)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTR</td>
<td>25 (93%)</td>
<td>10 (91%)</td>
<td>15 (94%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Vascular injury</td>
<td>1 (4%)</td>
<td>0 (0%)</td>
<td>1 (6%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Visual improvement</td>
<td>19/21 (90%) (5/5 (100%)</td>
<td>14/16 (88%)</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Need for postoperative radiation</td>
<td>4 (15%)</td>
<td>0 (0%)</td>
<td>4 (25%)</td>
<td>.123</td>
</tr>
<tr>
<td>KPS improvement</td>
<td>8.5 (6.6)</td>
<td>7.3 (6.5)</td>
<td>9.4 (6.8)</td>
<td>.429</td>
</tr>
<tr>
<td>Recurrences</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>—</td>
</tr>
<tr>
<td>Length of follow-up in months, min-max (mean)</td>
<td>2-100 (40.1)</td>
<td>2-100 (58.9)</td>
<td>2-64 (28.6)</td>
<td>—</td>
</tr>
<tr>
<td>Cumulative recurrence rate</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>—</td>
</tr>
</tbody>
</table>

GTR, gross total resection; KPS, Karnofsky Performance Score.
*Significance by Fisher Exact (unless noted).
†Among patients with preoperative visual impairment.
‡Significance by Fasst.

Although some trends emerged, as mentioned earlier, no significant statistical difference could be achieved secondary to the small sample size.

Case Illustrations

**Case 1 — Class I Tumor.** A 57-year-old woman presented with decreased left vision, diplopia, and seizures and was found to have a 17-mm tumor arising from the TS. The tumor had >5 mm extension into the left optic canal. Left ICA was encased by >180°. Per our classification, the patient had an overall score of 3 points and therefore was Class I. A frontotemporal craniotomy with orbital osteotomy was performed, and GTR was achieved. The tumor was graded pathologically as WHO I. Her vision improved with no diplopia, and she had no more seizures. There was no tumor recurrence at 73-months’ follow-up (see Figure 3).

**Case 2 — Class II Tumor.** A 51-year-old woman presented with progressive visual loss due to a 27-mm tumor arising from the TS and extending to the AC. Both optic canals were spared. Bilateral ICAs were encased by >180°. Per our classification, the patient’s tumor scored 5 points and therefore was class II. A frontotemporal craniotomy with orbital osteotomy was performed, and GTR was achieved. The tumor was graded pathologically as WHO I. The left eye was blind preoperatively, but the right eye’s vision improved. The patient had transient postoperative ptosis and dysconjugate gaze that resolved during the follow-up period. The patient did not have tumor recurrence at 17-months’ follow-up (see Figure 4).

**Case 3 — Class III Tumor.** A 75-year-old woman presented with dizziness and loss of balance due to a 45-mm tumor arising from the TS and extending to the dorsum sellae. The tumor completely occluded the left optic canal and had >5 mm extension into the right optic canal. Bilateral ICAs were encased by >180°. Bilateral ACAs were encased by >180°. Per our classification, the patient’s tumor scored 8 points and therefore was class III. A frontotemporal craniotomy with orbitozygomatic osteotomy was performed, and GTR was achieved. On histology, the tumor showed little mitosis but was graded pathologically as WHO I. The dizziness and loss of balance resolved, but the patient had partial oculomotor (third) nerve paresis (see Figure 5).

**Case 4 — Class III Tumor.** This was an illustrative case of a giant tumor involving the OG, PS, and TS. For these tumors, a different operative approach was used as described further. A 47-year-old woman presented with blindness in the right eye and decreased vision in the left eye (finger count) due to a 69-mm tumor arising from OG and extending into the PS. The tumor had <5 mm extension into both optic canals. Bilateral ICAs were encased <180°. ACAs were not encased, but preoperative angiogram showed displacement of both ACAs. Ethmoidal arterial feeders could not be embolized. Mild FLAIR signal was noted on MRJ imaging. Per our classification, the patient’s tumor scored 4 points and therefore was a class II. A modified bifrontal (one-and-a-half) craniotomy with naso-orbital osteotomy was performed, and a GTR achieved. Histological specimen showed a WHO grade II tumor. Left vision improved, and no tumor recurrence was found at 2-months’ follow-up (see Figure 6).

DISCUSSION

Surgical Procedures and Techniques

For removal of these tumors, cranial approaches have been the most frequently used. In comparing bifrontal, frontolateral, and frontotemporal craniotomies for resection of TS meningiomas, Nakamura found that the frontolateral approach provided the highest visual improvement (77.8%) while representing the least invasive surgical approach. The bifrontal approach had the highest mortality and morbidity rates, including anosmia, and the lowest rate of visual improvement (46.2%). No significant difference in extent of tumor resection between these approaches was reported. On the contrary, Chokyu9 reported a high rate (90.6%) of visual improvement using the bifrontal approach, with minimal postoperative CSF leak, anosmia, and frontal brain contusion.9 Goel2 reported that the unifrontal approach is superior to
frontotemporal approach because it provides symmetrical and wide exposure, as well as direct access to both ICAs. Compared with bifrontal exposure, it also has less risk of damage to the contralateral olfactory tract. Li reported similar results. Thus there is no consensus about the cranial approach. Each surgical group used the approach it is most familiar with, resulting in uniformly good results. Our standard technique for resecting PS and TS meningiomas was frontotemporal craniotomy with orbital osteotomy, even if there was a minor extension into the posterior olfactory groove. Modified one and a half bifrontal craniotomy was used when there was large tumor burden at the OG, whether the tumor originated from the OG primarily or was an anterior extension of a PS meningioma. In this technique, a low subfrontal access is reached through removal of the frontonasoorbital bone.

Transsphenoidal removal of PS and TS tumors started with microscopy and progressed to the endonasal endoscopic approach. Advantages are the absence of a craniotomy and no traction on the optic nerve. Disadvantages are the difficulty of removing tumors when the ICA or ACA is encased, significant extension of tumor into the optic canals, and postoperative CSF leak. The postoperative CSF leak has considerably improved due to technical advances such as the “Gasket-Seal” technique and the vascularized nasoseptal flap. However, it remains more problematic than the transcranial approach.

The endoscopic transsphenoidal approach has mostly replaced the microscopic transsphenoidal approach for resection of PS and TS meningioma in the past decade. However, in most series, the transcranial approach continues to be the most commonly used. Our retrospective analysis of the transcranial, endoscopic transsphenoidal, and comparison series showed that the transcranial approach is associated with significantly higher degree of GTR compared with the endoscopic transsphenoidal approach (85.4% vs. 74.6%). Mortality rate was also lower (1.7% vs. 4.8%). On the other hand, the rate of visual improvement was, again, higher using an endoscopic transsphenoidal approach (83.9% vs. 66.1%). These findings were recently summarized by de Divitiis.

A summary of the results published for microsurgery and endoscopic surgery therefore shows a higher rate of total
resection, fewer CSF leaks, but somewhat worse visual results for microsurgery. The comparison may be unfair because different types of tumors may be included in the 2 groups. However, in our series, we see a substantial visual improvement after our transcranial approach, which is comparable to the reported endoscopic data. This might be due to technical improvements in microsurgical removal as we performed extensive extradural and intradural decompression of the optic canals even if the tumor had not invaded the optic canals in the preoperative MRI. In this way, the optic apparatus was relaxed during the resection. Furthermore, this decompression allowed removal of any tumor in the optic canals and hence with decreased recurrence rate. Additional advantages with our technique are the high percentage of cranial resection, ability to dissect encased arteries free, ability to immediately manage any vascular injury, and an improved reconstruction technique minimizing the risk of CSF leakage. Tumors can be removed regardless of their size or extension.

The 3 major purposes of our classification system are to 1) direct surgeons to the major risk factors involved in the resection of these tumors; 2) allow surgeons to choose approaches optimally (e.g., a Class I tumor can be operated by a transsphenoidal approach, whereas a Class III tumor is by transcranial approach, and Class II tumors are in between and can be approached depending on surgeon’s preference); and 3) to allow comparison of different series. Our classification appears to correlate with tumor complexity and resection, but a larger patient sample is necessary to achieve statistical significance and validate our results. One particular point to address in the future is tumor consistency; our study was not designed to evaluate this, but we speculate that it is less important than vascular and cranial nerve encasement.

**Extent of Resection**

GTR was achieved in 25 patients, 92% of our cases, which is in the higher range of comparable previous reports including both transcranial and transsphenoidal approaches (58 to 100%). We did not
find a proportional relationship between the extent of resection and morbidity and mortality rates. The extent of resection did not appear to be related to the size of tumor or approach but had a tendency to correlate with the involvement of the surrounding structures. Optic canal involvement and decompression appear to be key elements in surgery and risk of recurrence.  

Postoperative Mortality
With the advance of microsurgery, postoperative mortality rates for resection of PS and TS meningiomas have decreased from as high as 67% to as low as 0%. Currently, mortality rate ranges from 0 to 11.1% for transcranial approaches4,11,24-26,31,33,34 and from 0 to 14.3% for endoscopic transsphenoidal approaches.4,6,19,22 Among craniotomies, the bifrontal approach is associated with the highest mortality rate.34  

In our series, no mortality was recorded during surgery or during the follow-up period.  

Postoperative Nonvisual Morbidity
The rate of postoperative complications significantly decreased after the advance of less invasive and less traumatic approaches, but it remains significantly problematic.  

CN Paresis Other Than Optic Nerve. CN manifestations represent the most commonly reported complications following transcranial approach. The most commonly affected nerves are the oculomotor and abducens and, less commonly, the olfactory nerve. In our analysis of the recent transcranial series, the rate of persistent CN injury, detected clinically, ranged from 0 to 58.8%.11 Among our patients, none had permanent oculomotor nerve paresis.  

Vascular Injury. A review of transcranial series showed that the rate of vascular injury ranged from 0% to 11.1%.19,22 Nakamura34 reported a higher risk of hemorrhage and venous brain
infarction for bifrontal approach compared with the frontotemporal approach. Li[11] reached a similar conclusion. Our series had only 1 patient (3.7%) with intraoperative vascular injury. The patient had an ICA injury that was immediately repaired with no persistent complications. Patients who have permanent with recurrent or suspected WHO grade II meningiomas, ICA encasement, and narrowing should have provisions made for possible extracranial to intracranial bypass if the ICA is damaged during the surgery.

**CSF Leak.** Postoperative CSF leak became a complication of major concern after the adoption of transsphenoidal approach. In our literature analysis, the rate of postoperative CSF leak was significantly higher in endoscopic transsphenoidal approach compared with a transcranial approach (21.6% vs. 3.9%). In our series, 2 cases sustained postoperative CSF leak: 1 occurred after a transcranial approach (1/25, 4%) early in our experience and was repaired by an endonasal endoscopic approach (1/2, 50%); the second occurred after a transsphenoidal endoscopic approach and was repaired using an AlloDerm (LifeCell Corporation, Branchburg, New Jersey, USA) patch and Duraseal (Covidien, Minneapolis, Minnesota, USA) dural sealant. Because the number of our PS/TS meningiomas operated on is small, this high percentage should not be an indictment of the endonasal endoscopic approach.

**Diabetes Insipidus.** DI was the most common endocrine complication associated with transcranial resection. The rate of immediate postoperative DI in the transcranial series ranges from 0% to 8.1%.[11,25] The majority of these cases were transient. In our series, no persistent DI was found and the single (3.7%) case with postoperative DI was transient and resolved during the follow-up period.

**Visual Outcomes**

Visual compromise is the most common presenting symptom in patients with PS and TS meningiomas. It was found in 70% of our series. The primary goal of surgery is therefore to preserve and

![Preoperative and postoperative magnetic resonance imaging findings of illustrated Case 4.](image)
improve visual function. This is achieved by careful attention to the optic nerves and chiasm and their blood supply, which is not to be mistaken as tumor feeders. The rate of postoperative visual improvement ranged from 42.4% to 91.7%. Tumor size and duration of preoperative visual disturbance are critical factors that influence visual outcome. Tumors <3 cm had better visual outcome than those >3 cm. These data, however, were not confirmed by other authors.

In our series, of 21 patients with preoperative visual disturbance, 19 of them (90%) had varying degrees of improvement and 2 of them (10%) were unchanged. No patient experienced worsening of vision or developed new permanent postoperative visual deficit. This represents one of the highest rates of visual improvement reported. Worsening vision following surgery is reported to range between 10% and 25% in some cases. Some authors have suggested that early extradural optic canal decompression might be associated with better visual outcome, by reducing tension on the optic nerve during tumor resection. In our series, involving early uniform decompression of the ipsilateral optic nerve (and intradural decompression of the contralateral optic nerve if necessary), from the opticocarotid cistern all the way to the globe, was the key to these excellent visual outcomes.

**Classification System**

**Earlier Classification.** Cushing and Eisenhardt originally classified TS meningiomas into 4 stages according to size, chiasmal deformity, and clinical presentation: I, initial stage; II, probably presymptomatic; III, early stage of syndrome, still surgically favorable (10–18 grams); and IV, surgically unfavorable (>20 gm). Their classification was largely based on the surgical and postmortem findings, and was rarely, if ever, applied later.

Yasargil divided the tumors into 3 types on the basis of their size. Type I tumors measure up to 2 cm, type II tumors measure between 2 and 4 cm, and type III tumors measure >4 cm. This classification, although considered an important determining factor, still lacks other factors like the involvement of the surrounding structures.

More recently, Goel proposed a more detailed classification based on a combination of multiple radiologic and clinical findings. His classification was never validated and has yet to reach universal acceptance. In a series of 44 patients with planum sphenoidale and olfactory groove meningiomas from the University of California at San Francisco, Zygourakis et al. found that tumor volume was the only factor associated with preoperative visual symptoms. Tumors with nasal sinus invasion were significantly more likely to cause preoperative surgical complications, and tumors with ACA encasement were more likely to be associated with preoperative complications and recurrence. Although our series of patients is focused on planum sphenoidale and tuberculum sellae meningiomas using our own particular cranial operative technique, we did not find an increased incidence of CSF leakage related to sinus opening or complications and higher recurrence rates related to the anterior cerebral artery encasement.

Thus despite being one of the more common anterior skull base tumor groups, a proper and widely adopted classification for PS and TS meningioma is still lacking. A simple classification that would allow the comparison of different series and approaches, as well as predict outcome, is thus highly desirable.

A patient with a tumor <2 cm, no or minimal vascular encasement, and minimal extension into the optic canals can undergo endoscopic transsphenoidal resection, whereas a patient with brain invasion, >180° vascular encasement, >4 cm in size, and severe optic canal invasion is better suited for the transcranial approach. This is also the opinion of De Divitiis, Cappabianca, and Gardiner et al. Vascular injury is also quite difficult to manage when operating by an endoscopic approach. Of course, a number of tumors may fall in an intermediate category, wherein the operative approach will be decided by the experience of the surgical team.

**CONCLUSION**

Due to close proximity to important neurovascular and endocrine structures, PS and TS meningiomas require special surgical attention to achieve the highest level of safety with maximal extent of resection. The optic apparatus is particularly important, and its decompression is a key step for maintaining and improving vision. With the microsurgical techniques used in this series, complications and outcomes have improved. Achieving gross total resection is dependent on proper decompression and tumor removal from the optic canals. A new classification system predicting surgical risk, clinical outcome, and recurrence is proposed and this can help the surgeon to choose a transcranial or endonasal transsphenoidal approach.

**REFERENCES**


