Meningiomas arising in the petroclival region are formidable lesions to treat; they are intimately associated with the brainstem, basilar artery, perforating arteries, and multiple cranial nerves and are partially obscured by the temporal bone. Their rarity has complicated attempts at classifying tumors in this region, and large reported series frequently include heterogeneous groups of tumors as a result. Castellano and Ruggeri\(^9\) classified meningiomas of the posterior fossa based on their origin. Thus, we define petroclival meningiomas as those originating medial to the fifth cranial nerve on the upper two-thirds of the clivus.

**Object.** The relentless natural progression of petroclival meningiomas mandates their treatment. The management of these tumors, however, is challenging. Among the issues debated are goals of treatment, outcomes, and quality of life, appropriate extent of surgical removal, the role of skull base approaches, and the efficacy of combined decompressive surgery and radiosurgery. The authors report on the outcome in a series of patients treated with the goal of total removal.

**Methods.** The authors conducted a retrospective analysis of 64 cases of petroclival meningiomas operated on by the senior author (O.A.) from 1988 to 2012, strictly defined as those originating medial to the fifth cranial nerve on the upper two-thirds of the clivus. The patients’ average age was 49 years; the average tumor size (maximum diameter) was 35.48 ± 10.09 mm (with 59 tumors > 20 mm), and cavernous sinus extension was present in 39 patients. The mean duration of follow-up was 71.57 months (range 4–276 months).

**Results.** In 42 patients, the operative reports allowed the grading of resection. Grade I resection (tumor, dura, and bone) was achieved in 17 patients (40.4%); there was no recurrence in this group \((p = 0.0045)\). Grade II (tumor, dura) was achieved in 15 patients (36%). There was a statistically significant difference in the rate of recurrence with respect to resection grade (Grades I and II vs other grades, \(p = 0.0052\)). In all patients, tumor removal was classified based on postoperative contrast-enhanced MRI, and gross-total resection (GTR) was considered to be achieved if there was no enhancement present; on this basis, GTR was achieved in 41 (64%) of 64 patients, with a significantly lower recurrence rate in these patients than in the group with residual enhancement \((p = 0.00348)\). One patient died from pulmonary embolism after discharge.

The mean Karnofsky Performance Status (KPS) score was 85.31 preoperatively (median 90) and improved on follow-up to 88, with 30 patients (47%) having an improved KPS score on follow-up. Three patients suffered a permanent deficit that significantly affected their KPS. Cerebrospinal fluid leak occurred in 8 patients (12.5%), with 2 of them requiring exploration. Eighty-nine percent of the patients had cranial nerve deficits on presentation; of the 54 patients with more than 2 months of follow-up, 21 (32.8%) had persisting cranial nerve deficits. The overall odds of permanent cranial nerve deficit of treated petroclival meningioma was 6.2%. There was no difference with respect to immediate postoperative cranial nerve deficit in patients who had GTR compared with those who had subtotal resection.

**Conclusions.** Total removal (Grade I or II resection) of petroclival meningiomas is achievable in 76.4% of cases and is facilitated by the use of skull base approaches, with good outcome and functional status. In cases in which circumstances prevent total removal, residual tumors can be followed until progression is evident, at which point further intervention can be planned.

**Key Words** • skull base • petroclival • meningioma • petrosal • oncology

---

Abbreviations used in this paper: CN = cranial nerve; GOS = Glasgow Outcome Scale; GTR = gross-total resection; KPS = Karnofsky Performance Status; LOS = length of stay; MRA = MR angiography; MRV = MR venography; OR = operating room.

* Drs. Almefty and Dunn contributed equally to this work.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
True petroclival meningiomas

medial to the fifth cranial nerve (CN V) and consider these “true” petroclival meningiomas for their distinct clinical and outcome considerations.6,9,24,41 They displace the brainstem and basilar artery posteriorly and to the contralateral side; may involve CNs III, IV, V, VI, and VII; and have variable extension into the internal auditory meatus, jugular foramen, Meckel’s cave, Dorello’s canal, and the ipsilateral cavernous sinus. Other tumors in this region with distinct anatomical differences from true petroclival tumors include sphenopetroclival, midclival, and posterior petrosal tumors.4

The relentless natural progression of these tumors often necessitates treatment.10,24,41 Due to their often benign pathology and the risks associated with operating in this region, there has been much debate over the proper management of these tumors. Advances in skull base approaches, microsurgical technique, intraoperative monitoring, and advanced imaging have drastically improved the once dismal surgical outcome to where mortality is a rare outcome and severe morbidity unlikely.

With the advent of radiosurgery, many have recommended subtotal removal and subsequent radiosurgery to avoid operative morbidity.4,7,21,28,33,34,42 One of the arguments for this approach is that subtotal removal decreases the likelihood of cranial nerve dysfunction and thus improves quality of life, and that pairing this approach with postoperative radiation may form the basis of safer tumor control. Cranial nerve dysfunction may still occur with a more cautious surgical approach and is often temporary after total or partial removal. Reports advocating subtotal resection and planned radiation have also been based on relatively short follow-up periods. Recent reports have demonstrated declining control, reaching below 50% after radiosurgery for posterior fossa meningiomas when followed beyond 12 years, with petroclival location predictive of new or worsening symptoms after radiation treatment.39

Total resection continues to be the only method of permanent tumor eradication for this benign pathology, with preservation or improvement in neurological function the goal of treatment. Total removal, however, may not always be possible. Commonly discussed reasons for subtotal removal include tumor adherence to the brainstem, encasement of neurovascular structures, tumor size, firm tumor consistency, and extension into the cavernous sinus. We herein describe our experience with “true” petroclival meningiomas and discuss our approach to dealing with these tumors, treatment outcomes, and challenges in their management.

Methods

We performed a retrospective analysis of 64 cases involving patients whose tumors met the definition of true petroclival meningioma and who were treated surgically by the senior author (O.A.) between 1988 and 2012. Clinical presentation, tumor histology, operative approaches, intraoperative findings, complications, imaging findings (including MRI, MR angiography/venography [MRA/MRV], preoperative CT, and postoperative MRI), and follow-up findings were reviewed. Statistical analyses were performed using MedCalc for Windows, version 9.3.9.0 (MedCalc Software).

Results

Clinical Characteristics

Sixty-four cases of petroclival meningioma were reviewed. The mean patient age in this case series was 49.03 years (range 30–73 years), and the female/male ratio was 3:1 (48 women, 16 men). Fifty-eight patients presented with de novo tumors; 6 had recurrent meningioma after having had surgery elsewhere. Four of these 6 patients had sizeable residual tumor after resection, and 3 patients had been treated with radiation therapy in addition to resection.

Ten patients had less than 2 months’ follow-up. The mean duration of follow-up for the remaining 54 patients was 70.57 months (range 4–276 months).

Fifty-seven (89%) of 64 patients had cranial nerve deficits on presentation, with CN V deficit being the most common (present in 64% of patients), followed by CN VIII deficit (present in 51.5%). A summary of the clinical findings at presentation is shown in Table 1. The mean Karnofsky Performance Status (KPS) score on presentation was 85.31 (median 90).

Radiographic and Pathological Characteristics

The average tumor size (measured as maximum diameter) was 35.48 ± 10.09 mm. Twenty-two patients (34.3%) harbored giant tumors (> 40 mm), with an average tumor size of 45.05 ± 5 mm. Thirty-seven patients (57.8%) had large tumors (> 20, ≤ 40 mm), with an average size of 28.76 ± 5.3 mm. Five patients (7.8%) had small tumors (≤ 20 mm); in 2 of these 5 cases, the tumors were asymptomatic. Posterior cavernous sinus extension was noted in 39 cases (18 giant tumors, 20 large tumors, and 1 small tumor).

Selected radiographic features are summarized in Table 2. The majority of tumors (89%) compressed the brainstem and many (67%) displaced the axis of the brainstem laterally. We graded the degree of compression. Grade 1 included cases with < 25% of the brainstem compressed; Grade 2 included cases with ≥ 25% but < 50% compression; and Grade 3 included cases with com-

<table>
<thead>
<tr>
<th>TABLE 1: Clinical presentation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms at Presentation</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>headache</td>
</tr>
<tr>
<td>diplopia</td>
</tr>
<tr>
<td>facial pain</td>
</tr>
<tr>
<td>facial numbness</td>
</tr>
<tr>
<td>hearing loss</td>
</tr>
<tr>
<td>dizziness</td>
</tr>
<tr>
<td>gait ataxia</td>
</tr>
<tr>
<td>swallowing difficulty</td>
</tr>
<tr>
<td>voice changes</td>
</tr>
</tbody>
</table>

* Pts = patients.
expression ≥ 50%. Of the 54 patients in whom this could be evaluated, the basilar artery was displaced by tumor in 32 (59%) and circumferentially encased by tumor in 7 (12.5%).

Fifty-eight percent of patients had a ribbon of T2 signal on MRI between the tumor and brainstem, suggestive of an arachnoid plane thought to facilitate dissection of the tumor. Brainstem edema was seen in 13 cases and may also be a radiographic surrogate to suggest vascular congestion or the absence of a discrete arachnoid plane due to pial invasion. In our series, tumors associated with brainstem edema were associated with Grade 2 (< 50%) or Grade 3 (> 50%) compression.

Fifty-eight patients had imaging appropriate to assess extension into the cavernous sinus, jugular foramen, or internal auditory meatus. In 39 of these patients, the tumor extended into the cavernous sinus, in 36 it extended into the internal auditory meatus, and in 9 it extended into the jugular foramen. A serrated interface between the tumor and brainstem was present in 16 (28.5%) of the 56 patients in whom this feature could be assessed.

Only 5 tumors (8%) were atypical (WHO Grade II) pathologically. In 3 of these cases, the patients had undergone prior surgery followed by radiation, and in 4 (80%) of the 5 cases, the patients were male. The rest of the tumors (92%) were Grade I (Table 3).

**Surgical Considerations**

The aim of surgery was an attempt at total removal facilitated by adequate exposure, preservation of arterial perforating vessels, special consideration of venous preservation, intra-arachnoidal dissection, and minimization of cranial nerve manipulation or devascularization.

Multiple factors influenced the choice of surgical approach, with a general overview of these factors provided in Fig. 1. The venous anatomy was the most influential factor in selecting the approach, and the majority of tumors were resected through modifications of the petrosal approaches as previously described. The posterior petrosal approach was most frequently used (27 cases), followed by a combined anterior and posterior petrosal approach (15 cases), an anterior petrosal approach alone (11 cases), and total petrosectomy (4 cases). A transmastoid retrosigmoid approach was used in 7 cases and was mandated by venous drainage felt to preclude posterior petrosal access. All patients underwent audiograms to assist in the determination of the extent of the petrous bone drilling. Functional hearing in a patient with a large tumor helped guide the decision to use a hearing-sparing retrolabyrinthine posterior petrosal approach.

In 13 cases, surgery was staged, with the approach work and tumor resection performed separately on consecutive days.

**Extent of Resection**

We analyzed the extent of resection in two completely independent parameters, one based on the intraoperative observations recorded in the operative reports and the other based on postoperative MRI findings with respect to residual enhancement.

Resection was graded on the modified Kobayashi scale (Table 4), which is an adaptation of Simpson grading for microsurgical resection of skull base meningiomas. Forty-two cases could be graded from the available operative reports and the other based on postoperative MRI findings with respect to residual enhancement.

Resection was graded on the modified Kobayashi scale (Table 4), which is an adaptation of Simpson grading for microsurgical resection of skull base meningiomas. Forty-two cases could be graded from the available operative reports and the other based on postoperative MRI findings with respect to residual enhancement.

Resection was graded on the modified Kobayashi scale (Table 4), which is an adaptation of Simpson grading for microsurgical resection of skull base meningiomas. Forty-two cases could be graded from the available operative reports and the other based on postoperative MRI findings with respect to residual enhancement.

Resection was graded on the modified Kobayashi scale (Table 4), which is an adaptation of Simpson grading for microsurgical resection of skull base meningiomas. Forty-two cases could be graded from the available operative reports and the other based on postoperative MRI findings with respect to residual enhancement.

Resection was graded on the modified Kobayashi scale (Table 4), which is an adaptation of Simpson grading for microsurgical resection of skull base meningiomas. Forty-two cases could be graded from the available operative reports and the other based on postoperative MRI findings with respect to residual enhancement.
Resectability did not correlate with the radiographic indicators of soft tumor consistency—tumor bright on T2-weighted MRI—or MRI suggestion of an arachnoid plane between tumor and brainstem as suggested by the presence of a cleft of T2 hyperintensity on T2-weighted MRI.

**Recurrence**

There were 14 recurrences for an overall recurrence rate of 21.8%. There were no recurrences in patients who had a Kobayashi Grade I resection (Fig. 2), and a marked significant difference in recurrence-free survival between Grades I and II together as compared with higher Kobayashi grades.

Among 23 patients with residual tumor there were 10 progressive cases (43%), whereas there were 4 recurrences (9.8%) in the 41 patients who underwent GTR; this differential rate of recurrence in patients with progressive growth of residual tumor and in patients with initial GTR was statistically significant (p = 0.00348). The median time for recurrence was 168 months in patients without residual tumor and 80.2 months in patients with residual tumor.

**Clinical Outcomes**

**Mortality.** There was one perioperative death (perioperative mortality rate of 1.56%); this occurred 15 days after discharge and was due to pulmonary embolism. During the long follow-up period, 2 additional patients died of tumor progression (51 months and 72 months after surgery). In one of these 2 cases, the patient clearly had residual tumor, which had remained stable for 5.5 years and then rapidly progressed. In the other case, the patient presented with recurrent atypical meningioma. The recurrent lesion was resected without evidence of residual tumor, but the patient suffered another recurrence and continued progression despite Gamma Knife (Elekta AB) treatment. Three other patients presented with de novo tumors and died during the follow-up period from other causes: ruptured aneurysm, myocardial infarction, and leukemia.

**TABLE 4: Modified Shinshu grade or Okudesa-Kobayashi grade**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>complete microscopic removal of tumor &amp; dural attachment w/ any abnormal bone</td>
</tr>
<tr>
<td>II</td>
<td>complete microscopic removal of tumor w/ diathermy coagulation of its dural attachment</td>
</tr>
<tr>
<td>IIIA</td>
<td>complete microscopic removal of intradural &amp; extradural tumor w/o resection or coagulation of its dural attachment</td>
</tr>
<tr>
<td>IIIB</td>
<td>complete microscopic removal of intradural tumor w/o resection or coagulation of its dural attachment or of any extra-dural extensions</td>
</tr>
<tr>
<td>IVA</td>
<td>intentional subtotal removal to preserve cranial nerves or blood vessels w/ complete microscopic removal of dural attachment</td>
</tr>
<tr>
<td>IVB</td>
<td>partial removal, leaving tumor of &lt;10% in volume</td>
</tr>
<tr>
<td>V</td>
<td>partial removal, leaving tumor of &gt;10% in volume, or decompression w/ or w/o biopsy</td>
</tr>
</tbody>
</table>
Functional Outcome. The mean KPS score on presentation was 85.51 (median 90); 1 patient was transferred with a preoperative KPS score of 30 (Table 5). The KPS score was independent of tumor size. On follow-up the average KPS score was 88.28 (median 90). Resection resulted in improved KPS scores in 30 patients (47%) while 23 patients (36%) had equivalent pre- and postoperative KPS scores. Of 11 patients with lower KPS scores after surgery, 9 demonstrated a decrease of only 10 points.

Patients with significant brainstem compression preoperatively (Grade 3) were more likely to show improvements in KPS after surgery (Fig. 3). Cavernous sinus involvement had an insignificant effect on KPS. The mean pre- and postoperative KPS scores in patients with cavernous sinus extension were 86 and 90, respectively; in patients without cavernous sinus involvement, the mean pre- and postoperative KPS scores were 88 and 94.

At follow-up, the mean Glasgow Outcome Scale (GOS) score was 5 in 50 (78%) of 64 patients, 4 in 11 patients, and 3 in one patient who suffered a stroke with resultant hemiparesis.

Cranial Nerves. Table 6 details cranial nerve function preoperatively, postoperatively, and on follow-up. Fifty-seven (89%) of 64 patients had deficits of one or more cranial nerves (103 nerves) preoperatively. Of the 54 patients with more than 2 months’ follow-up, 21 (39%) had persistent cranial nerve deficits. There were 40 cranial nerve deficits on follow-up. Notably CN V and VIII are more likely to improve from preoperative status while CN VI is the most at risk for permanent deficit.

Immediate postoperative improvement occurred in 4 cranial nerves only. Eighty-five new cranial nerve defi-

TABLE 5: Preoperative and postoperative KPS scores*

<table>
<thead>
<tr>
<th>Preop KPS</th>
<th>No. of Pts</th>
<th>Improved</th>
<th>Same</th>
<th>Worse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>No. of Pts</td>
<td>Score</td>
</tr>
<tr>
<td>100</td>
<td>8</td>
<td>—</td>
<td>NA</td>
<td>100</td>
</tr>
<tr>
<td>90</td>
<td>33</td>
<td>100</td>
<td>13</td>
<td>90</td>
</tr>
<tr>
<td>80</td>
<td>14</td>
<td>100</td>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td>70</td>
<td>6</td>
<td>100</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>60</td>
<td>1</td>
<td>80</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>80</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>70</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>total</td>
<td>30</td>
<td>23</td>
<td>36%</td>
<td>11†</td>
</tr>
</tbody>
</table>

* NA = not applicable.
† Four patients had short follow-up.
True petroclival meningiomas

Table 6: Cranial nerve analysis

<table>
<thead>
<tr>
<th>CN</th>
<th>Preop Deficit</th>
<th>Postop Evaluation</th>
<th>Deficit on Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(64 pts)</td>
<td>No Change</td>
<td>Deterioration</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>IV</td>
<td>5</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>34</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>VI</td>
<td>6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>VII</td>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>VIII</td>
<td>26</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>IX</td>
<td>8</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>X</td>
<td>10</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>XI</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>XII</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7: Surgically induced cranial nerve deficits and extent of resection

<table>
<thead>
<tr>
<th>Kobayashi Grade of Resection</th>
<th>No. of Pts</th>
<th>New or Worsened CN Deficit*</th>
<th>Status of Deficit on Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>17</td>
<td>11 (65%)</td>
<td>Improved†</td>
</tr>
<tr>
<td>II</td>
<td>14</td>
<td>9 (64%)</td>
<td>Not Improved</td>
</tr>
<tr>
<td>III–V</td>
<td>9</td>
<td>9 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

* New postoperative cranial nerve deficit or worsening of preoperative deficit.
† Statistically significant differences as follows: Grade I versus Grades III–V, p = 0.01664; Grade II versus Grades III–V, p = 0.009050; Grades I and II versus Grades III–V, p = 0.001099.

Complications. Early in the series, 3 patients suffered strokes resulting in major neurological deficits (1 left temporal lobe venous infarct, 1 repeated intraventricular hemorrhage, and 1 internal capsule perforator infarcts) (Fig. 4). In the patients who suffered stroke, there was no particular correlation between the ischemic event and tumor consistency as measured by T2 signal, presence of CSF cleft between tumor and brainstem on MRI, or MRI evidence of brainstem edema.

Complications related to CSF occurred in 8 patients (12.5%); 4 patients had subgaleal CSF collections that required lumbar drainage, and 4 patients had CSF leaks, with reoperation required in 2 of these 4 cases. Postoperative pulmonary complications included 2 cases of pulmonary embolism, one involving a patient with concomitant pneumonia. Two patients had deep vein thrombosis and one had seizure.

Length of Stay and Operating Time

We were able to calculate the length of stay (LOS), and the operating room (OR) time in the patients who were treated in the senior author’s (O.A.’s) current institution (9 patients). The mean hospital LOS was 5.3 days (median 3 days), and the mean operating room time was 11 hours and 40 minutes (median of 11 hours). Of 64 patients, 10 (15.6%) were discharged to a rehabilitation center.

Illustrative Cases

Case 1

This 43-year-old man underwent a craniotomy for attempted removal of a left petroclival meningioma at another institution 6 months prior to treatment at our center. Postoperatively, he developed hydrocephalus requiring ventriculoperitoneal shunt placement and deep venous thrombosis requiring anticoagulation therapy. Before the initial surgery he had dysfunction of CNs IV, V, VI, VII, and VIII, and left lower limb weakness. The preoperative MRI had demonstrated a giant petroclival meningioma with extension to the cavernous sinus associated with marked brainstem hyperintensity on T2-weighted images (considered in the literature as an ominous sign of pial infiltration and bad outcome), and paradoxically the presence of a hyperintense band at the brainstem-tumor interface (Fig. 5A–C). During that initial surgery, the central part of the tumor had been removed (Fig. 5D and E).

We performed a total petrosectomy for tumor resection. The tumor was extremely firm and fibrous and the presence of severe scarring and adherence prohibited a GTR; there was a crescent of residual tumor against the upper brainstem (Fig. 5F). The patient did well postop-
eratively and was discharged home 1 week after surgery without additional deficit or complications. Sadly, the patient died from a pulmonary embolism 3 weeks after surgery.

This case demonstrates the challenges of treating petroclival meningiomas. The serious brainstem compression in a relatively young person demands surgical intervention, but the characteristics of the tumor prevented total removal despite 2 different attempts at 2 different institutions. On T2-weighted images there was a severe hyperintensity in the brainstem prior to both surgeries, which is purported to be an ominous sign for postoperative neurological deficit, and the presence of a T2 cleft between the tumor and the brainstem. The presence of this cleft is thought to suggest a CSF plane between the tumor and brainstem, although this region was not dissectable in this case. There was serration at the tumor-brainstem interface, indicative of severe adhesion and an obstacle for complete resection. This case also highlights the prospect of poor outcome despite maximum effort.

Case 2

This 53-year-old woman presented with recently progressing diplopia and aspiration. On examination she had mild weakness of both upper limbs, with increased deep tendon reflexes of the left upper and lower limbs and a Babinski sign on the left, left cerebellar signs, left CN VI palsy, and a diminished gag reflex.
True petroclival meningiomas

An MRI study demonstrated a left petroclival meningioma with brainstem compression and extension into Meckel’s cave (Fig. 6A–C).

The patient underwent microscopic total resection of her tumor, confirmed by postoperative MRI (Fig. 6D–G). Her postoperative course was uneventful, with recovery of her preoperative deficits, and she was discharged neurologically intact in 1 week. This case demonstrates that microsurgical resection can be performed for total resection and can lead to recovery of neurological deficit caused by tumor.

Discussion

Distinction of “True” Petroclival Meningiomas

Petroclival meningiomas are rare, accounting for less than 0.15% of intracranial tumors. Several meningioma variants involve the petroclival region and are often grouped or classified based on location or other tumor characteristics. The tumor origin, however, is the most influential factor that determines the clinical characteristics, pathological anatomy, surgical difficulties, and outcome. Thus, we herein discuss what we term “true” petroclival tumors in contradistinction to sphenopetroclival, midclival, and posterior petrosal meningiomas. True petroclival tumors arise at the petroclival junction medial to the trigeminal nerve and compress the brainstem and basilar artery and perforators posteriorly and to the contralateral side. They displace CNs V, VII, and VIII posteriorly and often span the middle and posterior fossa with common extension into the cavernous sinus, internal auditory meatus, and jugular foramen. Sphenopetroclival meningiomas, however, are more extensive, extending through both cavernous sinuses, with en plaque extension along the ventral posterior fossa dura and the tentorium, and they frequently invade the bone of the clivus and the petrous apex with penetration of the sphenoid sinus, which renders them surgically incurable. Midclival tumors emanate from a

![Fig. 6. Illustrative Case 2. A–C: Preoperative axial (A), sagittal (B), and coronal (C) contrast-enhanced T1-weighted MR images demonstrating a petroclival meningioma with compression of the brainstem, displacement of the basilar artery to the right, and extension into the posterior cavernous sinus. D–G: Postoperative axial (D), sagittal (E), and coronal (F) contrast-enhanced T1-weighted MR images and CT scan (G) showing Grade 1 resection with removal of hyperostotic bone.](image-url)
broader central clival dural base and may involve bilateral cranial nerves, either displacing the basilar artery posteriorly or encasing it centrally. Their surgical complexity is compounded by the broad base of involvement and adherence to the brainstem and the need to work at a distance from the side of entry. Posterior petrosal tumors are based behind the internal auditory canal and present the most likely variant amenable to complete surgical removal. We elected to study true petroclival tumors as a distinct tumor entity to help establish feasibility of resection, outcomes, and management principles.

Surgery: Extent of Resection

The extent of resection remains the most salient factor in outcomes for patients with benign meningioma. Kobayashi et al. presented an adaptation of Simpson’s authoritative grading scale34 applicable to skull base meningiomas (Kobayashi K, Okudera H, Tanaka Y, presented to the First International Skull Base Congress, 1992). On applying this scale to our series we found no recurrences with a Grade 1 resection, confirming the durability of high-grade resections. Since Simpson and Kobayashi grading are based on intraoperative observation we also analyzed the extent of resection based on pre- and postoperative MRI. Gross-total resection (GTR) was defined as resection in which no macroscopic tumor was thought to be left intraoperatively and no enhancing regions were present on postoperative imaging. By these criteria, 64% of patients (41 of 64) had GTR. This is generally consistent with reported rates of GTR from other series in which complete resection seemed to be the therapeutic intent and tumors of all size were included, with the rate of total resection varying from 20% to 85% in major series.3,5,8,11,21,26–28,34 However, these reports may include different subtypes of petroclival region tumors other than “true” petroclival meningiomas as studied here.

Many factors are cited as affecting the extent of resection and complication rate for petroclival meningiomas. Chief among these are extension into the cavernous sinus, adherence to or compression of the brainstem, adherence to or encasement of neurovascular structures, firm tumor consistency, and tumor size. Attempts have been made to assess preoperatively the likelihood of complications and extent of resection in order to guide treatment.3,5,20,21,35

Cavernous sinus extension did not adversely affect the extent of resection in this series, as GTR was performed in 37 of 39 cases. This feature should not deter surgeons from the pursuit of total resection.

We did not find presence or absence of a T2 cleft between tumor and brainstem, or T2 brightness (thought to correlate with tumor consistency), to influence resectability. However, serration of the tumor-brainstem border and/or brainstem T2 hyperintensity (thought to correlate with pial invasion) were associated with a lower rate of complete resection. Interestingly, almost half of the patients with brainstem edema had an elevated proliferative index, atypical pathology, or abnormal results on chromosomal analysis. In our series, brainstem edema was an important imaging sign that portended a more difficult resection and heralded a more aggressive pathology.

Surgery: Approaches

The surgical anatomy of the petroclival region is complex and, consequently, one’s management of these technically challenging surgical lesions is usually refined over time.

While the more traditional suboccipital and pterional approaches to petroclival tumors16,33,37 have been propounded, lateral skull base approaches through the petrous bone have among their many advantages decreased operative distance to the tumor and neurovascular structures, improved visualization and illumination, and decreased need for brain retraction.5,15 In addition, the access for dissection is improved due to the lateral and anterior projection to the brainstem. Specific approaches through the petrous bone include removal of the petrous apex in the middle fossa approach,19 resection of the presigmoid retrolabyrinthine petrous bone in the posterior petrosal approach,5,18 and complete petrosectomy. A summary of the clinical and radiographic factors that influence the specific choice of surgical approach is shown in Fig. 1. A posterior petrosal approach is ideal for larger tumors extending below the internal auditory meatus in patients with serviceable hearing. Should a larger tumor extend across the clival midline or into the anterior cavernous sinus, a combined anterior and posterior petrosal approach may be used. If hearing is lost, additional exposure may be afforded by a complete petrosectomy, with removal of the labyrinth and cochlea. Careful study of the venous anatomy is critical in these cases. Greater risk may be incurred in patients with a dominant or isolated sigmoid or transverse sinus on the side of the tumor or with venous drainage through the tentorium. In the latter scenario, should the vein of Labbé drain into the tentorium or superior petrosal sinus before the sigmoid-transverse junction, it is crucial that the tentorial incision be made anterior to the insertion of the vein of Labbé, with sparing of the petrosal sinus.9,17 Alternatively, a transmastoid retrosigmoid approach may need to be adopted to avoid injury to critical draining veins.2

We believe that skull base approaches not only facilitate an improved chance of complete removal but also lessen the risk of morbidity, including cranial nerve deficits. However, their performance mandates a longer operative time than conventional approaches. In 13 cases in this series, surgery was staged over 2 days, with approach work done on Day 1 and tumor resection performed on Day 2. We are increasingly performing staged procedures, particularly when a total petrosectomy approach is adopted.

Outcomes

Once plagued by high mortality and morbidity, the outcome of surgically treated petroclival meningioma has remarkably improved. Although our study is retrospective and may be subject to selection bias, changes in management and technique over decades, and nonadjudicated outcome analysis, the rarity of these tumors and long-term follow-up led to the adoption of this methodology. In this series, there was 1 perioperative death (due to pulmonary embolism), for an overall mortality rate of 1.5%.
True petroclival meningiomas

These mortality data are consistent with other contemporary series. Functional outcomes, as measured by KPS and GOS scores, improved or were unchanged in 53 (83%) of 64 patients, with 47% showing improved KPS scores. Not surprisingly, patients with significant brainstem compression were more likely to have improved functional status after surgery. Furthermore, even among patients with a decline in KPS score after resection (11 patients), only 1 patient had a decrease in score by more than a single 10-point interval (from 80 to 60). By GOS, 95% patients had a good outcome (GOS score of 4 or 5), with 50 of 64 patients having a GOS score of 5. Thus in our series, resection either stabilized or improved patients’ functional status as measured by KPS and GOS.

Cranial Nerves

Considerable emphasis has been placed on cranial nerve deficits as a factor that might affect quality of life, with the concern that aggressive surgical removal may lead to a higher incidence of deficits. In this series, the incidence of postoperative cranial nerve deficit was even higher when gross-total removal was not achieved.

Not surprisingly, a high incidence of cranial nerve deficits has been reported with petroclival meningioma surgery (20%–100%)[1, 21, 26, 31, 34, 40] and has been the motivation for considering decompressive removal and/or the use of more conventional craniotomy flaps.[7, 33, 34]

Cranial neuropathies were present in 89% of our patients before surgery, with 103 affected nerves in 57 patients. On follow-up, 21 patients harbored deficits in a total of 40 cranial nerves. If one assumes that ipsilateral CNs III–XII are at risk from the disease or during surgical treatment of these tumors, and that in 64 patients 640 nerves are at risk, the odds of a cranial nerve deficit at follow-up in surgically treated tumors was 6.2%. Immediate postoperative transient deficits are frequent and not surprising since many of these nerves are intimately adherent, require extensive dissection, and are susceptible to devascularization. In the immediate postoperative period there were new deficits of 85 cranial nerves in 42 patients. Most of these deficits were resolved at follow-up within a few months of surgery.

Recurrence and Progression-Free Survival

The overall recurrence rate in this series was 20% (13 cases); in 9 cases, the recurrence was from progression of residual tumor after subtotal resection, while the other 4 patients had undergone initial GTR. The median time to recurrence was 168 months in patients who had no visible residual tumor and 80.2 months in patients in whom residual tumor was noted intraoperatively or on postoperative imaging. None of the patients who underwent Kobayashi Grade 1 (17 patients) resection had recurrence, reaffirming the time-honored principle in benign meningioma that recurrence is directly related to the extent of surgical removal.[25, 36] This dictum also applies to meningiomas at the skull base.[25, 36]

The once-dismal prognosis for petroclival meningiomas has been altered by several series demonstrating the technical feasibility and excellent outcomes enabled by contemporary microsurgery.[5, 8, 19, 21, 26, 27, 38, 41] Recently, however, some authors have endorsed more conservative surgical approaches coupled with radiotherapy, with the twin goals of brainstem decompression and avoidance of cranial neuropathies.[14, 21, 32, 34] One of the arguments for this approach is that subtotal removal decreases the likelihood of cranial nerve dysfunction and thus improves quality of life. In our series, however, the extent of resection did not correlate with cranial nerve impairment postoperatively; cranial nerve dysfunction was higher in patients treated with subtotal resection, although this may also reflect a greater difficulty in these particular cases. Thus a more cautious surgical approach will not necessarily eliminate cranial neuropathies. Moreover, a meta-analysis of all modern reported series confirms highly favorable functional outcomes with aggressive resection.[14]

The strategy of subtotal resection and radiosurgery also rests upon the assumption that radiotherapy is an equal surrogate to surgery in the long-term management of intentionally unresected tumor. In a large and long-term study, Mathiesen et al. confirm that recurrence might merely be delayed by the combination of subtotal resection and radiation and report that in the long term this paradigm is associated with a 75% recurrence rate and a radiation-induced complication rate of 56%.[2] Long-term reports of the results of radiosurgery have demonstrated progression-free survival in meningiomas below 50%.[30] Similar rates of progression-free survival have been reported for posterior fossa meningiomas when followed beyond 12 years, with petroclival location predictive of new or worsening symptoms after radiation treatment.[39] Anecdotally, we and others are seeing a surge in recurrent and progressive tumors treated initially with the paradigm of planned subtotal resection followed by radiation therapy. In these cases, the surgical landscape is so treacherous with scar from prior surgery and radiation vasculopathy that the chance for cure is essentially lost. It is difficult to quantify the extreme duress patients endure in these cases where repeat surgery is ultimately rarely curative.

Our results suggest that true petroclival tumors of all sizes, with or without cavernous sinus extension, can be resected safely, with excellent functional outcomes. Although postoperative cranial nerve deficits are a frequent complication, they are often transient and may not be as detrimental to a patient’s quality of life as some believe. We acknowledge, however, that complete resection may not be possible in some cases, and that paramount in the management in these patients is the ageless maxim to “do no harm.” We thus continue to espouse radical resection where possible, based on preoperative study and maximal operative effort coupled with careful intraoperative judgment, as the treatment of choice for true petroclival tumors. In our practice, residual tumor is first managed expectantly; radiation therapy is reserved for the surgically unfit patient or for the setting of complicated recurrence.

Conclusions

Meningiomas in the petroclival region represent a collection of similar but distinct entities; we describe...
here our experience with “true” petroclival tumors. Once treatment is indicated, these tumors should be held to the same standard that Simpson applied to all meningiomas: that is, that complete resection mitigates recurrence, and this can be achieved in the majority of cases with low mortality and morbidity and improvement of functional outcome. One must accept that not all petroclival meningiomas may be completely removed, but this should not alter the neurosurgeon’s goal of fully resecting these tumors. Residual tumor can be followed initially; subsequent growth or aggressive pathology may prompt radiotherapeutic consideration.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Al-Mefty, Almefty, Dunn. Acquisition of data: Al-Mefty, Dunn, Pravdenkova, Abolfotoh. Analysis and interpretation of data: all authors. Drafting the article: Al-Mefty, Almefty, Dunn, Pravdenkova. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Al-Mefty. Statistical analysis: Almefty, Pravdenkova, Abolfotoh. Administrative/technical/material support: Al-Mefty. Study supervision: Al-Mefty, Dunn.

References

True petroclival meningiomas


38. Spetzler RF, Daspit CP, Pappas CT: The combined supra- and infratentorial approach for lesions of the petrous and clival regions: experience with 46 cases. *J Neurosurg* 76:588–599, 1992


Manuscript submitted March 15, 2013. Accepted August 13, 2013. Please include this information when citing this paper: published online October 25, 2013; DOI: 10.3171/2013.8.JNS13535.

Address correspondence to: Ossama Al-Mefty, M.D., Department of Neurosurgery, Brigham and Women’s Hospital, PBB-3, 15 Francis St., Boston, MA 02115. email: oalmefty@partners.org.