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Petroclival meningiomas: surgical experience in 109 cases

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The surgical removal of petroclival meningiomas has historically been associated with a high incidence of morbidity and mortality. The 109 consecutive patients included in the present retrospective study represent a combined series of tumors operated on by the four authors during a period from 1980 to 1992. The series is composed of 40 men and 69 women ranging in age from 25 to 75 years (mean 51 years). Surgical approaches to tumors in this series included simple retromastoid (60 cases), combined supra- and infratentorial petrosal (22), transtemporal (primary transsigmoid retrolabyrinthine, translabyrinthine, or transcochlear (12)), subtemporal (11), and frontotemporal transcavernous (eight). Gross-total removal was achieved in 75 patients (69%). Recurrence or progression of disease occurred in 14 patients (13%) over a 6.1-year mean follow-up period, and it was found within the cavernous sinus in 12 of these cases. Four recurrent cases demonstrated histological compatibility with malignant meningioma. Perioperative death occurred in four patients, and there were 56 significant complications in 35 other patients. Review of this series, with the attendant complications, has facilitated the authors' decision-making when considering the risk of gross-total removal in selected patients with asymptomatic cavernous sinus invasion or tumor adherent to the brainstem.

KEY WORDS • brain neoplasm • clivus • meningioma • petrous bone • posterior fossa • skull base tumor

CONSIDERING their proximity to cranial nerves, the basilar artery and its perforating branches, and the brainstem, petroclival meningiomas are not statistically frequent, but they represent some of the most formidable challenges in skull base surgery.[1] These lesions may attain surprisingly large size with minimal symptoms; however, with continued growth in this location, their natural history is one of ultimate progression to fatality.[5,6,11,53] Prior to 1970, the risk of mortality from resection of petroclival meningiomas exceeded 50%.[5,7,11,44,52,53] Indeed, a successful total removal was reported in only one case prior to 1970,[36] and as recently as 1967 these tumors were deemed by some authors to be "inoperable."[40]

Many clinical decisions regarding the extent of necessary resection have been based on small series with limited follow-up periods.[22,36,44,49] The goals for resection of these tumors may vary among patients based on the particular location of the tumor and the age of the patient. For example, older patients with slow growing neoplasms may derive symptomatic relief with subtotal resection and careful postoperative follow up. In this regard, asymptomatic cavernous sinus extension of tumor originating in the posterior fossa or in the region of Meckel's cave represents a controversial indication for attempted total removal.

The present study reviews the combined experience of four surgeons, and proposes an individual approach to these tumors based on tumor size and associated region of local invasion as determined by both radiographic and clinical criteria. To this end, review of this series and comparison of extent of surgical resection with follow up data has provided information that has modified the authors' management of some of these difficult lesions.

We are in agreement with other authors in considering lower-third clival-located tumors as being primarily foramen magnum lesions and as such they will not be discussed here;[1] furthermore, using this strict definition we have not included the lateral petrous or petrotentorial lesions that have been included in other series,[36] because tumors in these locations pose a much lower risk for cranial nerve injury with their removal (Fig. 1).

Clinical Material and Methods

Patient Population

The 109 consecutive cases represent a combined series of patients operated on by the four authors in a period from 1980 to 1992. These patients were operated on in three hospitals (Mitsui Memorial Hospital, Tokyo, Japan,

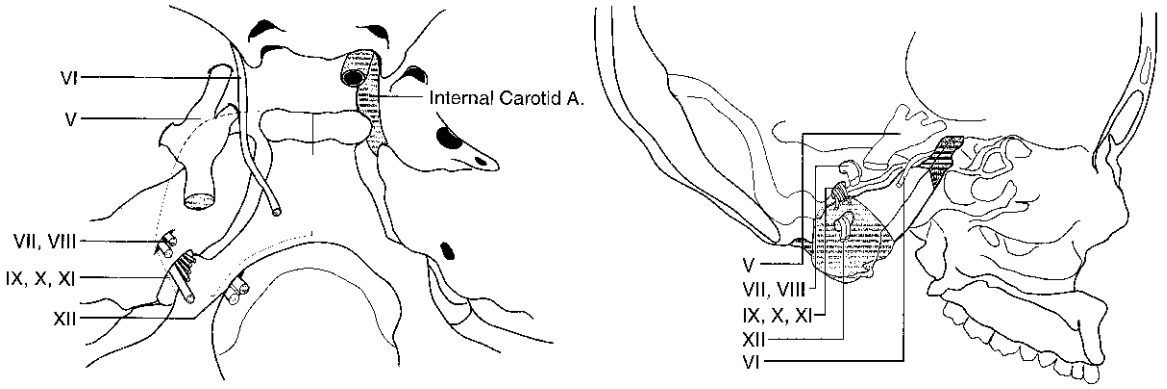

FIG. 1. Illustrations showing definition of petroclival meningiomas in the present study. Tumors defined as petroclival are those with basal attachments at or medial to the skull base foramina of cranial nerves V through IX, X, and XI. This area is demonstrated by the *shaded region* in the basal view *(left).* The upper and middle clival region includes the posterior clinoid processes, the dorsum sellae, and the clivus down to the jugular foramina. Lesions of the lower third of the clivus (*medium shaded region* of the lateral view, *right)* are best considered as foramen magnum in location when planning surgical strategies and will not be discussed here (from Couldwell and Weiss,[9] with permission).

80 cases; University of Southern California University Hospital, Los Angeles, and the Los Angeles County/University of Southern California Medical Center, Los Angeles, California, 29 cases). All patients' operative records, radiographs, and case histories with postoperative courses were reviewed for this retrospective study. The ages of patients in this series ranged from 25 to 75 years (mean 51 years). The male/female ratio was 40:69. Presenting symptoms were related to cranial nerve impairment, cerebellar or brainstem compression, or increased intracranial pressure. The most common presenting symptoms in our series were gait disturbance or headache (90%), whereas cranial nerve palsies represented the most common presenting signs. Symptoms such as motor deficit or gait disturbance are often very slowly progressive and in many cases the diagnosis is delayed. Cranial neuropathies included any within the posterior or middle fossa, with unilateral hearing loss or facial sensory disturbances the most frequently encountered.

Neuroradiological Evaluation

All patients underwent preoperative unenhanced and enhanced computerized tomography (CT) or magnetic resonance (MR) imaging. All tumors carried the preoperative radiological diagnosis of meningioma and were significantly contrast enhancing. The preoperative sizes of the lesions are presented in Fig. 2; note that 80% of these lesions were greater than 2 cm in their largest dimension. Four-vessel cerebral angiography was performed only in those cases with expected engulfment and compromise of the basilar artery or one of its major branches, or in those cases with cavernous sinus extension and suspected carotid artery involvement.

Surgical Procedures

The surgical approaches used are listed in Table 1. The most common procedure was a simple retromastoid approach. However, more recently the combined supra- and infratentorial transpetrosal sinus (or simply "petrosal") approach has been used, comprising 22 patients in the total series but a larger percentage in the most recent period (10 of the last 22 large tumors). The primary transtemporal approaches included transsigmoid (one case), translabyrinthine (eight cases), and transcochlear (three cases). A primary subtemporal approach was used in 11 patients, three of whom had previously undergone a retromastoid craniotomy for removal of the major posterior fossa component of the tumor. In four of these 11 patients, a posterior transcavernous dissection was performed for tumor present in Meckel's cave and extending into the posterior cavernous sinus. A pterional frontotemporal approach was chosen for the remaining eight cases in the series.

Regardless of the approach chosen, patients received high-dose glucocorticoids intravenously (solumedrol 40 mg q6h or dexamethasone 10 mg q6h), starting the day prior to surgery. Cranial nerve monitoring (brainstem auditory evoked response), evoked potential, and electroen-

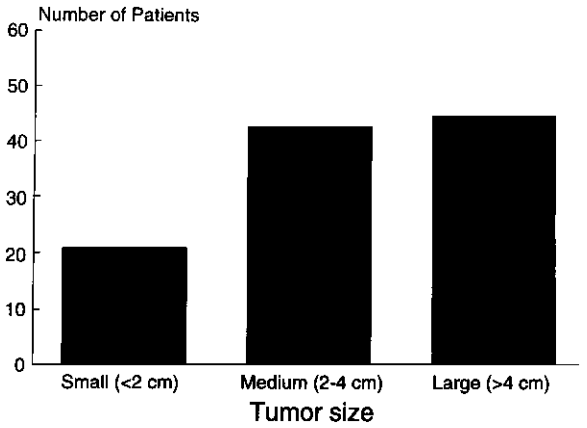

FIG. 2. Bar graph showing preoperative tumor size in this series of 109 patients. Histogram plots representing the number of patients presenting with small (< 2 cm), medium (2–4 cm), or large (> 4 cm) tumors. Note that the majority of tumors in this series presented greater than 2 cm in size (80%).

TABLE 1

*Surgical approaches used in the 109 patients with petroclival meningiomas**

Surgical Approach	No. of Tumors
retromastoid/retrosigmoid	60
combined petrosal (with retrolabyrinthine, translabyrinthine, or transcochlear temporal exposure)	22
primary transtemporal (presigmoid/retrolabyrinthine, translabyrinthine, or transcochlear)	12
supratentorial subtemporal	11
frontotemporal transcavernous	8

* Note that four patients underwent staged procedures for tumor removal.

TABLE 2

Surgical complications in 35 of 109 cases of petroclival meningioma

Complication/Result*	No. of Complications
brainstem stroke resulting in	
hemiparesis	9
ataxia	7
postop hematoma	4
neuropathies	
CN III	6
CN IV	7
CN V	6
CN VI	5
CN VII	5
CN VIII	5
vocal cord paralysis	2

* CN = cranial nerve.

cephalographic monitoring were used in most cases in the series and in all surgical cases since 1987.

Evaluation of Treatment

The extent of removal was evaluated by intraoperative observation and postoperative enhanced CT or MR imaging obtained within 3 months of surgery. Gross-total removal was determined by intraoperative evidence of no remaining tumor together with no evidence of enhancing tumor on postoperative radiographic evaluation. Any other criteria were considered to be a subtotal resection.

Results

Complete (gross-total) operative tumor removal was achieved in 75 (69%) of the 109 patients in this series. This was supported by complete intraoperative tumor resection with no evidence of tumor on postoperative CT and/or MR studies within 3 months of surgery. The remaining patients all had gross or microscopic residual tumor acknowledged to be remaining at the time of operative closure.

Clinical or radiographic evidence of recurrence (or progression in those patients with subtotal resection) occurred in 14 patients (13%) over a mean follow-up period of 6.1 years (range 2.1–14 years). In four of these 14 patients, the histology was determined to be malignant at the initial surgery, and all of these patients had received postoperative external-beam radiation therapy. The remainder of tumors operated on all had demonstrated benign histology at the initial resection.

Of the 34 patients with a subtotal tumor removal, 20 patients had acknowledged gross tumor extending into the posterior cavernous sinus. Twelve of the 20 patients demonstrated radiographic progression of the tumor within the remaining cavernous sinus component (comprising 12 of the 14 total patients demonstrating progression or recurrence); six of these patients then underwent a course of external-beam radiation therapy, and the remaining six patients underwent a staged removal of the cavernous component, with oncological total removal of tumor and involved nerves, with carotid artery resection and saphenous vein–carotid artery anastomosis. None of the 12 patients with cavernous sinus progression has demonstrated recurrence in the subsequent follow-up period (mean 4.4 years). Of the six patients who underwent surgical resection, all had clinically documented progressive cranial neuropathies (two patients had a complete cavernous sinus syndrome). The remaining eight patients with asymptomatic residual tumor within the cavernous sinus have demonstrated no radiographic or clinical progression during the follow-up period.

In the two remaining patients (of the 14 total) who demonstrated tumor recurrence or progression, one recurrent tumor was noted at the region of Dorello's foramen 18 months following removal of an upper clival tumor and the other in the inferior one-third of the clivus 2 years following resection of a midclival tumor. These were both resected without sequelae and the patients are currently recurrence free following the second surgery and postoperative radiation therapy.

Surgical Complications

The complications from surgery in this series are listed in Table 2. Death occurred in four patients (3.7%); all deaths were related to postoperative complications secondary to depressed neurological status (pulmonary embolus in one patient and sepsis secondary to pneumonia in three patients). There were 56 significant permanent complications in 35 additional patients. Major morbidity from significant brainstem infarction resulting in hemiparesis or gait instability occurred in 16 patients. Four patients developed postoperative hematomas, two of which required surgical removal and resulted in permanent neurological deficit. Permanent cranial nerve deficits occurred in 36 patients (33%); the most frequent were those involving the cavernous sinus (third, fourth, fifth, and sixth cranial nerves). Five patients had complete sensorineuronal hearing loss resulting from surgery (excluding translabyrinthine removal). Two patients developed true vocal cord paralysis with resulting aspiration, requiring temporary tracheostomy. Both of these patients were successfully decannulated with no permanent sequelae.

Illustrative Cases

Review of this series emphasizes two important clinical situations in which subtotal resection should be contem-

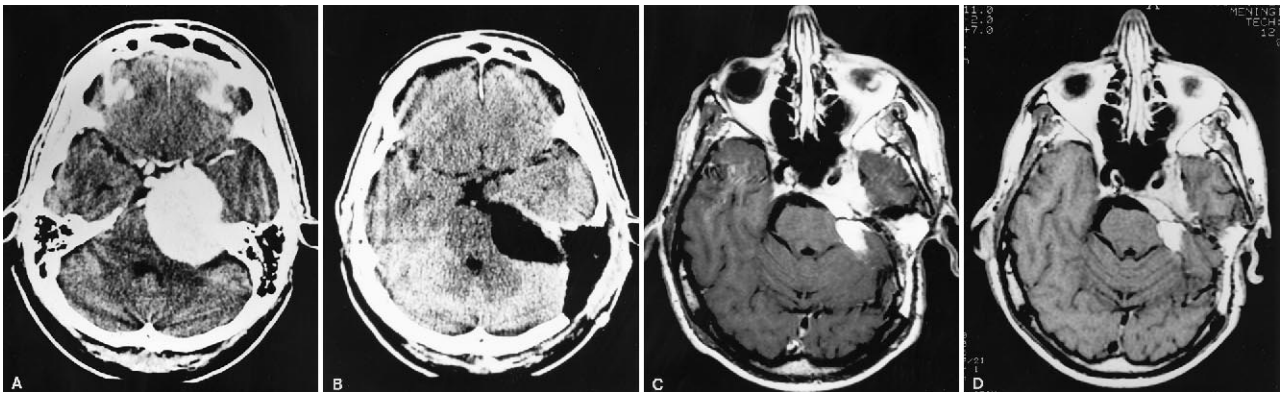

FIG. 3. Case 1. Computerized tomography (CT) and magnetic resonance (MR) images showing associated cavernous sinus involvement. A 72-year-old man presented with a 3-year history of progressive gait ataxia, right leg paresis, and left-sided hearing loss. There was no evidence of clinical oculomotor paralysis or facial sensory loss. Note the large left petroclival tumor with obvious cavernous sinus involvement (A). Following a combined supra- and infratentorial petrosal approach, the tumor was resected from the posterior fossa, although the portion of the tumor entering Meckel's cave was not removed. Postoperative CT (B) shows resection of the posterior fossa component with a fat graft placed in the temporal bone defect. Three-month postoperative MR images show residual tumor in the cavernous sinus (C) which remains unchanged over a 3-year follow-up period (D). Note the high-intensity fat graft remaining at the position of the apex of the petrous bone. The patient has demonstrated no clinical progression, with binocular vision.

plated given the potential morbidity involved with attempting total removal.

Case 1: Associated Cavernous Sinus Involvement

This 72-year-old man presented with a 3-year history of progressive gait ataxia, right leg paresis, and left-sided hearing loss (Fig. 3). The symptoms had been insidious, and workup had included only a previous lumbar spine MR image to rule out nerve root compression. Neurological examination was remarkable for near-total sensorineuronal hearing loss in the left ear, mild left arm dysmetria, and mild paresis of the right leg with no associated sensory abnormalities. Preoperative CT revealed a large (6 cm) broad-based lesion consistent with petroclival meningioma (Fig. 3A). The patient underwent a combined supra- and infratentorial (petrosal) approach, in combination with translabyrinthine temporal drilling, with resection of the posterior fossa mass. The tumor was noted to enter the cavernous sinus both on preoperative imaging and intraoperatively. Because the patient manifested no evidence of preoperative cranial nerve deficit from this cavernous involvement, a decision was made not to remove the intracavernous portion. The postoperative CT scans demonstrated removal of the posterior fossa component of the tumor, with a residual tumor within the confines of the cavernous sinus (Fig. 3B). The preoperative hemiparesis resolved. In a 3-year postoperative follow up, the patient showed no progression of cavernous sinus involvement either clinically or radiographically (Fig. 3C and D).

Case 2: Tumor Capsular Adhesion to Brainstem

This 57-year-old woman presented with an insidious history of progressive headaches and gait ataxia (Fig. 4). Clinical examination was remarkable for right-sided appendicular ataxia. With the exception of mild sensorineuronal hearing loss, there were no cranial nerve abnormalities. A preoperative MR image revealed a large gadolinium-enhancing petroclival tumor with marked brainstem compromise (Fig. 4A). The patient underwent a combined supra- and infratentorial (petrosal) approach; at surgery, the bulk of the tumor was removed without difficulty, although the medial margin of the tumor was noted to be very adherent to the brainstem. Because of this adherence, an intraoperative decision was made to abort the dissection from the brainstem and leave the adherent capsule. Scanning immediately after surgery (Fig. 4B) and 2 years later (Fig. 4C) showed no growth of the remaining capsule. With the exception of deafness in the ipsilateral ear, the patient had an uneventful postoperative course with return to complete activity.

Discussion

Classification Schemes

Posterior fossa meningiomas constitute some 10% of all intracranial meningiomas.[1,2,5,6] Classifications of posterior fossa tumors have been put forth by Castellano and Ruggiero[6] and Yaşargil, *et al.*[53] Using postmortem studies, Castellano and Ruggiero classified posterior fossa tumors by site of dural attachment. They described their location as either cerebellar convexity (10%), tentorium (30%), posterior petrous (42%), clivus (11%), or foramen magnum (4%). They also noted a group of tumors that extended from Meckel's cave into the posterior fossa. Yaşargil, *et al.*, classified posterior fossa tumors based on intraoperative observations into those with primary attachment to clival, petroclival, sphenopetroclival, foramen magnum, or cerebellopontine angle locations.

Unfortunately, these classification schemes do not differentiate the clinically recognized petroclival location exclusively from other tumor locations. Petroclival meningiomas represent only a percentage of meningiomas that reside in the posterior fossa. Tumors emanating at or

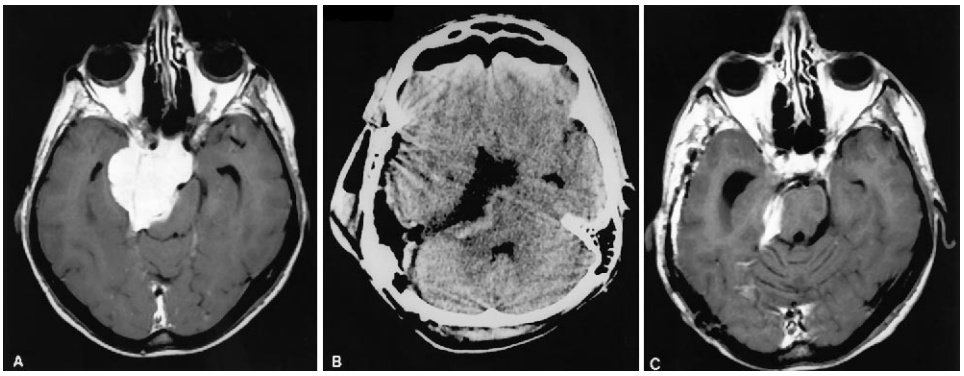

FIG. 4. Case 2. Magnetic resonance (MR) imaging and computerized tomography (CT) demonstrating tumor adherence to the brainstem in a 57-year-old woman with gait ataxia and headaches. Preoperative examination revealed mild sensorineural hearing loss and appendicular ataxia. The large right petroclival tumor (A) was resected via a petrosal approach. At surgery, it was noted that the medial tumor capsule was densely adherent to the brainstem, and a decision was made to leave a small margin of tumor. Comparison of the immediate postoperative CT scan (B) and the follow-up MR study 2 years later (C) demonstrates no evidence of progression. With the exception of complete ipsilateral sensorineuronal hearing loss, the patient is neurologically intact.

medial to the entrance or exit of cranial nerves at the base of the skull are those that should be strictly classified as within the petroclival area. These tumors present a surgical challenge: cranial nerves are interposed between the surgeon and the pathology, and the tumor often displaces or engulfs the basilar artery or its major branches and the perforating vasculature supplying the brainstem. The one exception in classifying these lesions by this method is the tumor that commonly emanates directly from the region of Meckel's cave, to which Cushing and Eisenhardt[10] ascribed the name "gassero-petrosal" (equivalent to the sphenopetroclival tumors of Yaşargil[53]). With continued growth, such tumors invariably become both supra- and infratentorial, and occupy both medial and lateral positions to the fifth nerve. From a clinical perspective, these tumors are to be considered together with those originating medial to Meckel's cave (either apical petroclival or pure clival), as surgical strategies for their attack will be similar. They are considered by most authors to be included in the petroclival classification.

Thus, the strict definition of petroclival tumors in the present series is suggested (Fig. 1), with particular attention being paid to the location of dural attachment in relation to the foramina of specific cranial nerves,[9] critical when determining the difficulties inherent in surgical resection. As noted in Fig. 1, tumors emanating from the lower third of the clivus at or medial to the hypoglossal canal are best considered as foramen magnum in location.

Surgical Morbidity and Mortality

Because of their location, the surgical removal of petroclival meningiomas has historically been associated with high morbidity and mortality.[5,6,11,22,23] With the advent of improved microsurgical technique, removal of these tumors has become increasingly safe, with more recently published series demonstrating less than 10% mortality.[1,4,22,43,44,48,49] The surgical results of the present study are in agreement with such contemporary studies. The 3.7% mortality in the present series compares favorably to the 9% mortality reported in a series of 35 patients by Mayberg and Symon,[36] and the 17% and 15% mortality reported by Hakuba, *et al.*,[22] and Yaşargil, *et al.*,[53] respectively, all of which were reported after the development of microsurgical techniques. The present series' mortality is also consistent with the absence of deaths reported in the more recent smaller series of Al-Mefty, *et al.*,[1] and Samii, *et al.*[44]

These tumors, however, remain a surgical challenge because of the relatively high incidence of permanent complications associated with their removal. In the present series, 35 (33%) of 105 patients developed a total of 56 permanent complications (Table 2). This figure compares favorably with the 53% complication rate reported in series prior to 1970;[53] the 50% incidence of permanent postoperative deficits reported by Mayberg and Symon;[36] and the recently published experience of Bricolo, *et al.*[4] However, it is only marginally improved over the 46% permanent complication rate reported in the series of Samii, *et al.*,[44] although it is consistent with the 4 of 13 patients who demonstrated new permanent postoperative deficits in the series of Al-Mefty, *et al.*[1]

Not surprisingly, cranial neuropathies were the most frequent complication encountered; the nerves most often involved were those associated with cavernous sinus tumor and its removal (third, fourth, fifth, and sixth cranial nerves). Consistent with previous experience, the size of the lesion was of significance in determining surgical morbidity and mortality.[4,43,45]

Recurrence Rate

The recurrence rate in the present series is low over the defined follow-up period, with 13% of patients having documented recurrence or progression (radiographic or clinical) over a mean follow-up period of 6.1 years. Four of these 14 patients demonstrated malignant tumor histology at the time of the initial resection. The low rate of recurrence for the benign tumors in this series corresponds to those reported in earlier smaller series: of 35 patients reported by Mayberg and Symon,[36] progression occurred in only 15% of 30 cases followed for a mean of 34

TABLE 3

*Choice of surgical approaches to remove petroclival meningiomas**

Surgical Approach	Factors Indicating Approach
retromastoid/retrosigmoid	small- or medium-sized tumors limited dural attachment mid or upper clivus
primary transtemporal	small- or medium-sized tumors medial or lateral location nonfunctional hearing status (transcochlear or translabyrinthine only)
petrosal	large tumor extensive basal attachment supra- and infratentorial
subtemporal	small- or medium-sized tumors majority of tumor volume above tentorium may be combined with posterior transcavernous exploration

* Factors considered in the choice of surgical approaches used in the present series. The decision regarding the approach was based on tumor size and site of dural attachment. A more limited approach was necessary if a subtotal resection was planned.

months. Furthermore, Sekhar and Samii[49] noted that only one (20%) of five patients known to harbor residual tumor experienced progression, and Samii, *et al.*,[44] noted no recurrence in 24 patients operated on over a 2-year period. Twelve of the 14 patients in the present series developed tumor progression from residual gross tumor within the cavernous sinus, which emphasizes the importance of this location as a likely site for recurrence in tumors straddling the petrous apex.

Surgical Approaches

An excellent review of potential approaches to petroclival meningiomas has been recently published[2] and includes frontotemporal,[53] subtemporal–transtentorial,[3,38,41] occipital–transtentorial,[51] suboccipital (that is, retromastoid),[10,35,42,49] combined subtemporal and translabyrinthine,[28,37] combined suboccipital and translabyrinthine,[24] and transcochlear[25] and transtemporal[19,46] approaches. Other more extensive or less commonly reported approaches to the intradural clival region include the extended transbasal,[12] midline approaches (transsphenoidal, transoral, transcervical),[12] infratemporal,[15,16] and facial translocation (degloving).[26]

In planning an approach to a meningioma in this region the most important factors considered by the authors were the location and extent of skull base attachment (Table 3). Examination of the preoperative gadolinium-enhanced MR images provides the most valuable information regarding skull base attachment and/or involvement by the tumor. In addition, with the use of high-field thin-section MR imaging many cranial nerves can be visualized in their intradural course and any deviation or loss of continuity within the tumor mass is carefully noted. In cases of sizable lesions whose entire mass was within the posterior fossa, suboccipital and/or transtemporal bone removal was performed; extension beyond the tentorial hiatus required additional supratentorial exposure if total removal was attempted. This was accomplished either by direct supratentorial transsylvian or subtemporal exposure or by opening the tentorium via the posterior fossa. With midline tumors entirely related to the clivus, a more lateral–basal approach was chosen to visualize the attachment. Ideally, an approach was chosen to expose and enable immediate interruption of the tumor blood supply at the base of the skull; this may be accomplished intra- or extradurally, depending on the location of the attachment. Midline approaches through contaminated fields were avoided; this was for reasons of both the inherent risk of meningitis from operating in a contaminated field and the difficulty in obtaining an adequate dural closure following resection.

Another major consideration in approaching the tumors in this series was the status of the patient's hearing. The acoustic nerve is prone to early injury from tumor growth, so hearing is often already diminished. If preoperative hearing assessment indicated functional hearing was significantly impaired ($>$ 50 dB hearing loss or $<$ 50% speech discrimination), a translabyrinthine or transcochlear exposure, which sacrificed remaining hearing, was considered to facilitate more medial exposure to the tumor attachment while providing early interruption of the tumor blood supply through removal of the temporal bone.

The surgical approaches used in the present series indicate the combined preferences of the four authors. The most popular approach was the simple retromastoid (retrosigmoid) craniotomy; this approach was used for smaller tumors that were medially or laterally situated, with a limited area of dural attachment, and in patients with intact hearing. In tumors with more extensive basal attachment and in tumors operated on more recently in this series, the combined supra- and infratentorial parapetrosal (or simply petrosal) approach was utilized with increasing frequency.[8,17,18,32,34,50] This approach has had a lengthy evolution[2,17] and has been recently popularized and refined by Malis,[33,34] Al-Mefty, *et al.*,[1] Kawase, *et al.*,[27] Spetzler, *et al.*,[50] and our group.[8,18] In the present series, the approach was used for tumors centered about the petrous apex and in large-sized lesions with significant supra- and infratentorial extension. The mastoid removal may be combined with any of the standard transtemporal exposures, depending on the status of hearing or the extent of bone removal desired. The approach has virtually eliminated staging tumor removal due to anatomical limitations. Primary transtemporal approaches (defined here to include presigmoid or transsigmoid retrolabyrinthine, translabyrinthine, and transcochlear) were chosen for a minority of tumors in this series (12 cases). Temporal bone drilling was used in those tumors with a more extensive medial–lateral attachment, with minimal supratentorial extension. The obvious disadvantage relates to hearing loss following drilling of the labyrinth or cochlea; in addition, the dural opening may be limited, but these approaches may be combined with a standard retromastoid craniotomy if the sigmoid sinus is sacrificed.[50] A primary subtemporal (supratentorial craniotomy) approach was performed in 11 patients in the present series, three of whom had previously undergone a retromastoid craniotomy for removal of the major posterior fossa component of the tumor. In primary removals, the approach was chosen in those instances in which most of the tumor was located supratentorially. In four of these 11 patients, a posterior transcavernous dissection was performed for tumor pres-

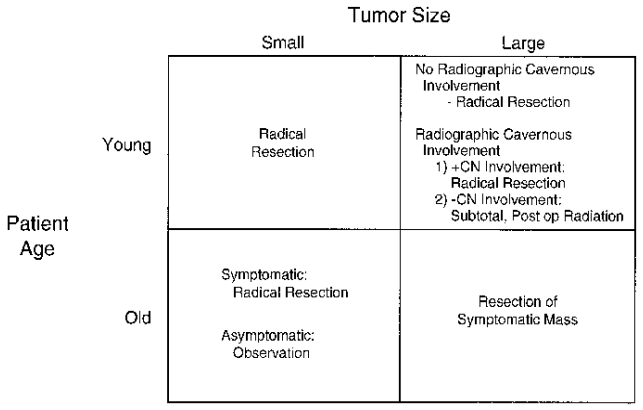

FIG. 5. Current general guidelines used by the authors as goals of surgical resection based on the age of the patient, size of tumor, and presenting symptomatology. (CN = clinical cavernous cranial nerve involvement.) In young patients aggressive removal is always undertaken except in situations in which the cavernous sinus is radiographically involved without cranial neuropathies. However, in elderly individuals a much less aggressive approach is taken, and the authors perform resections in symptomatic cases only. Large tumors involving the cavernous sinus are subtotally resected if cranial nerve function is intact, removing only the major compressive component. The information listed is general, and the individual situation and surgical judgement always prevail in final case management.

ent in Meckel's cave and extending anterior into the posterior cavernous sinus.[23] The authors have reserved the use of this posterior transcavernous approach for those cases in which removal of the posterior cavernous tumor component is a fundamental goal and in which the major tumor volume presents above the level of the mid-to-upper clivus. A frontotemporal approach was used in only eight patients in the present series; it was chosen in those cases in which the majority of the tumor was located supratentorially and involved the cavernous sinus and in which a preoperative decision was made to resect the cavernous component. Depending on the superior extent of the tumor above the dorsum sellae, an orbitozygomatic (or pure zygomatic) osteotomy was performed with this approach, ultimately to enable a lower visual trajectory to facilitate viewing of tumors projecting superiorly.

Goals of Surgical Resection

Review of this series has offered some insights that have modified the authors' present approach to the treatment of these lesions. When defining the goals of surgery in the management of these tumors, it is important to consider the age of the patient, the location of the tumor, and the presenting symptomatology (Fig. 5).

A general tenet practiced by the authors is that whenever possible aggressive surgical removal should be the goal; this prevails as the best hope for a cure or extended tumor control.[2] Exceptions to this rule arise if the risk of increasing neurological deficit is prohibitive.[39] Specifically, there are some intraoperative conditions that may preempt total removal, including the liability for significant morbidity from tumor involvement of cranial nerves or brainstem vasculature. Many of the final decisions regarding the amount of removal are made intraoperatively, based on the surgeon's judgment of risk involved with resection.

1) Cavernous Sinus Involvement. Because of the common source of origin of many of these tumors involving Meckel's cave, often there is cavernous sinus involvement that can be seen radiographically, with little or no cavernous cranial neuropathy. Mere radiographic cavernous sinus extension of tumor presently represents a controversial indication for attempted total removal;[13] it is our present practice to limit removal or exploration of this region if the patient has functional binocular vision (that is, no significant diplopia) and facial sensation that is not significantly impaired. Thus, in such patients a staged approach is planned, with observation of the intracavernous component or possible adjuvant radiation or radiosurgical treatment until such time as the patient develops evidence of progressive cranial neuropathies from tumor growth. In the present series, 12 (60%) of 20 patients with gross tumor remaining in this location showed progression radiographically and clinically over the follow-up period; it was at this juncture that consideration was given to a radical intracavernous exploration and removal. In a younger patient, this may require an aggressive approach with radical cavernous sinus resection, including the cavernous portion of the carotid artery if involved with tumor. The antiprogesterone agent RU 486[21,30,31] and radiosurgery[14,29,32] may offer alternative treatments for the intracavernous component, pending the long-term follow-up results of current ongoing trials.

2) Patient Age. In elderly patients, especially in those with associated medical problems, the goals of surgery must be limited appropriately. In selected cases, subtotal removal or staged procedures may be considered, such as in patients with minimal or no cranial nerve symptoms but with significant brainstem compression. In these individuals a subtotal procedure designed to debulk the compressive mass of the tumor may be justified, with no attempt to remove that part of the tumor invading the cavernous sinus or adherent to the brainstem. As demonstrated by the patient in Case 1 (Fig. 3), these patients may be followed for years with little evidence of progression of cranial nerve compromise despite gross cavernous invasion. Because many of the tumors in this location are slow growing, asymptomatic lesions in elderly patients clearly warrant an observation period before attempting surgical removal.

3) Vascular Involvement and Pial Invasion of the Brainstem. Additional difficulty arises when a tumor encases the basilar artery,[47] lies between the artery and brainstem, or parasitizes the microvascular supply to the brainstem. In such instances extreme care must be exercised in removing this tumor, because interruption of perforating vasculature may result in grievous brainstem infarction. However, as noted by Sekhar and Javed,[47] an arachnoidal plane surrounding a blood vessel allows it to be dissected free by experienced surgeons in the majority of cases. Tumor adherence to the brainstem may be anticipated in some cases on preoperative MR imaging; some authors have reported such parameters as loss of arachnoidal plane on T_1- and T_2-weighted images, and edema of the brain-

stem seen best on T_2 images as indicators of pial invasion.[45] An intraoperative decision must be made to ascertain whether removal of the tumor in this location is justified; in those cases in which removal is difficult or the tumor is adherent to vascular structures a more conservative approach is advocated. As illustrated in Fig. 4, in these cases we do not hesitate to leave a thin portion (< 4 mm) of capsule adherent to these structures.

Adjuvant Radiation Therapy

Several retrospective studies have documented the efficacy of radiation therapy following surgery for subtotally resected meningiomas (recently reviewed by Goldsmith, *et al.*[20]) Moreover, the advent of focused radiosurgical techniques has enabled delivery of radiation doses with a steep fall off to limit radiation to nontumor locations. Meningiomas, characterized by well-defined radiographic margins, no brain invasion in benign cases, and vascularity that may be obliterated with radiation therapy, are particularly well-suited to delivery of this type of therapy.[14,29] Little published data with significant follow-up periods exist for cranial base meningiomas, but initial reports by Lunsford[32] suggest that greater than 90% 4-year actuarial tumor control rates may be achieved with gamma knife therapy of skull base meningiomas. Specifically with tumors involving the cavernous sinus, they noted a low 6% incidence of delayed cranial nerve compromise; if this experience is substantiated in ongoing trials, then this therapy should become a regular adjuvant to the overall management, decreasing recurrence rates in subtotally resected lesions. Although patients in the present series did not undergo routine radiosurgical treatment of residual tumor for reasons of limited availability during most of the era, our current practice is to offer this option to this select group of patients.

Conclusions

The review of the present large series of patients has illustrated that the surgical removal of petroclival meningiomas still presents a surgical challenge. Although mortality in the present and other contemporary series has been dramatically reduced, surgical morbidity remains significant, largely from associated cranial neuropathies. The appropriate management strategy should be based on the age of the patient and presenting clinical symptoms, radiographic definition of the lesion, and goals of surgical resection for that particular individual. Although it is appropriate to strive for total removal of all tumors, in specific instances subtotal resection may be indicated. Overall recurrence rates remain low, but the present review has identified the cavernous sinus as a likely region for recurrence or progression of subtotally resected lesions. It is in this group of patients that adjuvant therapy, such as radiosurgery, may be indicated to prevent or delay cavernous cranial neuropathies from tumor recurrence. The surgeon must remain cognizant of the frequency with which patients presenting with minimal symptoms may be functionally impaired postoperatively, while attempting a potential "curative" operation; we are in agreement with other authors in that avoidance of surgically induced neurological deficit remains a primary consideration.[13,39]

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