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813 Microsurgical Removal of Petroclival Meningiomas: A Report of 33 Patients
Clinical Study

AUTHOR(S): Bricolo, Albino P., M.D.; Turazzi, Sergio, M.D.; Talacchi, Andrea, M.D.; Cristofori, Luciano, M.D.

Department of Neurosurgery, University Hospital, Verona, Italy

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ABSTRACT: THIS IS A report of 33 consecutive cases of petroclival meningioma treated surgically at our institution over the last 10 years; there were 21 women and 12 men between the ages of 27 and 68 (mean age, 52). All patients were assessed by computed tomographic scans including coronal sections and bone algorithm studies; in most cases, digital subtraction angiography and magnetic resonance imaging were also done. The largest tumor diameter was between 2 and 3.5 cm in 14 cases, 3.5 to 6 cm in 15 cases, and over 6 cm in 4 cases. Dural attachment predominantly involved the clivus and apical petrous bone on one side only; in 14 cases, however, the tumor grew over the clivus midline or crossed the tentorial notch. Cranial nerve deficit was extant in all cases and was commensurate with tumor size. Cerebellar signs and somatic motor deficits were present in 60 and 30% of cases, respectively. The surgical approaches used were the retromastoid-retrosigmoid in 23 cases, subtemporal in 5 cases, and combined retromastoid subtemporal presigmoid in the remaining 5. Total removal was achieved in 26 cases (79%); incomplete removal occurred in 7 cases (21%). The extent of tumor removal and operative morbidity were not significantly related to tumor size. Brain stem indentation, arterial and cranial nerve encasement, and epidural invasion were the main factors that prevented total tumor removal and influenced operative morbidity. There was no intraoperative mortality, but three patients (9%) died perioperatively. In the postoperative period, most patients went through momentary neurological deterioration, chiefly due to new cranial nerve deficits. The average follow-up was 4.3 years in 27 patients; of these 17 were unchanged and 10 were improved. Before surgery, only 13 patients were self-sufficient; at long-term follow-up, another 6 had achieved independence. Our experience suggests that, even though real petroclival meningiomas still represent a formidable surgical challenge, such tumors can in most cases be removed completely with low attendant mortality and acceptable morbidity.

KEY WORDS: Basilar artery; Cerebellopontine angle; Clivus; Cranial nerves; Meningioma; Microsurgery; Petrous apex

Petroclival meningiomas constitute the group of meningeal tumors of the basal posterior cranial fossa offering the greatest challenge to neurosurgical skills. In addition to the clivus and petrous apex, these tumors may involve the medial tentorium, Meckel's cave, the middle cranial fossa, the parasellar area, the petrosal and cavernous sinuses, and the transmission foramina of cranial nerves (CNs) III through XII. Such tumors are wedged in the brain stem; they may encase the basilar and carotid arteries and their roots, perforate the dura, and invade the underlying bone.

Advances in neuroimaging, microsurgery, and approaches to the skull base have afforded better preoperative definition of these tumors while making their removal at once easier and less conducive to iatrogenic damage [2,4,6,18,20,24,26,33,40,45]. These advances have also begun to undermine the sinister reputation attached to these lesions for so many years [9,12,15,19,22,25,28,31,36]. Actually, these tumors are slow growing and produce worrisome symptoms only after reaching considerable size and extension. Two aspects of such meningiomas plague the neurosurgeon: 1) the tumor is histologically benign and causes relatively mild neurological impairment with which the patient learns to live; and 2) major surgery is needed to remove it--with some risk that the patient will be worse after surgery than before. In this article, we report our experience with surgery for petroclival meningiomas, which we have done over the past 10 years in a total of 33 patients. We offer this experience as an addition to the little more than 200 cases published from other sources during the same period.

PATIENTS AND METHODS

Our series consists of 33 consecutive patients treated by microsurgical methods for the removal of meningiomas in the petroclival area. These patients represent 32% of all meningiomas of the posterior fossa operated on in the same period at our institution. We classified as petroclival (and, hence, included in this series) only meningiomas of the basal posterior cranial fossa, growing from the dura of the clivus and petrous apex medial to the trigeminal and CNs VII and VIII (see Al-Mefty's comment in ref. 40). Therefore, we excluded meningiomas of the pontocerebellar angle and the posterior aspect of the rocca with more lateral dural attachments.

All clinical records, neuroimaging studies, detailed descriptions of surgical procedures, and intraoperative photographs were reviewed, as were the clinical controls and repeat computed tomographic (CT) and nuclear magnetic resonance scans made in long-term follow-up. There were 21 women and 12 men between the ages of 27 and 68 (mean age, 52; standard deviation, ±12.4 yr).

Clinical features

Table 1 displays the first and last symptoms to emerge in our series of patients as part of the preoperative clinical picture. Gait ataxia, facial dysesthesia, and loss of hearing were the more frequent initial symptoms, and the trigeminal nerve was the single structure most often involved from the beginning. Later symptoms (those appearing more recently and leading to diagnostic suspicion) were, in

addition to gait ataxia, dysphagia and somatic motor deficit of various types.

The onset of symptoms (Table 2) generally occurred later (on average, 35 months for all symptoms together), varying from 7 months to 17 years. The two complaints occurring earlier were trigeminal neuralgia (43 months) and impaired hearing (35 months); the two occurring closer to the time of diagnosis were diplopia (4 months) and facial weakness (3 months).

Table 3 summarizes the physical signs seen at the time of objective examination shortly before surgery. The clinical picture was dominated by deficits by the intermediate CNs, these being present to various degrees in nearly all patients, with concomitant cerebellar signs in 60% of patients. Cranial nerve V was affected both earlier and more often (67% of patients), followed by CNs IX, X, and XI (45% of patients). Probably the more typical sign of a petroclival meningioma was a relatively fair preservation of hearing in contrast to severe trigeminal involvement and marked impairment of the CNs below VIII, with accompanying cerebellar signs. The preoperative performance status, as expressed by the Karnofsky scale, was more than 70 in 23 patients (70%) and less than 70 in 10 (30%).

Diagnostic studies

All patients were studied with contrast-enhanced CT scans in axial and coronal views and exploration of the skull base through a bone window to detect any erosion or hyperostosis. In addition, 22 of our initial 33 patients received a complete angiographic examination of the vertebral artery and the internal and external carotid arteries with selective contrast injections and digital subtraction imaging.

As the necessary equipment became available, we added magnetic resonance imaging to the study protocol--more recently, with the further refinement of paramagnetic contrast injection. Altogether, 19 of our patients were studied preoperatively by this technique. The salient information to emerge from the battery of neuroimaging tests administered preoperatively is summarized in Table 4. All tumors showed more or less definite projection to one side with no significant predominance (16, right; 17, left). In all patients but four, one side of the clivus was free of tumor attachment, whereas the spheno-occipital synchondrosis and petrosal apex on the affected side were invariably involved (Figure 1). Tumor size, expressed as maximum measurable diameter, was less than 3.5 cm in 14 patients (medium-size group, where the smallest tumor was 2 cm across); 15 patients had tumors between 3.5 and 6 cm across (large); and 4 had tumors over 6 cm across (giant). In 8 patients, tumor base development involved the clivus beyond the midline; in 6 patients, it went past the tentorial notch; and in 14 patients, it showed both of these characteristics. In 16 patients, CT scans revealed skull base alterations in the form of bone erosion, hyperostosis, or both. The intracranial bulge involved mainly the posterior fossa in 26 patients and the supratentorial region in 7.

Patients with medium-size meningiomas had an aggregate CN deficit averaging 1.4, as opposed to 2.6 in those with large or giant tumors. There was also a significant relationship between bone erosion and the number of CN deficits observed: from 1.6 in patients without bone erosion to 2.7 in those with detectable erosion ($P < 0.01$). The significance of bone erosion was even more marked in the group with large and giant tumors (1.7 versus 3.6; $P < 0.001$).

As expected, angiography revealed indirect evidence of the tumor mass in terms of dislocation of the basilar artery and its branches (posterior cerebral and superior, anterior, and posterior inferior cerebellar arteries); in addition, it revealed any choking of the basilar and carotid arteries by the tumor and gave some information about tumoral blood supply. This was not always evident; at any rate, blood was supplied to various degrees by the meningohypophyseal trunk of the internal carotid artery, the posterior branch of the middle meningeal artery, the meningeal branch of the vertebral artery, the clivus artery originating from the carotid siphon, the petrosal branches of the meningeal arteries, and the ascending pharyngeal branches of the external carotid artery. In 30% of our patients, definite tumor staining was visible in the capillary and venous phases of angiography.

The latest entrant in the arsenal of diagnostic tools, nuclear magnetic resonance imaging (especially with added paramagnetic contrast), proved to be superior to any of the earlier methods in terms of defining the exact structure of the tumor in multiplanar spaces. At the same time, this method affords direct vision of distortions caused by tumor masses on the brain stem, cerebellum, and supratentorial nerve structures and of relationships between arteries and veins.

Surgical techniques

Only one of our patients, who was found to harbor concomitant hydrocephalus when first diagnosed with a petroclival meningioma, received a shunt before surgery to obviate a poor neurological status due to intracranial hypertension. Another two patients had been given shunts elsewhere. In all other patients, we preferred to remove the tumor without any other preparations. On the 2 days before surgery, each patient was given dexamethasone and prepared physically (breathing exercises, etc.) and psychologically for the upcoming events. In particular, they were told that they would very probably awaken in a worse condition than before surgery, in an intensive care unit, perhaps hooked up to a mechanical respirator for as many days as might be needed for them to recover autonomy of their vital functions. Table 5 specifies the surgical approaches used in this series; as can be seen (Figure 2), the lateral suboccipital retrosigmoid route (the same one we use for acoustic nerve neurinomas) was vastly preferred (23 of 33 patients).

Particular care is devoted to extending bone drilling upward and laterally to unroof the lateral sinus and sigmoid sinus all the way to the jugular bulb. That done, the incised dura is drawn upward and sideways with traction sutures arranged to pull the lateral and sigmoid sinuses out of harm's way.

This creates a very lateral access to the pontocerebellar angle, parallel to the posterior aspect of the rocca petrosa and to the insertion angle of the tentorium on the petrosal ridge. This allows less retraction of the cerebellum and makes it possible to initiate tumor exeresis by devascularization through coagulation of the dural vessels, first on the petromastoid and then on the clivus.

Next, with bleeding well under control, we proceed to debulk the tumor, with the help of the ultrasonic aspirator, through the fissures of CNs V, VII-VIII, and IX-XI. The tumor is thus detached in succession from the CNs and the brain stem; last, its insertion or site of attachment is demolished on the petrosal apex, tentorium, and upper clivus. The greatest possible care is taken to identify and preserve the arachnoid layers of the cisterns next to the CNs, the brain stem, and arteries (Figures 3 and 4). At this stage of the procedure, coagulation is practically abandoned and replaced by continuous irrigation with saline solution--a trick for which we are indebted to M. Samii (personal communication). When the pontocerebellar angle is completely freed of the tumor, there remains an open space between the brain stem and the free margin of the tentorium, through which the supratentorial space can be accessed. Through that exposure (with a cut into the tentorium if necessary), one can reach and remove even the more rostral projection of the tumor into the middle cranial fossa and parasellar area by dissecting it away from CNs IV and III and from the arteries of the circle of Willis (Figure 5). With exeresis thus completed, through the keyhold delimited inferiorly by the trigeminus, laterally by the tentorium, and medially by the rostral brain stem, the surgeon can enjoy a beautiful upward landscape of neurovascular structures of the interpeduncular, carotid, chiasmatic, and crural cisterns (Figure 6).

In our series, five tumors were accessed through the middle fossa, two through the frontotemporal Sylvian approach developed by Yasargil et al. [45], and three through the subtemporal route after a temporal craniotomy, always with the patient in the supine position (Figures 7 and 8). Both the splitting of the Sylvian fissure and the retraction of the temporal lobe in the former technique, and the sole retraction of the temporal lobe in the latter, give access to the tentorial notch and afford an immediate view of the upward bulge of the meningioma into the temporal fossa and parasellar area. CNs II-V are easily identified, as is the internal carotid artery. These structures can be freed from the tumor that stretches or displaces them. The tentorium can be divided for better exposure of the posterior fossa and continued tumor removal through dissection of its attachment on the clivus and petrosal apex. Last, the tumor is loosened from the basilar artery and its branches while still surrounded, as in a basket, by CNs VII-VIII and IX-XI.

In five of the patients treated more recently, we resected the tumor through the combined suprainfratentorial presigmoid sinus avenue (Figures 9 and 10), as originally described by Hakuba et al. in 1977 [20] and further refined by Al-Mefty and his colleagues [2] with the advantage of avoiding the division of the sigmoid-lateral sinus [33]. The key opening points of the presigmoid route are removal of the mastoid process to expose the sigmoid sinus all the way to the jugular bulb, plus generous drilling of the petrous pyramid, barely stripping the labyrinth bone and staying out of the fallopian canal to avoid deafness and injury to the facial nerve. The dura thus exposed in front of the sigmoid sinus is divided by an incision running upward, parallel and lateral to the sinus, and then higher up above the transverse sinus (i.e, supratentorial). This inverted capital L incision is completed into a capital T cut by extending the horizontal arm anteriorly to expose the basal and posterior convolutions of the temporal lobe and identify the vein of Labbé, which is preserved and protected with the utmost care throughout the procedure. With the posterior fossa and supratentorial region thus exposed simultaneously without undue sacrifice of the vein, the superior petrous sinus is coagulated and the tentorium is transected completely from the outside in. This maneuver affords a broader access because the cerebellum will fall away from the posterior aspect of the petrous bone practically of its own accord. At this point, complete access to the lateral convexity of the tumor is obtained by pushing the sigmoid sinus and cerebellum dorsally and medially with one retractor and holding the temporal lobe slightly elevated with another retractor. Tumor removal is initiated and continued by the usual technique.

RESULTS

Tumor removal

The degree of removal achieved at surgery in terms of tumor volume is illustrated in Table 6. Removal was rated complete when no trace of subdural intracranial tumor was visible at the end of the operation and the dural base of the tumor was completely demolished and/or cauterized. Removal was considered subtotal when more than 90% of the intrathecal tumor was removed but there were evident remnants of it around blood vessels and CNs and or in the dura and bone. Removal was considered partial when surgery failed to remove at least 90% of the intrathecal part of the tumor. Thus defined, tumor removal was complete in 26 patients (79% of cases), namely 12 (86%) of 14 patients with medium-size tumors, 12 (80%) of 15 of those with large tumors, and 2 (50%) of 4 of those with giant tumors. Removal was incomplete in seven patients, namely two medium-size, three large, and two giant tumors. Tumor size was not an important factor in determining the extent of removal achieved, at least for tumors less than 6 cm across. Invasion of the cavernous sinus (four patients with subtotal removal) made complete removal difficult. Other complicating factors were the onset of cardiovascular difficulties during dissection of the tumor from the brain stem and basilar artery, necessitating prompt discontinuation of surgery (two patients with partial removal) or carotid artery encasement with invasion of the cavernous sinus (one patient with partial removal). In such cases, tumor remnants were left in

the cavernous sinus (five patients) and upper clivus around the basilar artery (two patients).

Several technical difficulties were encountered during surgery, as shown in Table 7. Some did not preclude total removal but certainly constituted an obstacle and may have added to postoperative morbidity. In our experience, the main factors that stood in the way of complete exeresis were brain stem indentation, arterial encasement, and the same dural and epidural bone infiltration-erosion that is nearly always the cause of cranial nerve encasement. These anatomical anomalies often occur together and tend to be more frequent and more severe with increasing tumor size. Brain stem indentation, a manifestation of the loss of arachnoid layers that protect the brain from the tumor, was managed successfully (i.e., without apparent injury to the structure of its blood supply) in all but two patients. We found it most helpful to irrigate the field and cleaving plane continuously with saline solution and avoid coagulation as much as possible.

Arterial encasement (as distinct from arterial displacement or engulfment) was seen in 11 patients; it involved the basilar artery and/or its branches in 9 patients and the internal carotid artery in the other 2. Even in such cases, however, the arteries encased in the tumor are often really only engulfed in it and are separated from tumor tissue by a thin arachnoid film, so that gentle, blunt dissection can free them completely without injury. This occurred in seven of our nine patients with apparent basilar artery encasement. In one patient, the high basilar trunk and the superior cerebellar artery were invaded by a bud of tumor tissue that was deliberately left behind. In another patient, we inadvertently sacrificed the anterior inferior cerebellar artery inside the tumor. Invasion of the dura and epidural space is the most difficult condition because it involves the cavernous sinus and CNs. The latter, however, stretched, displaced, or thinned out by the tumor, can nearly always be stripped and preserved in their intracranial subdural course from their origin in the brain stem to their exit from the dura, precisely where they are choked or strangled by tumor tissue. Our persistent efforts to free these nerve roots from the embrace of tumor tissue at a point where, among other things, the nerves are no longer protected by arachnoid tissue resulted in the anatomical disruption of 8 CNs (two VI, two IV, one III, two V, and one IX) and major injury to another 14. Tumor vascularity, although not always faithfully predicted by angiography, never caused major surgical difficulties.

The mean duration of surgery (skin to skin) was 8 hours and 22 minutes (range, 5.30 to 14.10 hours; standard deviation, ±3.17), with no significant difference by surgical approach or tumor size, except for the group of medium-size tumors that were approached by the retromastoid route, which proved significantly less time consuming.

Operative results

Table 8 displays the clinical status of patients and the complications observed during the first week and 1 month after surgery. There was no intraoperative mortality; three deaths occurred in the next weeks as follows: one patient with a giant meningioma removed subtotally through a retromastoid craniectomy died 12 days after surgery from a brain stem failure attributed to unnoticed intraoperative closure of the anterior inferior cerebellar artery; another died 16 days after surgery from intracranial hypertension due to brain swelling and cerebral infarction after partial removal of a large tumor approached by the subtemporal route; the third died 21 days after surgery from a gastrointestinal hemorrhage while recovering from total tumor removal.

In nearly all cases, the patient is in worse clinical and neurological conditions after surgery than before and therefore needs constant, meticulous assistance. Nine of our patients failed to regain consciousness after surgery, and two of them died, as mentioned above, 2 and 3 weeks after surgery without ever regaining consciousness. All patients surviving 1 month after surgery were fully awake and cooperative by that time.

What contributes more than anything else to postoperative neurological deterioration is the onset of new CN deficits or the aggravation of preexisting deficits. Only 8 (24%) of our 33 patients emerged from surgery without any change in CN function; all others showed the onset of at least one new CN deficit, and 12 showed definite aggravation of preexisting deficits as well. Fortunately, many patients with either kind of deterioration showed some evidence of improvement within the first month after surgery, so that morbidity of this type is materially reduced at 4 weeks. The most dangerous types of impairment are palsies of CNs IX and X, causing severe dysphagia and requiring utmost care to prevent aspiration pneumonia. A lesser but still significant contribution to overall neurological deterioration is caused by the onset or aggravation of somatic motor deficits. In our series, four patients developed hemiparesis, abating in two within a few weeks. Altered states of consciousness, the deregulation of brain stem functions, and functional impairment of the lowest CNs were the cause of respiratory problems, requiring mechanical ventilation beyond the second postoperative day in six patients and necessitating tracheostomy in two.

Follow-up

Most of our patients were monitored through suitably timed controls. In October 1990 (a mean of 4.3 yr after surgery; standard deviation, ±2.6 yr), all surviving patients were reexamined clinically and by neuroimaging studies. None of the patients had been irradiated in that time. Three had died as a direct or indirect consequence of tumor recurrence. One patient, some 10 years after radical surgery for angioblastic meningioma with good result, showed rapid deterioration with conspicuous tumor recurrence and died of brain stem failure 3 weeks after repeat surgery. The other two died 3 and 4 years, respectively, after partial removal; one underwent a new operation, whereas the other was not in a condition to tolerate surgery. Our 3 patients surviving

after subtotal removal are ostensibly well 7, 5, and 3 years after surgery, with no evidence of tumor recurrence.

Table 9 summarizes the incidence of CN deficits over time, these being the disorders most conducive to neurological impairment. Before surgery, the average total CN deficit for the whole series of patients was 2.2, with a significant 1.4 increase in the early postoperative period ($P < 0.01$), decreasing to 2.7 at the last follow-up, for a net increment of only 0.5 relative to the preoperative status of the patient (not significant). Here, tumor size seemed to influence postoperative morbidity significantly. Patients with medium-size tumors showed a 0.2 increment of CN deficits, as opposed to 0.6 in patients with large and giant tumors ($P < 0.001$). It remains evident that patients with medium-size tumors are more likely to have fewer permanent CN deficits than are those with large or giant tumors.

Functional status, as expressed by the Karnofsky scale, was on the whole satisfactory, with 24 patients rating a long-term follow-up score better than 80 (Table 10). Neurological improvement usually continued after the first postoperative month, with 70% of patients reaching their preoperative performance status, 30% improving on it, and none rating a long-term follow-up score lower than the starting score. To attempt an overall assessment of our results, we used a rating scale similar to that proposed by Sekhar and Jannetta [34], whereby the results were judged good if the patient was improved relative to his or her preoperative conditions, or if he or she remained self-sufficient and able to carry on his or her previous occupations; fair if the patient was unchanged and self-sufficient but not able to resume previous activities; and poor if the patient was still disabled and needing assistance. Table 11 displays these data arranged by surgical approach and by extent of tumor removal.

DISCUSSION

Classification

Until about 10 years ago, meningiomas of the posterior fossa were classified by the criteria elaborated in 1953 by Castellano and Ruggiero [11] based on Olivecrona's clinical material and adopted by the same author in his *Handbuch der Neurochirurgie* [28]. This classification includes five groups: 1) cerebellar convexity; 2) tentorium; 3) posterior surface of the petrous bone; 4) clivus; and 5) foramen magnum. That grouping was accepted and used until the advent of the CT scan as a diagnostic aid and of the microscope as a surgical tool. By 1980, articles began to appear suggesting that the classification must be revised in order to regroup under a single heading such meningiomas of the basal posterior cranial fossa that could no longer be assigned to the clivus or to the pontocerebellar angle. Yasargil et al. [45] were the first to deny, on the strength of direct microsurgical observations, the existence of rigorously midline clivus meningiomas. "Our impression," they wrote, "is that these tumors arise along the petroclival line (lateral clivus)." They added that "the separation of basal meningiomas into topographical areas such as clival, cerebellopontine angle, etc., is artificial because there are always transitional cases." The same authors recommended a subdivision of the basal posterior cranial fossa into clival, petroclival, and sphenopetroclival areas, the foramen magnum, and the cerebellopontine angle. In 1984, Sekhar and Jannetta [34] stressed that "the site of dural attachment of these tumors often extends from one area into another"; in describing their respective series of cases, Mayberg and Symon [26] speak of "meningiomas of the clivus and apical petrous bone." Sekhar and Samii [36] speak of "petroclival and medial tentorial meningiomas," Al-Mefty et al. [2] and Samii et al. [33] speak of "petroclival meningiomas," Spetzler et al. [42] speak of "meningiomas involving the clivus and cerebellopontine angle," and Fukushima [17] speaks of "petroclival cavernous meningiomas." From such nomenclature emerges a group of meningiomas probably best labeled **petroclival**, to include the **old** clival meningiomas of earlier classifications and a subgroup of meningiomas of the cerebellopontine angle attached medial and anterior to the acoustic nerve canal and trigeminal nerve.

The group so defined is actually homogeneous in more ways than one. Thus, 1) in addition to the clivus area proper, the dural attachment may involve the petrous apex, the medial tentorium, Meckel's cave, the parasellar region, and the petrous and cavernous sinuses; 2) dural attachment often goes beyond the dura to affect the extradural space and bone and to infiltrate CNs at their exit points; and 3) these tumors always develop medial to CNs V, VII-VIII, and IX-XI and may encase the basilar artery and its branches as well as the carotid and circle of Willis. For all of these reasons, the group as a whole presents difficult surgical problems. In other words, these tumors are also homogeneous in terms of surgical challenge. We agree with Mayberg and Symon [26] and Al-Mefty et al. [2] that this group should be sharply separated from the others under the label of "petroclival meningiomas" or "meningiomas of the clival area." We also feel that the single most important characteristic of the group so defined is that the attachment must be medial to CNs V and VII-VIII (Figure 3). Unless a general consensus about these criteria is achieved, published series of cases will remain poorly comparable, as Sekhar and his colleagues have pointed out [40]. Worse, some authors may find it convenient to include in their case lists some meningiomas of the pontocerebellar angle--a neat little trick, because these are a good deal easier to remove.

Diagnosis

Currently, available neuroimaging technology (high-resolution CT scanning, bone algorithms, MRI, and selective digital subtraction angiography) affords accurate diagnosis of these meningiomas, covering their size and location as well as the extent of tumor implantation on the skull base. With this information at hand, the surgeon can build himself or herself a realistic mental image of the lesion and its relationships to neighboring nerves and blood vessels, thereby minimizing the risk of unforeseen

difficulties. The surgeon will also be better able to choose the surgical approach most suitable for the individual patient, although that choice will always depend largely on personal experience [1,16,32,40,42,43,45].

Unfortunately, these tumors are still being diagnosed too late, as shown by the long duration of reported symptoms (35 months on average, and 45 months for trigeminal neuralgia) and the large volume of the tumors once discovered, in our own series just as in others for the same period [23,33,40]. It is to be hoped (and somewhat expected) that tomorrow's physician will pay more attention to the symptoms of petroclival meningiomas, as seems to be the case with acoustic neurinomas. More precisely, whenever surgeons detect impairment of an intermediate CN, however isolated, they should immediately request a CT scan and MRI exploration. CN V is often the first to show signs in the early stage of tumor development, and it stands to reason that nowadays, with refined diagnostic tools widely available, earlier diagnosis should be the rule, with the attendant benefits in terms of easier surgery and reduced morbidity [8,26,33,34,40,45]. To date, in our own experience, as well as in that from reports by other sources, tumor size at the time of surgery emerges as the prime factor influencing the patient's final outcome. Early on, the young meningioma growing on the petroclival line into the lateral clivus [45] proceeds with the protection of the arachnoid from the superior cerebellopontine, prepontine, and ambient cistern, making surgical manipulation a good deal easier and safer (Figure 3). Later on, the tumor's base grows larger, digs through the dura, and invades the underlying bone, violating the arachnoid layers and implicating CNs and arteries.

Surgical approaches

Because our current basket of surgical techniques does not comprise the so-called major complex approaches recently described and used by other groups [1,3,4,17,21,27,35,37,39,41,42], our choice was essentially confined to three routes, namely the retromastoid, the subtemporal, and the combined supratentorial and subtentorial presigmoid transpetrosal routes. The classical retromastoid approach in a semisitting position, with unroofing of the transverse and sigmoid sinuses to keep them out of the surgical field and moderate, readily tolerated, cerebellar retraction, affords the simplest access to the region of the cerebellopontine angle and lateral clivus. An attendant drawback may be found in the fact that the surgeon must conduct the whole phase of removal through the fissures made by the tentorium and by CNs V, VII-VIII, and IX-XI, all of which may be contused in the process. Supratentorial, subtemporal, and parasellar tumor expansion do not alone disqualify or contraindicate this simple and thoroughly tested approach, which has rewarded many surgeons with excellent results [33-35]. Access to the area is prepared by the tumor itself, located as it is in the tentorial hiatus, and it can be amplified by resection of the tentorial flap. Thus, even the upper pole of the tumor, if not attached to the parasellar dura, can be dislocated downward and removed by being separated from the arachnoid of the interpeduncular and chiasmatic cisterns (Figures 5 and 6).

Approach through the middle fossa is a fascinating proposition because it affords immediately visibility and complete control of the supratentorial tumor bulge. In our experience, however, it is also a highly hazardous route. Both the pterional [34,40,45] and, even more so, the posterior subtemporal approaches actually afford excellent exposure of the parasellar area and tentorial notch. Yet, retraction of the temporal lobe, however limited, causes some heavy postoperative morbidity, especially on the dominant side. Access to the posterior fossa also remains narrow and tedious, affording insufficient command of CNs below V.

The last to be applied in this series was the combined posterior subtemporal and presigmoid transpetrous approach without sinus division, which embodies some important refinements [2,33] of the original approach developed by Hakuba and his associates [20]. This approach turns out to be the more elegant and less dangerous way to reach (and possibly remove) petroclival meningiomas that involve a large portion of the skull base from the lower clivus to the parasellar area [32,33]. The access afforded by the retromastoid or subtemporal route is too restricted unless one is willing to face a two-stage operation, for which we feel no particular inclination. The approach of Hakuba et al. allows the surgeon to work about 2 cm closer to the tumor than would be possible through the retrosigmoid approach and in front of the brain stem [24,38,40]. Division of the tentorium materially reduces the need for retracting the cerebellum and temporal lobe, preserves drainage of the vein of Labbé, and creates an excellent exposure, opening an unimpeded vista from the lowest CNs to the sella. In particular, it affords control of the whole intracranial course of CNs III and IV with less risk of injuring those structures (Figure 10). The trunk of the basilar artery and its terminal branches are eventually well exposed, as are the contralateral V and III CNs and the pituitary stalk. The approach requires good knowledge of periotic bone anatomy to spare the labyrinth and facial nerve. It also requires a good deal of patience and meticulousness because, like the retromastoid, this approach forces one to work lateral to CNs V-XI as well as between them. In the long run, however, it is rewarding.

At this point in our experience, we must say that the retromastoid approach is still our favorite, because it proved suitable for tumors involving the upper clivus and tentorial notch. Accordingly, we would be less restrictive than Sekhar et al. [40] in its use. We find that the identification and preservation of arachnoid layers of cisterns of the posterior cranial fossa, which protect CNs, blood vessels, and the brain stem from the tumor, are helpful precautions both to avoid damaging them when exposed and to guess where they are when hidden (Figure 3). Only those tumors that are implanted all the way to the dura of the cavernous sinus and sella turcica and those that

involve Meckel's cave and tentorium to encase CN III and/or the carotid artery really require some alternative approach. In such cases (now easily recognized beforehand by modern CT scanning and MRI), we often prefer the combined suprainfratentorial presigmoid sinus route, because it affords the best exposure of the whole skull base from the sella to the lower clivus with the least possible injury to the brain and wide-angle surgical visibility. Thus, according to our policies, the subtemporal approach is reserved for tumors that expand into the middle fossa (to which they facilitate access) and occupy the upper clivus without dipping into the posterior fossa.

Management and conclusions

Patients with petroclival meningiomas are first seen by the neurosurgeon in a variety of clinical conditions ranging from isolated trigeminal neuralgia to multiple CN deficits associated with ataxia and somatic sensorimotor deficits. Within certain limits, the severity of the clinical picture is commensurate with the size of the tumor. Our own experience confirms a rather widespread opinion [15,22,33,34,40,45], namely that the smaller the tumor, the greater the possibilities of total removal and the lesser the possibility of residual morbidity.

Because the natural history of these tumors is characterized by progressive (if slow) deterioration [11,12,26,40], we find that the indication for surgical removal is justified, or should be taken for granted, in all patients with medium-size or large tumors who still enjoy good clinical and neurological conditions. The problem is whether to operate on patients with tumors of comparable size who are also neurologically disabled. In such patients, the risk of doing more harm than good with surgery is great, as pointed out by Sekhar and his associates [40], among others. Yet, the risk is just as great if one decides not to operate, with precious little hope that whatever radiotherapy appears justified in tumors of some size will slow tumoral growth [5,10,29,44] and not cause unduly severe adverse effects [13,30]. Here, we may reason that the results of ablative surgery tend to improve steadily with increasing experience. Conversely, in our own series as in others [6,7,33,40], the worst results were obtained in the first few patients. We believe that, at the present state of the art, surgery may rightly be considered for these patients as well. What remains a problem, however, is whether we should invariably pursue radical exeresis or be satisfied with less drastic measures. Obviously, total eradication remains the prime and ideal objective of meningioma surgery, because repeat surgery for recurrence entails a higher failure rate. Yet, we must recognize that many petroclival meningiomas that are only subtotally removed remain stationary for long periods without any evidence of regrowth [40]. In such circumstances, surgery done at all cost in pursuit of radical removal, at the risk of adding permanent dysphagia or ophthalmoplegia to an already poor picture of brain stem distress, does not seem to be the proper thing to do. In our own experience, indeed, these two added iatrogenic infirmities are the hardest to digest, both for the surgeon and for the patient.

If we look at recently published series of microsurgical petroclival meningiomas, as in the table by Sekhar et al. [40], and if we remember that not so long ago the same lesions were associated with frightening mortality and morbidity [9,14,28], we cannot help being impressed and pleased with such spectacular improvement. There is no doubt that progress in neuroimaging, microsurgical techniques, and approaches has changed the picture dramatically. Surgery once unthinkable is being performed more and more often with good success, and enthusiasm is growing apace. We are willing to share in this attitude, only with some reservation. We find it necessary to recall that truly radical excision of a tumor with all involved dura and bone is at times not feasible. Some petroclival meningiomas are invasive and leave no room for complete removal because of severe indentation of the brain stem, tight encasement of important arteries and CNs, and bone invasion. In two of our patients rechecked by gadolinium MRI after what seemed to have been a complete removal, we found an unexpected, thick dural enhancement (Figures 11 and 12), a finding most disturbing to us, as it had been in similar circumstances to Al-Mefty (see comment in ref. 40).

In summation, therefore, we must admit that some problems relative to surgery for petroclival meningiomas are far from solved. The choice of surgical approaches alone, now that leading teams have developed complex approaches affording a formerly unthinkable degree of skull base exposure [4,17,21,35,41,42], accounts for a good deal of continuing debate. Whereas it seems legitimate to expect that microsurgery for basal meningiomas will prove more and more effective in achieving complete removal with reasonably reduced risk, it remains highly desirable that such tumors be diagnosed at an earlier stage in their natural history, when important vessels and nerves of the skull base have not yet been involved. Actually, the next step forward in terms of improving the final outcome of these patients seems to rely just as heavily on more audacious and safe surgery and on earlier diagnosis.

ACKNOWLEDGMENTS

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Reprint requests: Prof. Albino Bricolo, Department of Neurosur-gery, University Hospital, Piazzale Stefani 2, 37126 Verona, Italy.

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COMMENTS

Professor Bricolo and coworkers have presented their operative results of 33 patients with petroclival meningiomas. I think this is a creditable presentation of one group's management of a very difficult neurosurgical problem. The article is well written with detailed description of their surgical strategies and conscientious analysis of their results. I am rather impressed with the fact that approximately two thirds of the patients harbored such large-size tumors and that the dominant presenting symptoms were cerebellar signs (60%) and hemiparesis (30%). The mortality rate of 9% and the additional 20% incidence of postoperative obtundation may well be explained by the large size of the tumors. However, 80% of the patients emerged from surgery with either an exacerbation of preexisting cranial nerve deficits or a new injury to cranial nerves, which would result in a rather higher rate of morbidity than would be expected from surgery of petroclival meningiomas. It has been my opinion that the majority of complications in operations on petroclival meningiomas are attributable to either the individual surgeon's microsurgical technique or to the stripping of adherent tumor capsules from the brain stem, cranial nerves, and vital perforating vessels. The most important surgical principles in approaching skull base meningiomas are 1) early detachment and devascularization of the tumor origin (dural attachment); 2) sufficient internal debulking; 3) division of the tumor capsule into several pieces; and 4) meticulous dissection of the capsule with retraction of the tumor capsule. In my experience, in approximately 20% of the large petroclival meningiomas, the fibrous tumor capsules adherent to the neural and vascular structures were impossible to resect completely without producing significant morbidity. The petroclival meningiomas can be approached through five different routes: 1) retromastoid craniectomy; 2) subtemporal craniotomy; 3) combined subtemporal and retromastoid approaches; 4) combined petrosal approach; and 5) frontotemporal transcavernous approach. As may be evident in the authors' series, a simple retromastoid craniectomy is still a preferable and low-risk operative approach to those tumors when intradural gross total resection (Simpson Grade II) is attempted. The subtemporal posterior transcavernous or transpetrosal approach can be performed either as the primary procedure or as an addition to the retromastoid approach, for more radical and extensive removal. Usually, it is better to reserve the combined infrasupratranstentorial petrosal approach for those large dumbbell-shaped masses or for younger patients who may tolerate a more extensive procedure. I would add the above thoughts to the authors' discussion of the selection of operative approaches.

Takanori Fukushima
Los Angeles, California

Dr. Bricolo and his colleagues have impressive and sizable experience with this still-challenging lesion. I fully agree with their emphasis on classification, especially their point that the tumor's attachment on the clivus or medial to the fifth nerve crucially differentiates this tumor from relatively easier ones with a more posterior insertion on the petrous apex [(1)].

What the authors were able to achieve through a

retrosigmoid approach is surprising and is a credit to their experience and skill, not to the approach. The high incidence of postoperative deficits of cranial nerves in their series can be attributed with certainty, as the authors admit, to the retrosigmoid approach, which forces the surgeon to work between the cranial nerves. By the retrosigmoid approach, the posterior clinoid area must be reached through a long, narrow tunnel, severely restricting the ability of the surgeon to dissect. The authors rightly praise their experience, however limited, with the petrosal approach. I have no doubt that, as they continue to use the petrosal approach for these lesions, it will become their "favorite," and they will abandon the retrosigmoid approach for petroclival meningiomas.

The message gleaned from this outstanding article should be that lesions of the petroclival area are now amenable to total removal because of our advancements in surgical technique. The merits of attempting total surgical removal are clear through the authors' results on long-term follow-up. The gravity of this undertaking, however, is evident by the morbidity figures presented in Tables 8 and 9. These lesions are proven operable; it now behooves us to bring the morbidity to a minimal level.

Ossama Al-Mefty
Maywood, Illinois

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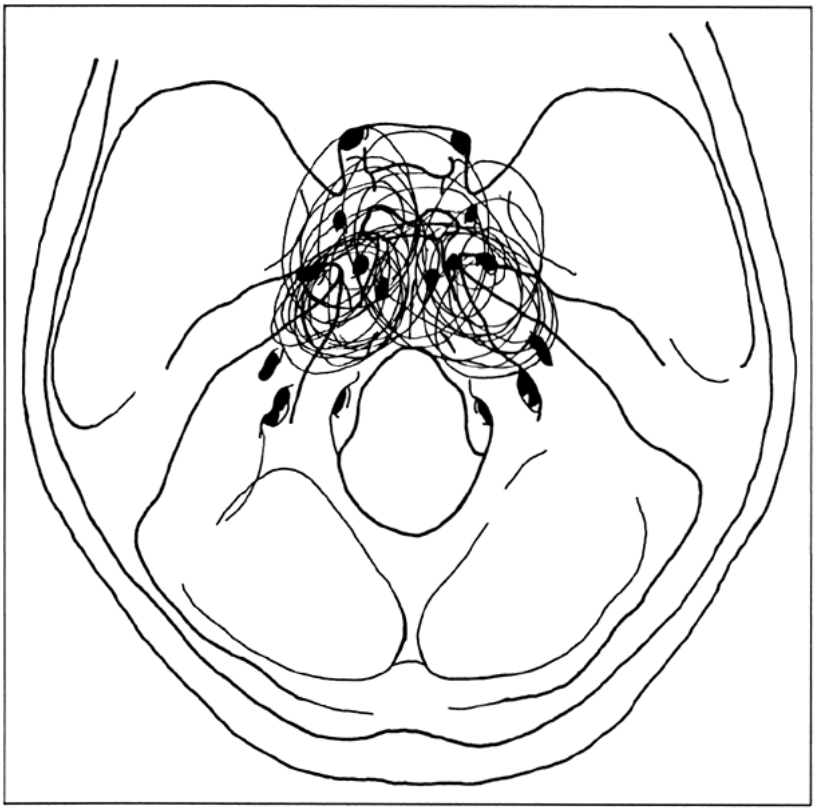

Figure 1. Schematic depiction of the dural attachments of the tumors of the series presented here, reconstructed on the basis of CT scans and operative reports.

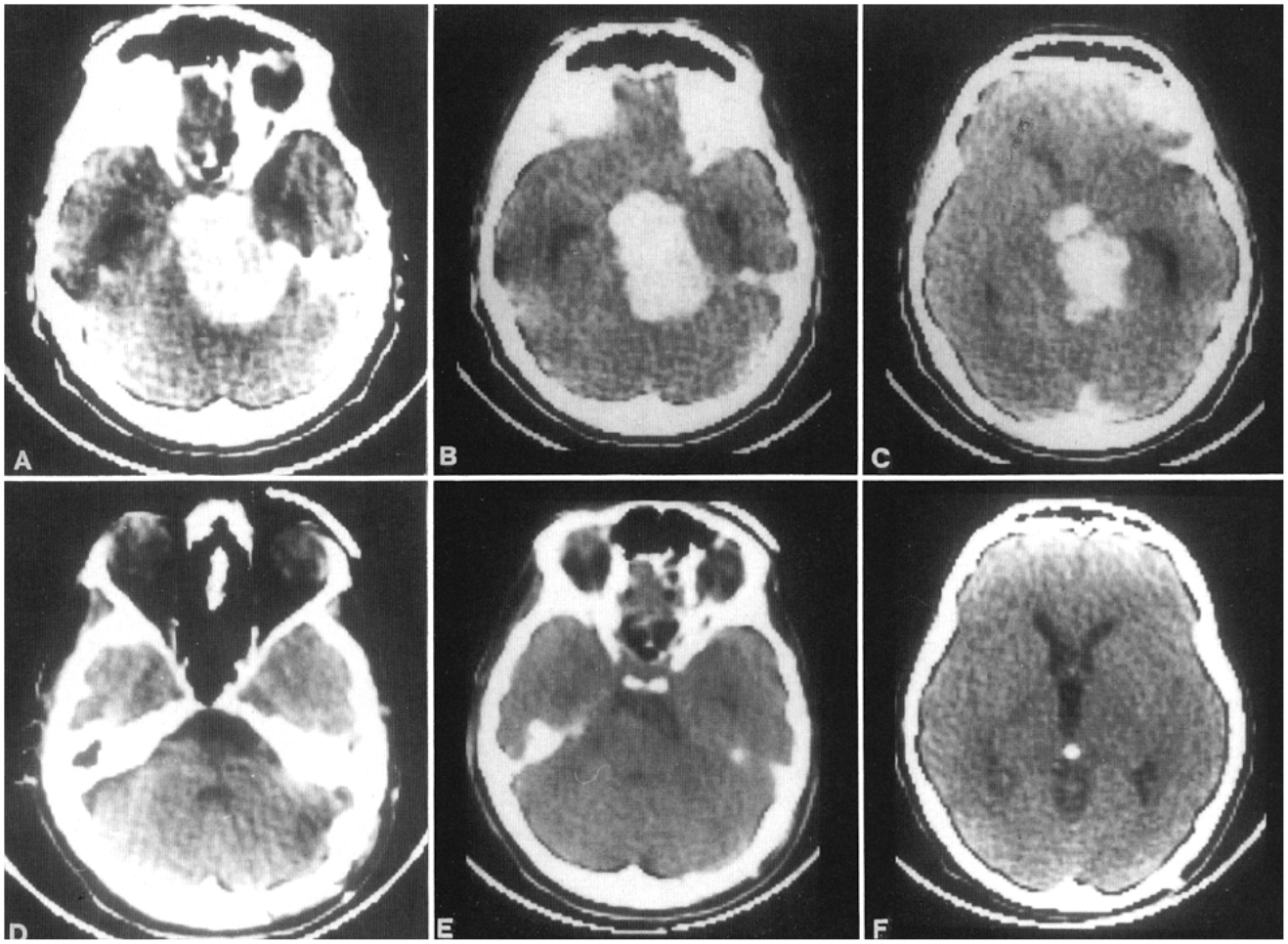

Figure 2. Contrast-enhanced axial CT scans of one of the first patients of this series. *A*, *B*, *C*, preoperative; *D*, *E*, *F*, 5 years after total excision of the tumor achieved by a retromastoid approach. The large meningioma involved the sellar and upper, middle, and lower clival areas.

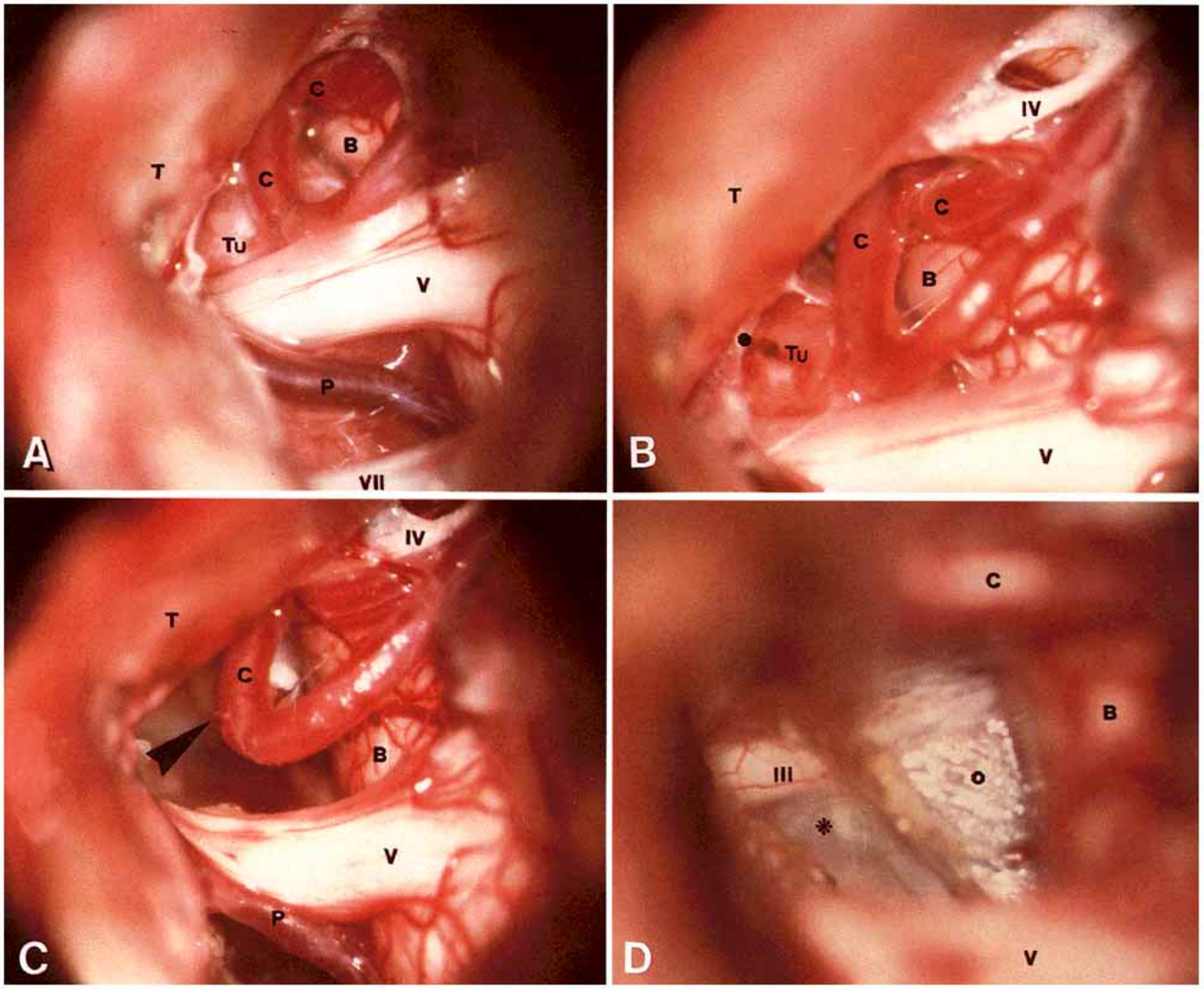

Figure 3. Intraoperative views of the left cerebellopontine angle exposed by a suboccipital retromastoid approach for the removal of a petroclival meningioma in the semisitting position. *A*, the tumor lies behind the trigeminal and facial nerves, which are stretched on it together with the superior petrosal vein. *B*, the superior cerebellopontine cistern covering the tumor and trigeminal nerve is open, as is the ambient cistern containing the trochlear nerve. The trunks of the superior cerebellar artery loop around the pons. *C*, the tumor is removed. *D*, through the keyhole between the superior cerebellar artery, pons, and trigeminal nerve, the oculomotor nerve and the crural and interpeduncular cisterns are still intact. *T*, tentorium; *Tu*, tumor; *V*, trigeminal nerve; *P*, superior petrosal vein; *VII*, facial vestibulocochler nerves; *B*, brain stem; *C*, superior cerebellar arteries; *IV*, trochlear nerve and ambient cistern; *III*, oculomotor nerve; ° superior cerebellopontine, ° crural, and * interpeduncular cisterns.

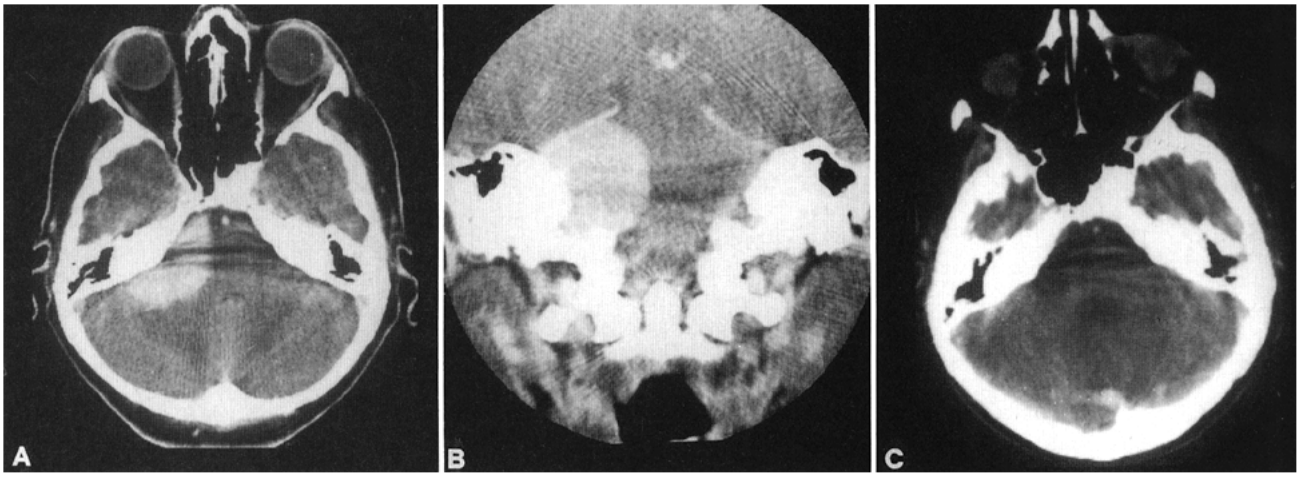

Figure 4. Same patient as that shown in Figure 3. Preoperative axial (*A*), coronal (*B*), and axial postoperative (*C*) enhanced CT scans.

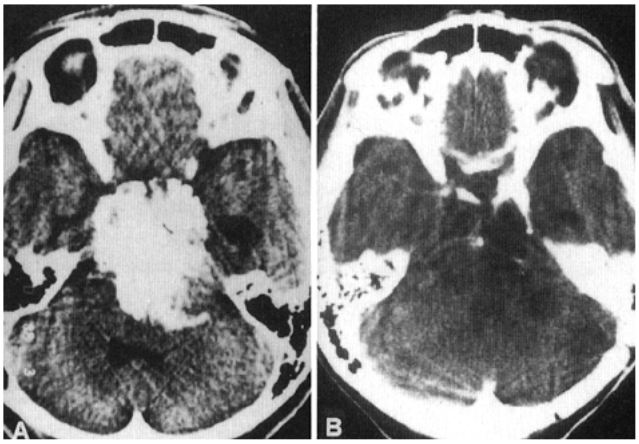

Figure 5. Preoperative (*A*) and 1-year postoperative (*B*) contrast-enhanced CT scans of a huge petroclival meningioma extensively involving the clivus and suprasellar areas. The tumor was totally removed via a right retromastoid craniotomy.

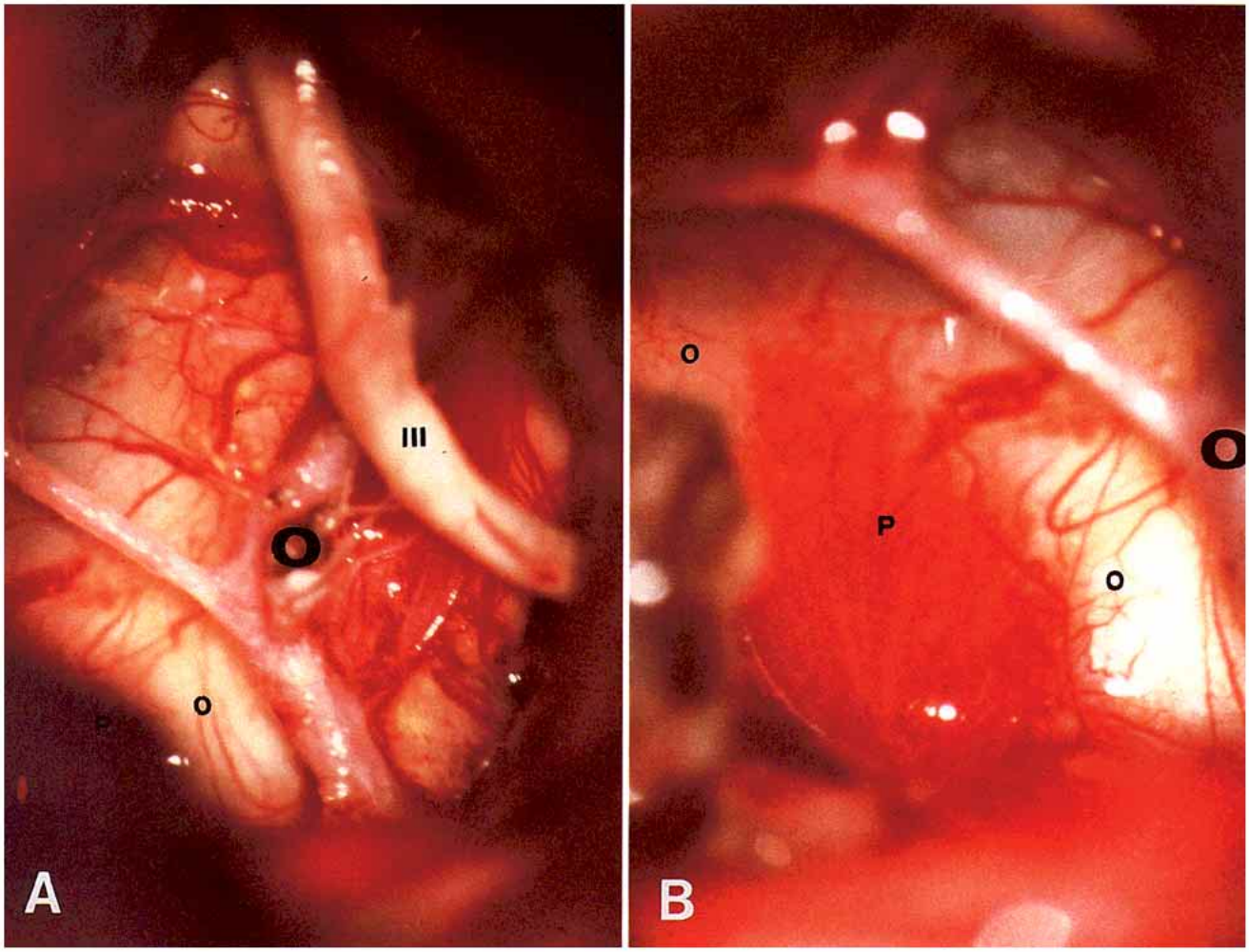

Figure 6. Intraoperative photographs of the same patient as shown in Figure 5. *A* and *B*, interpeduncular and chiasmatic cisterns are seen from below. The keyhole is the fissure between the trigeminal nerve and the free edge of the tentorium. *P*, pituitary stalk; *o*, optic tract; *III*, oculomotor nerve; *O*, posterior communicating artery.

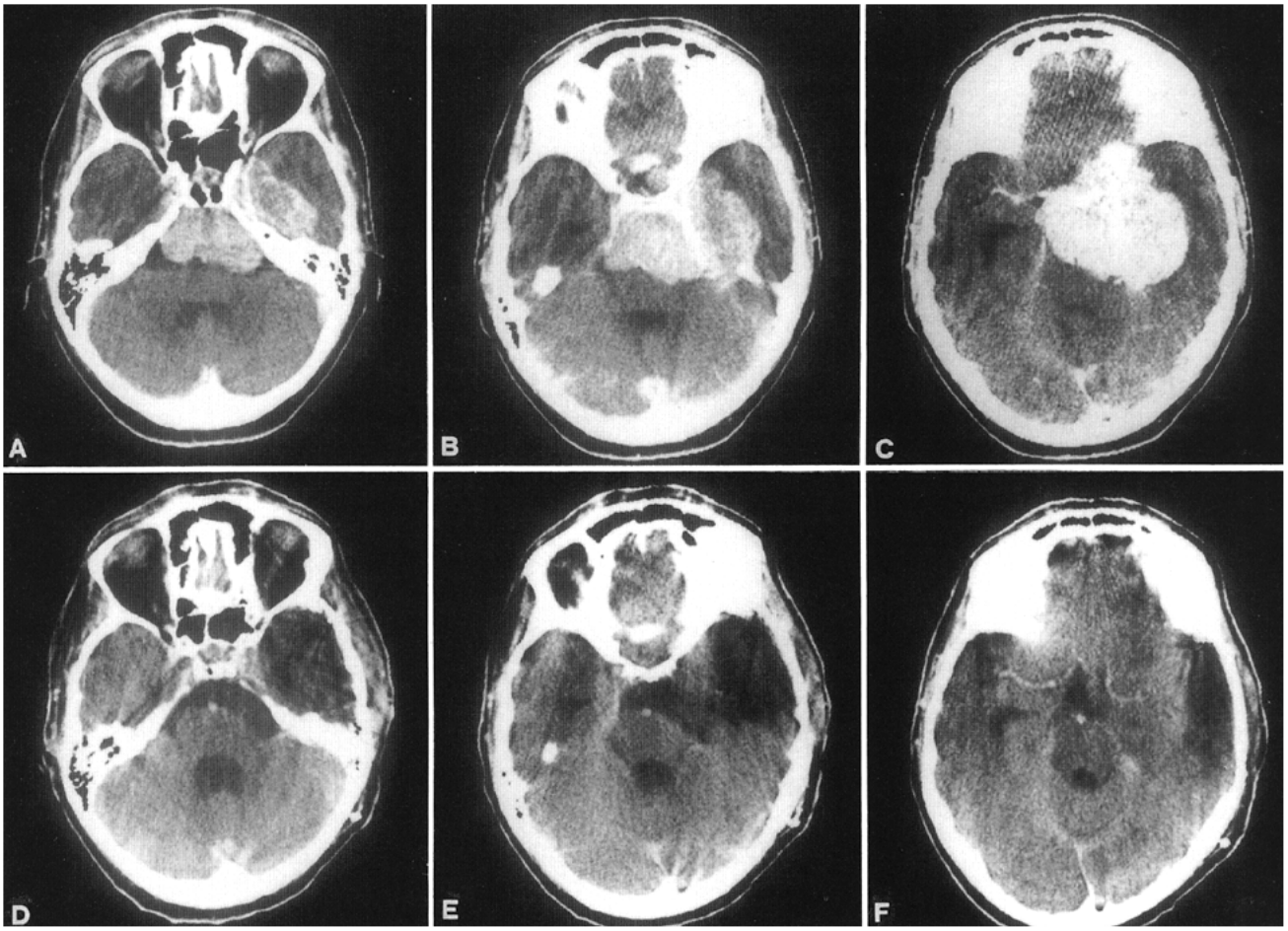

Figure 7. Contrast-enhanced axial CT scan of a large petroclival-subtemporal cavernous meningioma before (*A*, *B*, *C*), and 1 year after surgery (*D*, *E*, *F*). The tumor was completely removed via a subtemporal approach.

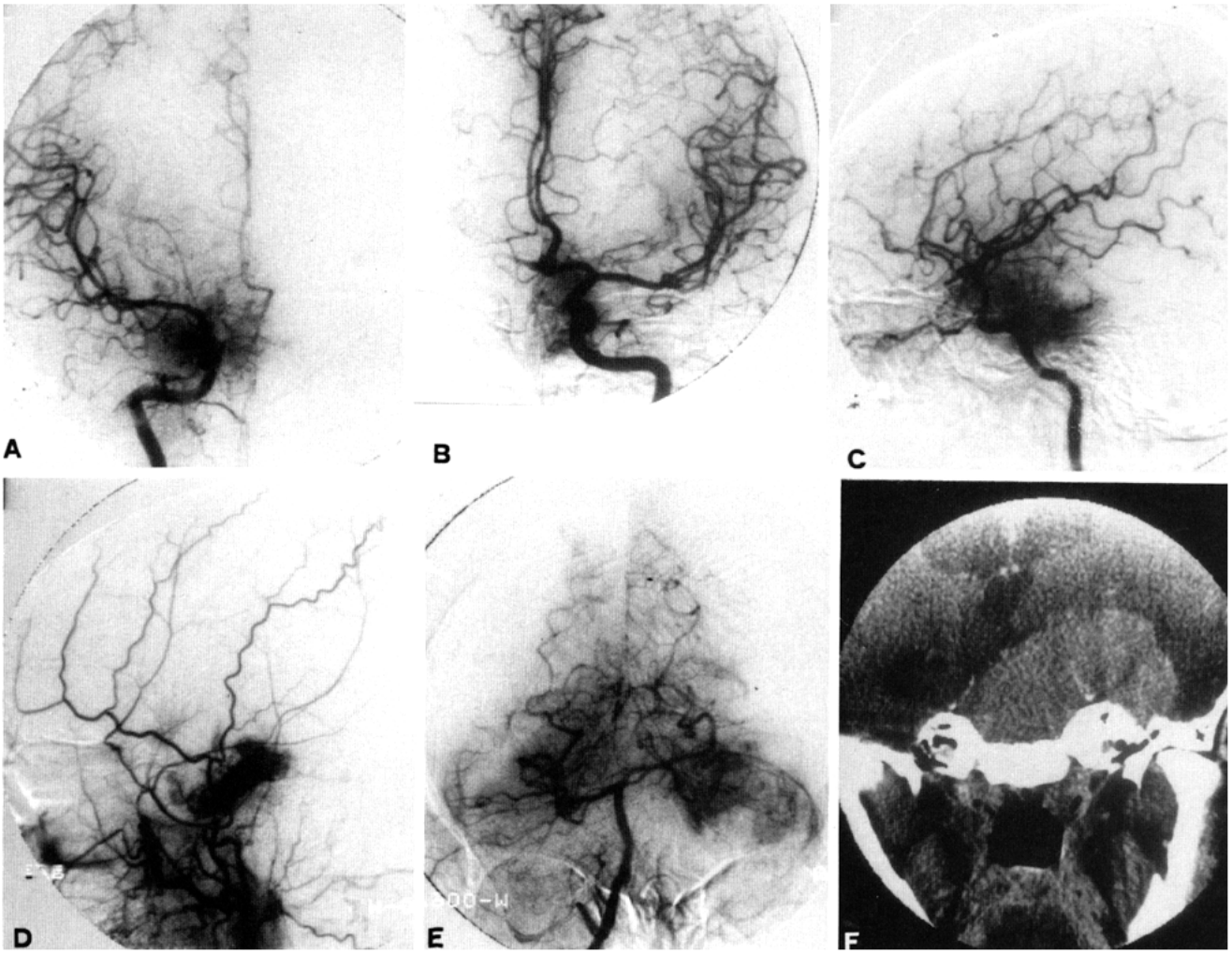

Figure 8. Same patient as shown in Figure 7. Subtraction cerebral angiograms demonstrate the complexity of the blood supply to the tumor. Anteroposterior left internal carotid (*A*), anteroposterior (*B*) and lateral right internal carotid (*C*), lateral external carotid (*D*) and anteroposterior vertebral (*E*) angiograms. Coronal enhanced CT scan (*F*) visualizes the extension of basal attachment.

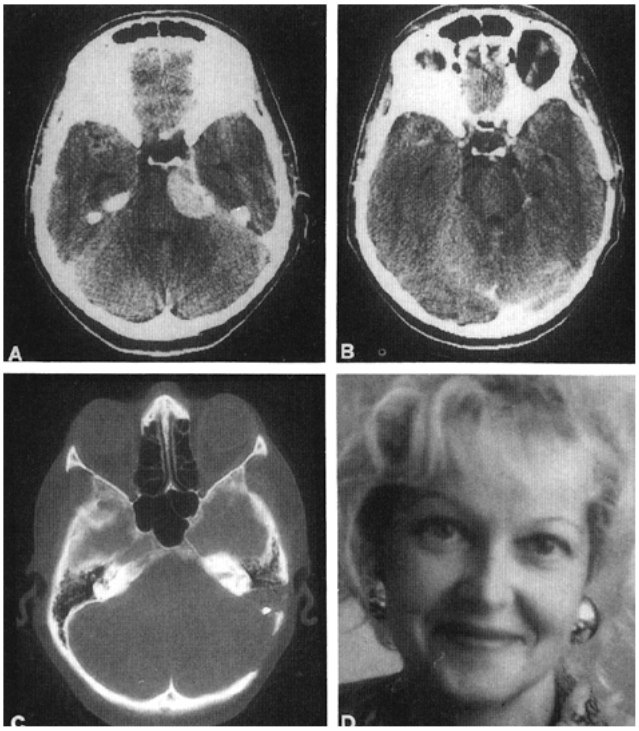

Figure 9. Preoperative (*A*) and postoperative (*B*) contrast-enhanced CT scans of a petroclival meningioma, the first in this series to be removed via a combined subtemporal presigmoid petrosal approach. The postoperative bone window axial CT scan (*C*) shows the extent of petrosectomy. The patient is neurologically intact 3 months after surgery (*D*).

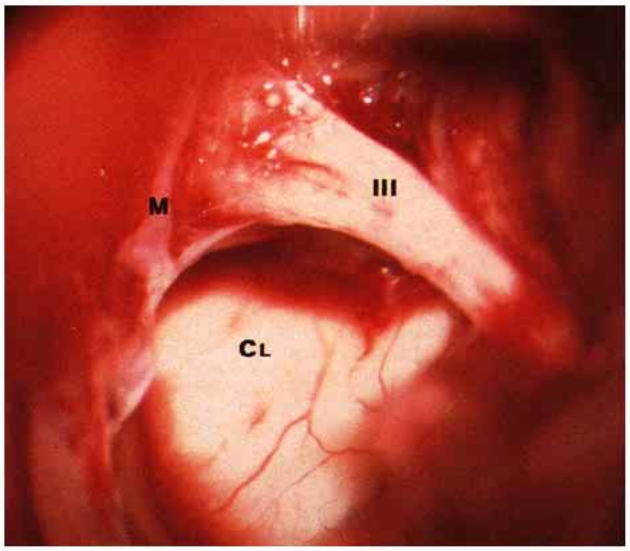

Figure 10. Same patient as shown in Figure 9. Intraoperative photograph taken at the end of the tumor removal. The right CN III is seen from a lateral view in its entire intracranial course. *III*, oculomotor nerve; *CL*, posterior clinoid processes; *M*, midbrain

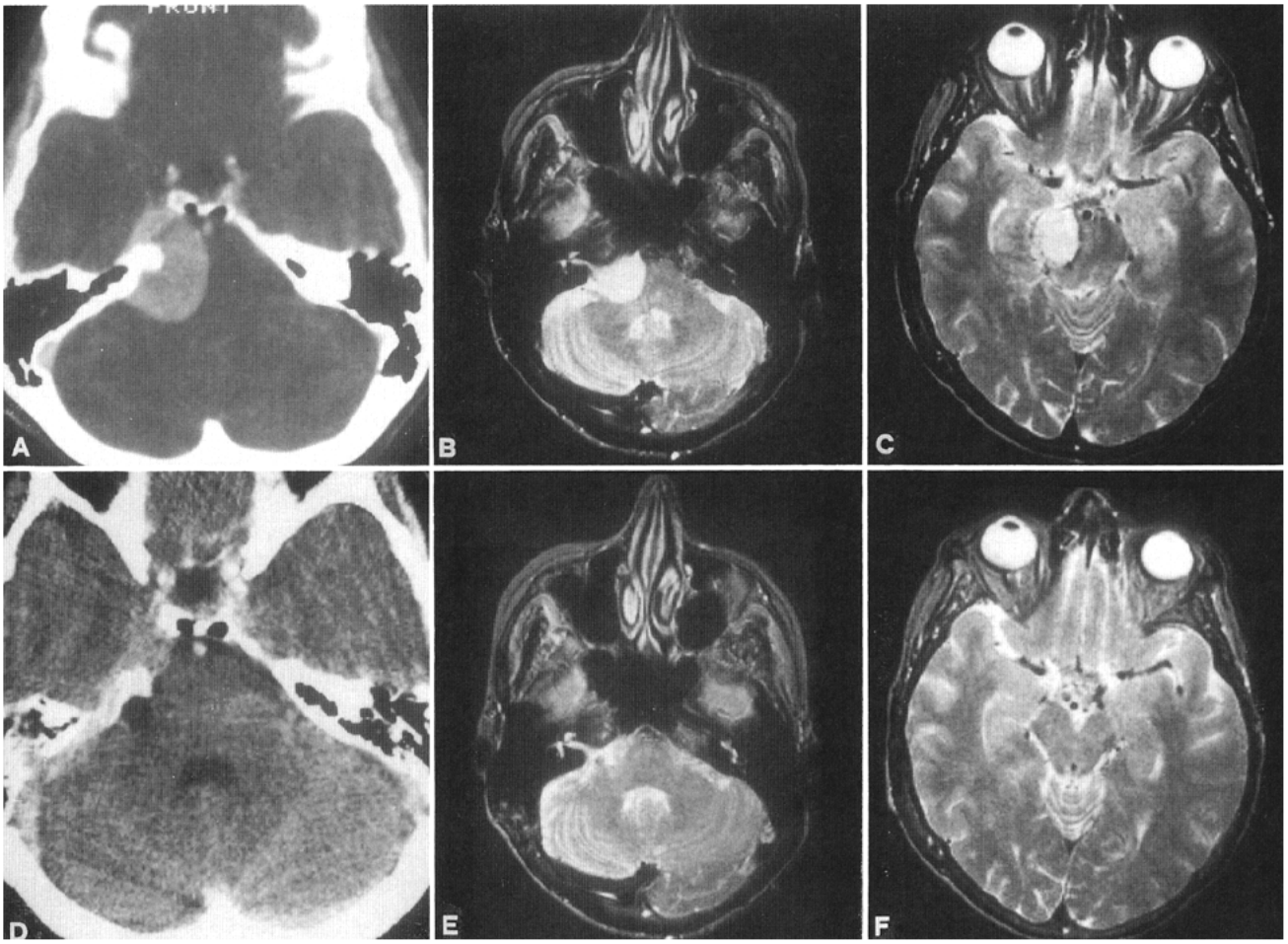

Figure 11. Preoperative (*A*) contrast-enhanced CT and T2-weighted MRI (*B* and *C*) scans showing a left petroclival meningioma removed via a retromastoid approach. A follow-up neuroimaging investigation performed 2 months after surgery (*D*, *E*, *F*) seems to confirm the surgeon's impression by revealing no evidence of tumor residual.

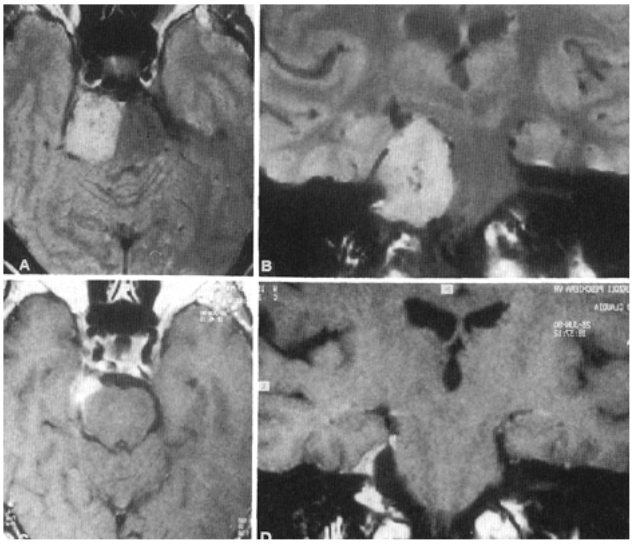

Figure 12. Same patient as shown in Figure 11. Nine months after surgery, a gadolinium-enhanced MRI study (*C* and *D*) reveals a small tumor remnant and/or a regrowth. Panels *A* and *B* are the preoperative comparable images previously obtained by the same technique.

Symptom	No. of Patients	
	First	Last
Gait ataxia	7	6
Facial hypo/paresthesia	6	3
Hearing impairment	5	2
Trigeminal neuralgia	4	4
Headache	3	1
Diplopia	3	2
Dysphagia	2	5
Somatosensory deficit	1	
Dysphonia	1	3
Depression	1	
Facial weakness		1
Drop attacks		1
Somatomotor deficit		5

Table 1. Earliest and Latest Symptoms of Petroclival Meningiomas in 33 Patients

Symptom	Months	No. of Patients
Trigeminal neuralgia	43	6
Hearing impairment	35	13
Visual disturbance	19	3
Gait ataxia	19	17
Facial hypo/paresthesia	15	13
Dysphagia	10	13
Dysarthria	10	1
Headache	9	10
Dysphonia	7	9
Depression	7	1
Somatomotor deficit	6	10
Somatosensory deficit	6	3
Diplopia	4	7
Facial weakness	3	10

Table 2. Mean Duration of Presenting Symptoms

Physical Findings	No. of Patients	%
CN deficits	33	100
III	3	9
V	22	67
VI	7	21
VII	10	30
VIII	13	39
IX–X	15	45
XI–XII	3	9
Cerebellar signs	20	60
Gait ataxia	18	54
Nystagmus	11	37
Dysmetria	8	24
Dysarthria	3	9
Somatomotor deficits	10	30
Unilateral	4	12
Bilateral	6	18
Somatosensory deficits	3	9
Unilateral	3	9

Table 3. Clinical Signs at the Time of Surgery in This Series

Tumor Features	No. of Patients	%
Prevalent side		
Right	16	48
Left	17	52
Size (maximum diameter; cm)		
Medium (<3.5)	14	43
Large (3.5–6)	15	45
Giant (>6)	4	12
Basal involvement		
Beyond clivus midline	8	21
Beyond tentorial notch	6	18
Both extensions	14	42
Bone abnormalities	16	48
Prevalent expansion		
Clivus	12	37
Cerebellopontine angle	9	27
Tentorial notch	5	15
Middle fossa	7	21
Arteriographic blood supply		
Internal carotid	18	58
External carotid	10	30
Vertebral-meningeal	3	9
Basilar	2	6
No angiography	11	33
Hydrocephalus[a]		
Mild	9	27
Moderate	8	24

[a] Three patients had shunts placed previously.

Table 4. Neuroimaging Data of the 33 Tumors

Approach	No. of Patients	%
Retromastoid Semisitting position. Lateral suboccipital craniotomy. Infratentorial restrosigmoid route to cerebellopontine angle	23	70
Temporal Supine position. Extended frontopterional craniotomy, splitting of Sylvian fissure, across floor of middle fossa. Supra- and transtentorial route	5	15
Presigmoid "petrosal" Semisitting position. Combined posterior temporal and retromastoid craniotomy. Petrosectomy and tentorial resection. Presigmoid suboccipital subtemporal route, without sinus division	5	15

Table 5. Operative Approaches Used in This Series

Removal	Tumor Size			No. of Patients	%
	Medium	Large	Giant		
Complete	12	12	2	26	79
Subtotal	1	2	1	4	12
Partial	1	1	1	3	9
Total	14	15	4	33	100

Table 6. Extent of Tumor Removal Related to Tumor Size

Factor	No. of Patients	Tumor Size		
		Medium	Large	Giant
Brain stem indentation	13		9	4
Arterial encasement	11		7	4
Epidural bone invasion	11	1	6	4
No. of CNs encased				
1	9	9		
2	10	5	5	
3	4		4	
4	7		6	1
5	3			3

Table 7. Anatomical Factors Opposing Tumor Resection

	First Week		1 Month	
	No. of Patients	%	No. of Patients	%
Death	0	0	3	9
Consciousness				
Stuporous	7	21		
Coma	2	6		
CN deficits				
Worsened	12	36	9	27
New	25	76	17	56
Somatic motor deficits				
Worsened	1	3	1	3
New	3	9	1	3
Respiratory problems				
Mechanical ventilation	6	18		
Tracheostomy			2	6
Severe dysphagia	5	15	2	6

Table 8. Early and 1-Month Postoperative Clinical Status

Tumor Size	No. of CN Deficits/No. of Patients (Ratio)		
	Preoperative	Postoperative	Last Follow-up
Medium	24/14 (1.7)	38/14 (2.7)	27/14 (1.9)
Large and giant	49/19 (2.6)	71/16 (4.4)	42/13 (3.2)
Total	73/33 (2.2)	109/33 (3.6)	75/27 (2.7)

Table 9. CN Deficits per Patient Related to Tumor Size

Score	Preoperative Cases	Perioperative (1 month)				Last Follow-up (4.3 yr)			
		Cases	Unchanged	Improved	Worsened	Cases	Unchanged	Improved	Worsened
100	1	1	1			2	1	1	
90	15	14	12	2		17	13	4	
80	8	2	2			5	3	2	
70	1	4		1	3	1		1	
60	1	3	1	1	1				
50	6	3	2		1	2	2		
40		3		1	2				
30	1								
Total	33	30	18 (60%)	5 (17%)	7 (23%)	27	19 (70%)	8 (30%)	

Table 10. Performance Status (Karnofsky Scale)

Approach and Removal	No. of Patients	Recurrence	Outcome			
			Good	Fair	Poor	Dead
Retromastoid	23					
Complete	20	2	16		1	3
Incomplete	3	3	1	1		1
Subtemporal	5					
Complete	3	1	2			1
Incomplete	2	1			1	1
Presigmoid	5					
Complete	4		3	1		
Incomplete	1		1			
Total	33	7 (21%)	23 (70%)	2 (6%)	2 (6%)	6 (18%)

Table 11. Overall Outcome Related to Approach and Extent of Tumor Removal