Surgical management of petroclival meningiomas: factors determining the choice of approach

KADIR ERKMEN, M.D., SVETLANA PRAVDENKOVA, M.D., PH.D.
AND OSSAMA AL-MEFTY, M.D.

Department of Neurosurgery, University of Arkansas for Medical Sciences, Little Rock, Arkansas

Petroclival meningiomas remain one of the most challenging intracranial tumors to treat surgically. This is attributable to their location deep within the skull base and their association with multiple critical neural and vascular structures. Over the years, many skull base approaches have been described that are meant to improve resection and decrease patient morbidity. Appropriate selection of the surgical approach requires a thorough preoperative evaluation of clinical and radiological factors. In this paper the authors retrospectively reviewed 97 patients treated surgically for petroclival meningiomas by the senior author (O.A.M.) between 1995 and 2005 to assess the factors used to determine the choice of surgical approach, and to assess complication rates based on the approach selected. The skull base approaches used in these patients included the middle fossa anterior petrosal, posterior petrosal, and combined petrosal approaches, and complete petrosectomy. Factors found to be important in determining the selection of approach included the size, location, and extension of the tumor, preoperative hearing evaluation, and venous sinus anatomy.

KEY WORDS • petroclival meningioma • skull base • petrosal approach • middle fossa approach

Resection of petroclival meningiomas has been associated with a high level of morbidity and mortality in the past. Left untreated, these tumors will grow and induce symptomatic deterioration.⁴⁶ Advances in microsurgery and more recent descriptions of skull base techniques have decreased the risk associated with surgery for these tumors.^{3,4,7,12,19,33} Multiple skull base approaches have been described for the management of these tumors; however, there is limited information on how to decide which approach is appropriate for a particular patient. In this article we describe the factors found to affect the choice of skull base approach used in the treatment of 97 patients with petroclival and sphenopetroclival tumors by the senior author (O.A.M.). A simple algorithm is proposed for selection of the approach.

Petroclival tumors are defined as arising from the upper two thirds of the clivus, at the petroclival junction, and medial to the trigeminal nerve.² They tend to compress the brainstem and BA and push these structures toward the contralateral side. These tumors often span the middle and posterior cranial fossae, and can involve the posterior cavernous sinus through the Meckel cave. Sphenopetroclival meningiomas are more extensive, involving the anterior cavernous sinus, invading the sella turcica and the sphenoid sinus, and occasionally involving bilateral cavernous sinuses. Tumors arising from the midline clivus and displacing the brainstem and BA posteriorly are defined as clival me-

ningiomas, and those arising from the lower third of the clivus are defined as foramen magnum lesions. Posterior fossa meningiomas arising lateral to the trigeminal nerve are called petrosal meningiomas, and are split into anterior and posterior petrosal meningiomas. In this article we assess the choice of surgical approach to petroclival and sphenopetroclival tumors.

Multiple surgical approaches have been developed over the years to attack these formidable lesions. Central to all approaches to the petroclival region is the ability to visualize the tumor and the important neural and vascular structures that these tumors are adjacent to, compressing, and encasing. The petrous temporal bone is an obstacle on the approach to the petroclival region. Oftentimes neurosurgeons are unfamiliar with the anatomy of the petrous bone, prompting surgical approaches through more common suboccipital and pterional routes. Some authors have advocated using traditional neurosurgical approaches to these tumors.^{8,16,44} The advantages of lateral skull base approaches include decreasing the operative distance to the tumor and neurovascular structures, improving visualization and lighting, and allowing access to the tumor with minimal brain retraction. In addition, the access for dissection is improved due to the lateral and anterior projection to the brainstem. Strategies to overcome the petrous bone as an obstacle have included resection of the petrous apex with the middle fossa approach, resection of presigmoid, retrolabyrinthine petrous bone with the posterior petrosal approach, and resection of the entire petrous bone with complete petrosectomy.

Abbreviations used in this paper: BA = basilar artery; CT = computerized tomography; IAM = internal auditory meatus; MR = magnetic resonance.

The selection of approach is critical to providing the safest avenue for the most complete resection.

CLINICAL MATERIAL AND METHODS

Patient Population

The records for patients treated surgically by the senior author for petroclival and sphenopetroclival meningiomas between 1995 and 2005 were retrospectively reviewed. Information was extracted from the corresponding operative reports about the surgical approaches used in each case with respect to the factors that affected the choice of approach. Patient demographics and approach-related complications were evaluated in each case.

Information was available for 97 patients who were treated surgically for petroclival and sphenopetroclival meningiomas during the period between 1995 and 2005. The mean age of the patient population was 50 years, and the male/female ratio was 1:4 (19 men and 78 women). An electronic database containing the preoperative, postoperative, and follow-up imaging studies for the patients was searched for images pertaining to choice of approach. The studies evaluated included MR images, CT scans, and vascular studies consisting of angiograms, venograms, MR angiograms, or MR venograms.

DESCRIPTION OF APPROACHES

The surgical approaches used in the resection of petroclival tumors have been described in the past. The following is a summary of each of these approaches.

Extended Middle Fossa Anterior Petrosal Approach

The patient is positioned supine on the operating table with a shoulder roll placed under the ipsilateral shoulder.¹² The head is turned to the contralateral side and the vertex is dropped. A curvilinear incision is made beginning anterior to the tragus at the level of the zygomatic arch, and is continued behind the hairline to the midline. The flap is rotated anteriorly. The superficial and deep layers of the temporal fascia are elevated with the skin flap to protect the frontal branch of the facial nerve. The zygomatic arch is cut anteriorly and posteriorly, and the temporalis muscle is elevated and retracted inferiorly. A craniotomy is made along the floor of the middle fossa and crossing the sphenoid wing. The dura mater is elevated from the floor of the middle fossa until the middle meningeal artery is encountered. This vessel is coagulated and cut. As the dura mater is elevated farther, the foramen ovale and third division of the trigeminal nerve are identified. The greater superficial petrosal nerve is identified and carefully dissected to prevent traction injury to the geniculate ganglion. The dura is separated from the lateral wall of the cavernous sinus along the third and second divisions of the trigeminal nerve until the gasserian ganglion is exposed and the trigeminal impression is encountered. The bone of the petrous apex is drilled medially to the carotid artery, extending from the trigeminal impression to the IAM, and exposing the posterior fossa dura (Fig. 1A). The dura mater is opened along the base of the temporal lobe. The superior petrosal sinus is coagulated and cut to allow opening of the tentorium to the incisura, exposing the middle and posterior cranial fossae (Fig. 2).

Posterior Petrosal Approach

The patient is positioned supine with the head turned to the opposite side and the ipsilateral shoulder raised slightly.^{3,4} A skin incision is made extending from the zygoma anterior to the ear, and extending in a curvilinear fashion behind the ear to below the mastoid process. The skin flap is rotated anteriorly and inferiorly, and the temporal fascia is incised and reflected inferiorly in continuity with the sternocleidomastoid muscle. The temporalis muscle is cut along the superior edge of the incision and retracted inferiorly and anteriorly. Four burr holes are placed straddling the transverse sinus, two in the posterior fossa and two supratentorially. A single bone flap is created covering the middle and posterior fossae (Fig. 3). The transverse-sigmoid sinus junction is exposed with the craniotomy. The mastoid cortex is scored and cut, and a mastoidectomy is performed, exposing the presigmoid dura mater, and keeping the bone labyrinth intact (Fig. 1B). The sigmoid sinus is skeletonized to the jugular bulb. The dura is opened along the floor of the temporal fossa and in the presigmoid region. Care is taken to locate and protect the vein of Labbé at its insertion into the sigmoid sinus. The superior petrosal sinus is coagulated

Fig. 1. Postoperative CT scans obtained in patients undergoing the petrosal approaches. The examples demonstrate the extent of petrous bone resection based on the approach chosen. A: Resection of the petrous apex in an anterior petrosal approach. B: Resection of the retrolabyrinthine petrous bone in a posterior petrosal approach. C: Combined petrosal approach in which the petrous apex and retrolabyrinthine bone have been resected. The IAM, middle ear apparatus, and labyrinth are intact. D: Complete petrosectomy, with resection of the entire petrous temporal bone, except for a thin shell of bone surrounding the seventh cranial nerve.

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Fig. 2. Illustration depicting the exposure provided by the anterior petrosal approach. The petrous apex has been resected from the trigeminal impression to the IAM. The middle fossa dura mater is opened and the tentorium is cut after coagulation of the superior petrosal sinus.

ed or occluded with a clip, and then it is cut to connect the dural openings. The tentorium is sectioned in a parallel plane to the petrous ridge and across the incisura after the surgeon locates and preserves the fourth cranial nerve insertion (Fig. 3). The posterior temporal lobe is elevated and the sigmoid sinus is retracted posteriorly, allowing access to the supra- and infratentorial spaces (Fig. 4).

Combined Petrosal Approach

The skin incision is similar to that described for the posterior petrosal approach. The anterior limb of the incision can be carried up to the midline to allow the skin flap to be reflected anteriorly.¹² The superficial temporal artery is preserved on the muscle layer. The skin is reflected anteriorly along with the temporal fascia to preserve the frontal branch of the facial nerve. The zygomatic arch is cut anteriorly and posteriorly and the temporalis muscle is reflected inferiorly. The bone flap is similar to the posterior petrosal flap, although it is extended farther anteriorly along the floor of the middle fossa and crosses the sphenoid wing (Fig. 5). The mastoid is drilled to skeletonize the labyrinth and the petrous apex is also drilled (Fig. 1C). The dura mater is opened in a similar fashion to the description of the posterior petrosal approach, but the incision is extended farther anteriorly along the floor of the middle fossa. The dura mater along the floor of the temporal fossa can be connected with a dural incision along the sphenoid wing to expose the sylvian fissure as well. The tentorium is incised anteriorly to the incisura posterior to the trochlear nerve insertion, and is connected with a tentorial cut paralleling the superior petrosal sinus from the posterior direction (Fig. 6). With this exposure, the tumor can be approached through the petrous bone anterior and posterior to the labyrinth and middle ear apparatus.

Complete Petrosectomy

The skin incision is similar to the combined petrosal approach. As the skin is reflected anteriorly, the external auditory canal is sectioned and closed in a blind sac.² The mastoidectomy is performed, followed by a labyrinthectomy. The facial nerve is then skeletonized along its course through the temporal bone and is left within a thin bone canal for protection. The tympanic membrane and inner ear

Fig. 3. Illustrations of the posterior petrosal approach. A single bone flap is constructed spanning the middle and posterior cranial fossae. After the mastoidectomy and skeletonization of the sigmoid sinus, the presigmoid dura mater is opened and connected with the middle fossa dural opening across the superior petrosal sinus. The tentorium is cut to a point posterior to the trochlear nerve entrance.

ossicles are resected. The petrous apex and cochlea are then drilled to complete the petrosectomy (Fig. 1D). This approach allows unobstructed lateral visualization of the petroclival, clival, and cavernous sinus regions (Fig. 7).

RESULTS

The surgical approaches used were as follows: 28 patients underwent an anterior petrosal approach, 27 a posterior petrosal approach, 34 a combined petrosal approach, and eight underwent a complete petrosectomy. Of the 28 patients who were treated with an anterior petrosal approach, 22 had a combination cranioorbitozygomatic approach. Exposure-related complications occurred in eight patients. No patient undergoing an anterior petrosal approach experienced trigeminal neuralgia. Of the 61 patients

Fig. 4. Illustration depicting the exposure provided by the posterior petrosal approach. The sigmoid sinus is released by cutting the superior petrosal sinus and tentorium and is mobilized posteriorly into the area provided by the posterior fossa craniotomy.

who underwent a posterior petrosectomy (those in the posterior and combined groups), five (8%) suffered loss of hearing ipsilateral to the exposure. Two patients who had undergone a complete petrosectomy experienced new facial weakness, and two others experienced worsening of preoperative facial nerve deficits.

Cerebrospinal fluid leakage occurred postoperatively in 10 patients (10%): in one (3.6%) of the 28 patients who underwent an anterior petrosal approach; in four (15%) of the 27 who underwent a posterior petrosal approach; in five (15%) of the 34 who underwent a combined petrosal approach; and in none (0%) of the eight who were treated with a complete petrosectomy. Only three (3%) of the 97 patients required surgical repair of cerebrospinal fluid leakage. Postoperative meningitis occurred in two (2%) of the 97 patients.

Preoperative imaging was reviewed to assess factors involved in the selection of the surgical approach. The location of the tumor was evaluated, specifically examining the involvement of the cavernous sinus, location along the petroclival groove (medial or lateral to the IAM), and whether the tumor crossed the midline. Of the 55 tumors with cavernous sinus involvement, in 45 (82%) we used an anterior petrosal exposure as part of the approach (anterior petrosal alone in three, combined petrosal in 17, complete petrosec-

tomy in five, and an anterior petrosal combined with a cranio-orbitozygomatic approach in 20). Ten patients with cavernous sinus involvement underwent a posterior petrosal approach; these cases were all tumors that involved the posterior cavernous sinus at the Meckel cave. Thus, anterior cavernous sinus involvement was an indication for an anterior petrosal approach as part of the exposure. Tumors located above the IAM all were treated via an anterior petrosal approach, whereas those extending below the IAM required posterior petrosal, combined petrosal, or complete petrosectomy. Tumors that crossed the midline along the clivus required an anterior petrosal approach.

The patients' preoperative hearing status was also assessed. All patients who underwent a complete petrosectomy had nonserviceable hearing.

Although the preoperative venous sinus anatomy was useful in planning surgery, specific variations on this anatomy rarely altered the choice of approach. Venous anatomy evaluated using preoperative angiograms or MR venograms provided information on which cases required further care when exposing the sigmoid sinus in posterior petrosal approaches, but no sinus anatomy was found to be an absolute contraindication for any approach. A high jugular bulb was considered a difficult exposure, because this anatomical variation shortens the length of the presigmoid dura mater

Fig. 5. Illustration of the combined petrosal approach. The temporalis muscle is reflected anteriorly and inferiorly. The bone flap is similar to the one made for the posterior petrosal exposure, although it extends farther anteriorly to the sphenoid wing to allow resection of the petrous apex.

Fig. 6. Illustration of the exposure provided by the combined petrosal approach. A wide view is available after resection of the petrous apex and retrolabyrinthine petrous bone. CN = cranial nerve; SS = sigmoid sinus.

that can be exposed, which limits the posterior petrosal approach. The anatomy of the vein of Labbé was also a factor that caused some alteration of the approach. If the vein drained into the sigmoid sinus anteriorly or through the tentorium, the posterior petrosal approach required modification. The vein of Labbé is inspected intraoperatively in all cases during dural opening. If this vein drains into the superior petrosal sinus and runs in the tentorium before draining into the sigmoid sinus, the tentorium cannot be divided as usual. In this scenario, the petrous ridge is drilled farther anteriorly until the superior petrosal sinus is located anterior to the vein of Labbé entry. The superior petrosal sinus is coagulated and the tentorium is divided at this location.

DISCUSSION

The morbidity and mortality rates in surgically treated petroclival and sphenopetroclival tumors was high in the past. The development of newer microsurgical and skull base techniques, along with improvements in anesthesia, radiology, and neuromonitoring have made these tumors treatable with low morbidity.^{3,12,13,25,40} The challenge of surgical treatment is due to the location of the tumors deep along the skull base and in less accessible regions. The skull base approaches described in this paper make treating these tumors more feasible and safer. Access to petroclival meningiomas and the critical neurovascular structures associated with these tumors requires lateral skull base approaches with petrous temporal bone resection for improved exposure. The extent of temporal bone resection required for adequate exposure depends on many factors. Anterior, posterior, combined, and complete petrous bone resections must be tailored to each case (Fig. 1). To be able to treat

Fig. 7. Illustration of the exposure provided by a complete petrosectomy. The facial nerve is skeletonized throughout its course in the temporal bone.

these lesions, one must be comfortable with all of the possible skull base approaches, and one must tailor the approach used based on preoperative evaluations. In such cases, the choice of approach becomes critical in minimizing morbidity. In this article we look at factors involved in the preoperative choice of surgical approach. We also describe many surgical technical pearls gained through treating a large number of tumors in this location.

Surgical Technique

Anterior Petrosal Approach. The anterior petrosal approach was first described in 1975 by Bochenek and Kukwa.⁷ They described drilling of the petrous apex through the middle fossa to expose the cerebellopontine angle and cutting of the tentorium to visualize the brainstem and BA. Further

modifications to this approach were made through the years by Kawase and colleagues,^{24–26} first applying the middle fossa approach to the lower BAs, and then for petroclival and sphenopetroclival tumors. Since then other groups have reviewed the anatomical basis for the approach¹⁵ and have described their experiences with the middle fossa approach for treatment of vascular and neoplastic lesions at the petroclival and interpeduncular regions.^{6,14,15,29}

The anterior petrosal approach is best suited for smaller petroclival meningiomas that do not extend lateral to the IAM (Fig. 8). Once a tumor has extended farther into the posterior fossa, lateral to the IAM, a posterior petrosal approach should be used.²⁴ The anterior petrosal approach is limited in its ability to expose tumors deeper in the posterior fossa, and requires more manipulation of the trigeminal nerve. During this approach, the fifth cranial nerve is exposed and is the center of the exposure. Tumor resection occurs in the spaces above and below the nerve. Manipulation of the trigeminal nerve introduces the possible complication of deafferentation pain within the trigeminal distribution that is often difficult to manage. With careful dissection, however, this complication is rare. In this series, this complication was not seen in any patient.

The anterior petrosal approach has the added benefit of allowing visualization of the midline clivus.¹ If a tumor extends more medially or contralaterally, the posterior approach may yield limited exposure, and thus an anterior middle fossa approach should be used alone or as an addition to a posterior petrosal approach.

Posterior Petrosal Approach. The posterior petrosal approach allows visualization of tumors deeper within the posterior fossa, lateral to the IAM.³ The petrous resection is retrolabyrinthine, allowing for preservation of hearing. Indeed, within this series, only five patients who under-

Fig. 8. Preoperative (*upper row*) and postoperative (*lower row*) T₁-weighted MR images obtained a patient who underwent resection of a petroclival meningioma via an anterior petrosal approach. The tumor is an example of a small petroclival mass located superiorly to the IAM, allowing complete resection via the anterior approach.

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went a posterior petrosal or combined petrosal approach experienced new hearing loss postoperatively, for a hearing preservation rate of 92%. In addition, the presigmoid route allows for exposure with minimal temporal lobe retraction, and further reduces the operating distance to the petroclival junction. This is the approach of choice for larger petroclival tumors and for those that extend below the IAM (Fig. 9).

Resection of the petrous temporal bone increases surgical exposure of the petroclival region by allowing a more lateral view of the brainstem and petroclival groove. The extent of petrous bone drilling required for adequate exposure has been debated. Resection of the labyrinth and the cochlea increases the operative exposure, but hearing is sacrificed, and the facial nerve is at risk of being weakened.⁵

The more extensive, hearing-sacrificing translabyrinthine approach was originally pioneered by Morrison and King,³³ and exposed the cerebellopontine angle through drilling of the mastoid and labyrinth and cutting of the tentorium. This approach was modified by Hakuba, et al.,¹⁹ with the addition of posterior fossa craniotomy to the labyrinthectomy. The transcochlear approach was described by House, et

al.,²³ and required transposition of the facial nerve for complete exposure. Al-Mefty, et al.,⁴ described the retrolabyrinthine approach, which had the goal of maintaining exposure without sacrificing the hearing or facial nerve function. Other groups have used the retrolabyrinthine approach with good success of tumor resection and hearing preservation.^{9,28,36,37,39,41,43} The posterior petrosal approach has also been used in the treatment of vascular lesions in the posterior fossa.^{34,35}

The retrolabyrinthine posterior petrosal approach is built on the ability to mobilize the sigmoid sinus.¹⁷ This requires skeletonization and exposure from the transverse sinus to the jugular bulb to provide enough length to be able to mobilize the sinus. Uncovering a shorter distance of sinus will limit the ability to move it posteriorly, and will limit the exposure. In addition, a posterior fossa craniotomy is required to allow room for displacement of the sinus. Finally, the sigmoid sinus cannot be mobilized until the tentorium is cut to detether the sinus. Once these steps are performed, the sinus can be mobilized posteriorly, allowing adequate exposure.

Some surgeons have described transection of the sigmoid

Fig. 9. Preoperative (*upper row*) and postoperative (*lower row*) MR images demonstrating a large petroclival meningioma extending below the IAM in a patient with intact hearing, prompting a posterior petrosal approach for resection. The postoperative images demonstrate complete resection via the posterior approach.

sinus to allow sufficient exposure for resection of petroclival meningiomas.^{10,30,31,45} Based on our experience, transection of the sigmoid sinus is not necessary, because it is associated with complications of venous outflow and does not add to the exposure obtained with a posterior petrosal approach. In patients with an ipsilateral dominant sinus or nonconnecting sinuses, this maneuver is not even possible, and will not allow exposure of the tumor. With mobilization of the sigmoid sinus by using the techniques described earlier, transection of this structure is unnecessary.

In certain scenarios, the posterior petrosal approach is feasible, yet requires further care during surgery. These cases are related to the venous sinus anatomy as evaluated on preoperative venography. Cases in which the posterior petrosal approach is dangerous include lesions in patients who have a dominant or single sigmoid sinus on the side of the tumor, in patients with transverse sinuses that do not connect at the torcular herophili, and in patients with venous sinus drainage through the tentorium (Fig. 10). Patients with a dominant or single sigmoid sinus require further precautions to prevent injury to this structure (Fig. 11).

Injury to the sinus requires meticulous repair. Patients with transverse sinuses that do not connect at the torcular herophili also present a danger because often the venous drainage may be split, with one side draining the superior sagittal sinus and the other side draining the deep venous system. Finally, patients with sinus drainage through the tentorium pose a problem because the tentorium cannot be transected. In these patients, the tentorium is cut medially and laterally to the tentorial sinus and tumor resection is performed above and below that structure.

Additionally, the anatomy of the vein of Labbé plays a critical part in the planning of the posterior petrosal approach.³⁸ Anatomical variations of the vein exist where it inserts into the superior petrosal sinus in the tentorium before the transverse–sigmoid sinus junction (Fig. 10A). This anatomical variant needs to be recognized on preoperative venography. During dural opening, the insertion of the vein must be inspected to ensure that the incision across the tentorium is made anterior to the insertion of the vein.

In certain scenarios, the posterior petrosal approach is limited in its ability to provide adequate exposure for tumor resection. Patients with an anatomically high jugular bulb do not have adequate presigmoid space to allow exposure. In these patients another approach, such as the anterior petrosal one, can be considered. Additionally, the posterior petrosal approach will not allow exposure of tumors that extend to the midline of the clivus; in such patients a combined petrosal approach may be needed. Finally, the bone labyrinth obstructs the view of the anterior corner of the petroclival groove and the posterior cavernous sinus. In this scenario, additional exposure can be added by performing a translabyrinthine approach or a complete petrosectomy in patients without hearing, or a combined petrosal approach in patients with intact preoperative hearing.

Combined Petrosal Approach. The combination of approaches can further extend the exposure, taking advantage of the benefits of each individual approach. This was first described by Hakuba, et al.,¹⁸ who combined the preauricular and postauricular transpetrous approaches, including resection of the labyrinth and endolymphatic sac. The cochlea and ossicles of the ear were left intact with an at-

Fig. 10. Venous phase angiograms demonstrating venous anatomy that is critical to the petrosal approaches. A: Angiogram demonstrating anatomy in a case in which the vein of Labbé traversed within the tentorium, making a posterior petrosal approach more difficult because the tentorium cannot be cut across the vein. B: A dominant sigmoid sinus on the side of the tumors is demonstrated. This anatomical variation requires care with the posterior petrosal approach when skeletonizing the sigmoid sinus. C: Angiogram demonstrating nonconnecting sinus anatomy.

Fig. 11. A–D: Preoperative MR images demonstrating a petroclival meningioma on the side of a dominant sigmoid sinus. E–F: Postoperative MR images demonstrating complete resection via a posterior petrosal approach.

tempt to preserve hearing. Among the eight patients treated using this approach, seven had hearing loss.

Partial resection of the labyrinth has been described by Sekhar and colleagues⁴² as a technique that has the potential to preserve hearing while extending the temporal exposure.²⁰ This approach was used in a series of 36 patients, with 80% preservation of hearing. The technique was slightly modified by another group, with similar hearing preservation rates.^{22,27} The superior and posterior semicircular canals are resected, allowing a corridor to drill the petrous apex above the meatus of the internal auditory canal. In anatomical studies, Chanda and Nanda¹¹ and Horgan, et al.,²¹ have demonstrated an increase in horizontal exposure with labyrinth resection, although other groups have found that partial labyrinth resection does not supplement the critical exposure required for resection of tumors in the petroclival region.³² Indeed, Sekhar explains that the

extra exposure gained with the partial labyrinthectomy petrous apicectomy is secondary to the resection of the petrous apex. The combined petrosal approach as described in this article and elsewhere¹² takes advantage of the ability to resect the petrous apex from the middle fossa exposure as opposed to increasing the risk of hearing loss with a partial labyrinthectomy.

The combined petrosal approach is optimal for patients with large petroclival tumors who have serviceable hearing.¹² This exposure takes advantage of the benefits of both anterior and posterior petrosal approaches, while saving hearing. Specifically, one can resect large tumors in the posterior fossa below the IAM through the posterior petrosal exposure while using the anterior petrosal exposure to visualize the midline clivus, ventral brainstem, the contralateral side, and the anterior cavernous sinus. In addition, this approach allows exposure of the petrous apex and the

Fig. 12. Preoperative (A and B) and postoperative (C) MR images demonstrating complete resection of a large petroclival meningioma via a combined petrosal approach.

Meckel cave. The ability to expose the ventral brainstem allows visualization of the BA and perforating vessels, providing a safer approach to resection (Fig. 12).

Complete Petrosotomy. In patients with large tumors and loss of hearing, the complete petrosotomy allows the most extensive surgical exposure. Removal of the inner ear apparatus connects the posterior and anterior exposures, allowing a true anterior, lateral, and posterior approach to the petroclival region, and to all areas into which these tumors extend (Fig. 13). The limitation of this approach is the longer preparation time required to drill the entire petrous bone. Often we will stage these procedures, performing the exposure on one day and following with tumor resection on the following day. Additionally, there is risk of injury to the facial nerve because the exposure requires skeletonizing the nerve along its course through the temporal bone.

Leaving a thin shell of bone surrounding it during exposure can decrease the risk of facial nerve injury. In this series, new facial weakness developed in two patients, and two experienced worsening of preoperative facial weakness. It is difficult to assess whether this symptom is secondary to the surgical exposure or to dissection of the tumor, because patients who undergo complete petrosotomy often have tumors that involve the facial nerve.

CONCLUSIONS

To treat petroclival and sphenopetroclival meningiomas effectively, the surgeon must be familiar with the skull base techniques described here. In addition, it is critical to have an understanding of the benefits and risks associated with the different approaches to allow selection of the best one

Fig. 13. Preoperative MR images (*upper row*) demonstrating a large petroclival meningioma in a patient whose hearing was nonserviceable preoperatively. Postoperative MR images (*lower row*) demonstrating complete resection via a complete petrosotomy.

to minimize the morbidity of resection. A simple algorithm is proposed for selection of the approach. Before this selection is made, careful examination of the preoperative MR imaging, hearing evaluation, and venous anatomy is required. Resection via an anterior petrosal approach can be effective in patients with small petroclival lesions superior to the IAM. Patients with larger tumors that extend below the internal auditory canal and who have intact or serviceable hearing should undergo a posterior petrosal approach. Tumors extending across the midline of the clivus or into the anterior cavernous sinus require a combined petrosal approach. Patients with large tumors who suffer loss of hearing benefit from the extended exposure provided by a complete petrosectomy. With this algorithm, petroclival tumors can be treated effectively with resection, resulting in minimal morbidity.

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Manuscript received July 12, 2005.

Accepted in final form July 25, 2005.

Address reprint requests to: Ossama Al-Mefty, M.D., Department of Neurosurgery, University of Arkansas for Medical Sciences, 4301 West Markham, Slot 507, Little Rock, Arkansas 72205. email: aekeeland@uams.edu