Classification and quantification of the petrosal approach to the petroclival region

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Object. The petrosal approach to the petroclival region has been used by a variety of authors in various ways and the terminology has become quite confusing. A systematic assessment of the benefits and limitations of each approach is also lacking. The authors classify their approach to the middle and upper clivus, review the applications for each, and test their hypotheses on a cadaver model by using frameless stereotactic guidance.

Methods. The petrosal approach to the upper and middle clivus is divided into four increasingly morbidity-producing steps: retrolabyrinthine, transcrusal (partial labyrinthectomy), transotic, and transcochlear approaches. Four latex-injected cadaveric heads (eight sides) underwent dissection in which frameless stereotactic guidance was used. An area of exposure 10 cm superficial to a central target (working area) was calculated. The area and length of clival exposure with each subsequent dissection was also calculated. The retrolabyrinthine approach spares hearing and facial function but provides for only a small window of upper clival exposure. The view afforded by what we have called the transcrusal approach provides for up to four times this exposure. The transotic and transcochlear procedures, although producing more morbidity, add little in terms of a larger clival window. However, with each step, the surgical freedom for manipulation of instruments increases.

Conclusions. The petrosal approach to the upper and middle clivus is useful but should be used judiciously, because levels of morbidity can be high. The retrolabyrinthine approach has limited utility. For tumors without bone invasion, the transcrusal approach provides a much more versatile exposure with an excellent chance of hearing and facial nerve preservation. The transotic approach provides for greater versatility in treating lesions but clival exposure is not greatly enhanced. Transcochlear exposure adds little in terms of intradural exposure and should be reserved for cases in which access to the petrous carotid artery is necessary.

KEY WORDS • petrosal approach • surgical approach • skull base • meningioma

The transtentorial petrosal approach to the petroclival region is performed at various medical centers in a variety of permutations, and the terminology alone is quite confusing. Furthermore, as novel variations of the technique continue to evolve as a result of efforts to preserve function, a systematic assessment of the benefits and limitations of each approach has lagged behind.

The transtentorial petrosal approach can be used for a variety of neoplastic and vascular lesions involving the middle and upper clivus. We review the otology and neurosurgery literature and base our classification on these historical contributions. We add a term (transcrusal) coined to describe a technique of hearing preservation for which we use a variation of the partial labyrinthectomy approach described originally by McElveen, et al., and Hirsch, et al., and later expanded on by Sekhar, et al.

Retro labyrinthine, transcrusal (partial labyrinthectomy), transotic, and transcochlear are terms that describe four successive steps of temporal bone resection. Although cranial nerve vulnerability increases with each step, little attention has been paid to quantifying the additional exposure attained. The operative approach remains one of personal style. In this paper we have objectified these approaches in terms of what is gained to better gauge their benefit compared with potential morbidity. By using frameless navigational techniques, we quantified the area of clival exposure at each successive step as well as the area of surgical freedom used to manipulate instruments outside the surgical site.

Materials and Methods

Cadaver Preparation

A total of four cadavers were prepared to yield eight data sets. Our preparation was based on that described by Diaz Day, et al. After disarticulation of the heads, the cerebral arterial and venous systems were flushed with normal saline, followed by 500 ml of an arterial conditioner (Metaflow; Dodge Chemicals, Cambridge, MA). The heads were soaked in a diluted solution of conditioner overnight and then in methanol for 24 hours. The CAs were next flushed with 5% buffered formalin, and the heads were soaked in this solution for 1 to 2 days. The cerebral vessels were then flushed with acetone, and pigmented silicone latex compound (Dow-Corning, Midland, MI) was injected into the cerebral vasculature, which was allowed to harden overnight. Small frontal craniectomies were made, and the CAs were sewn into the dura mater.
Petrosal approach to the petroclival region

TABLE 1
Features of four stages of the petrosal approach to the petroclival region

<table>
<thead>
<tr>
<th>Stage</th>
<th>Temporal Bone</th>
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<tbody>
<tr>
<td>Retrolabyrinthine</td>
<td>Semicircular canals remain fully intact</td>
</tr>
<tr>
<td>Transcrusal</td>
<td>Superior and posterior semicircular canals are removed from ampulla to common crus</td>
</tr>
<tr>
<td>Transotic</td>
<td>Otic capsule entered w/ complete removal of semicircular canals &amp; skeletonization of facial nerve; wall of external auditory canal resected &amp; ear canal over-sewn &amp; reflected forward</td>
</tr>
<tr>
<td>Transcochlear</td>
<td>As w/ transotic, but includes posterior mobilization of facial nerve w/ completion of cochlear removal &amp; exposure of petrous CA</td>
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performed bilaterally to monitor brain fixation. Fixation was then continued for 1 to 2 weeks by using 5% buffered formalin, until the elasticity and consistency of the brains mimicked that of living tissue.

Dissection Techniques

Specimens were held in place with a three-point rigid head holder fixed to a laboratory bench top. The initial steps for the petrosal approach are the same for each of the four variations and are well described in the literature. A curvilinear incision is made beginning 1 cm anterior to the tragus, extending superiorly for several centimeters, then posteriorly and inferiorly over the asterion toward the mastoid tip. Drilling of the mastoid is then begun and continues until all three semicircular canals and the vertical segment of the facial nerve are exposed. The dura of the temporal lobe and posterior fossa is exposed and the bone is removed from over the sigmoid and distal transverse sinus. Dural exposure is continued 1 cm posterior to the sigmoid sinus as well.

After the temporal craniotomy was performed, the dura over the temporal lobe was opened and a self-retaining retractor was placed under the temporal lobe. The fourth cranial nerve was identified and the superior petrosal sinus and tentorium were divided. A retractor was placed on the cerebellum and gentle retraction was exerted to mimic that which would be used on living tissue. The retractors were left in place for the remainder of the dissection to ensure accuracy of the stereotactic measurements taken between each of the subsequent steps of the dissection (Table 1).

A retrolabyrinthine exposure was continued with further drilling of the petrous apex medial to the semicircular canals. After a series of stereotactic measurements were taken, the transcranial variation was performed with removal of the superior and inferior semicircular canals from ampulla to common crus, which allowed for more freedom medically and further drilling of the petrous apex. This was followed by the transotic variation, which features complete skeletonization of the facial nerve. The transcochlear variation was completed after sectioning of the greater superficial petrosal nerve and reflection posteriorly of the facial nerve. The horizontal segment of the CA was identified.

Stereotactic Data Gathering

After each step of the approach was completed, four parameters were measured: 1) the exposed petroclival area; 2) the exposed length of the clivus; 3) a spatial cone over the surgical field depicting the surgical freedom for manipulation of instruments within the wound; and 4) the exposed length of the fifth cranial nerve (Figs. 1 and 2). The measurements were made with the aid of a frameless stereotactic navigation device (Stealth Station; Sofamor–Danek, Memphis, TN). The reference arc of this device was positioned in a vice close to the cadaver head, and both the vice and headholder were fixed to the desktop, forming a rigid construction. The actual stereotactic measurements were made using the pointer of the frameless navigational device.

The first and second set of calculations were designed to measure

the exposed petroclival area and length of clivus that could be observed at each respective step of the dissection. To enable mathematical superposition and comparison of the areas measured in subsequent steps of the approach, we marked three points on the clivus after the retrolabyrinthine dissection was complete. These three points formed a triangle and thus a plane on the clivus that could be referred to and reregistered with each subsequent dissection. This was facilitated by injection of methylene blue at each of these three points. With each variation, seven additional points were registered around the unhindered periphery of the observed area as defined by the three reference points. It was necessary to adjust the microscope repeatedly to visualize each of the seven peripheral points in turn. These points were registered in a standardized pattern: five at the superior, lateral, and inferior margins of the exposed area, and two on the medial margin.

The third set of measurements was designed to estimate the surgical freedom available to the surgeon’s hands and instruments; that is, to define a spatial cone through which surgical instruments could be inserted to manipulate a deep target. We used the junction of the vertebral artery and AICA as the target point. The spatial cone was defined by placing the tip of a microdissector into this bifurcation and rotating its handle circumferentially around the field. After rotation to each region of the field as defined later, the position of the microdissector handle was registered by placing the pointer of the frameless navigation device on the handle of the microdissector. A total of seven data points were collected at each step of the dissection in the following locations: Point 1 at the AICA, forming the vertex of the cone; Point 2 superiorly and anteriorly; Point 3 superiorly in the direction of the temporal lobe retractor; Point 4 superiorly and posteriorly; Point 5 posteriorly in the direction of the cerebellar retractor; Point 6 inferiorly; and Point 7 anteriorly. The final set of data consisted simply of measuring the length of the fifth cranial nerve exposed at each step of the approach. For this the stereotactic pointer was simply registered at the dorsal root entry zone and again distally toward the foramen magnum.

Data Analysis and Interpretation

A spreadsheet algorithm was used to calculate the area of petroclival exposure defined by the seven points registered at the periphery of the exposure. Each data set, including the three reference points, was used to calculate the cross-sectional area by the method of mathematical superposition, and comparison of the areas measured in each variation in the following locations: Point 1 at the AICA, forming the vertex of the cone; Point 2 superiorly and anteriorly; Point 3 superiorly in the direction of the temporal lobe retractor; Point 4 superiorly and posteriorly; Point 5 posteriorly in the direction of the cerebellar retractor; Point 6 inferiorly; and Point 7 anteriorly. The final set of data consisted simply of measuring the length of the fifth cranial nerve exposed at each step of the approach. For this the stereotactic pointer was simply registered at the dorsal root entry zone and again distally toward the foramen magnum.
points and the seven peripheral points, was translated and rotated mathematically to place the three reference points in the x-y plane. The x and y coordinates of each of the seven peripheral points were then read, and the area of the resulting heptagon calculated by summation of triangles. Thus, the area of exposure was measured in a plane defined by the three reference points marked on the clivus. The z-axis deviation of the peripheral points from the x-y plane defined by the reference points was on average only a few millimeters. The small triangle formed by the three fixed reference points in the clivus was confined within the heptagon and was used to superimpose the data obtained at the different steps of the approach.

Surgical freedom was likewise calculated with a spreadsheet algorithm. Each data set was translated to place the reference point at the coordinate origin (x = y = z = 0) and the entire data set was rotated to align its arithmetic center with the z axis. A heptagonal area was created by taking a slice through the polygonal cone at a height of 10 cm on the z axis. The area of this heptagon was calculated by summation of triangles. Thus, the area of exposure was measured in a plane defined by the three reference points marked on the clivus. This provided for improved facial and auditory function, Al-Mefty, et al., first reported a combined presigmoid, transpetrosal approach to vestibular schwannomas, thereby paving the way for what is now generally referred to as the petrosal approach: a combined presigmoid, supra- and infratentorial exposure of the petroclival region. A transcochlear exposure involving posterior mobilization of the facial nerve described by House and colleagues5,6 was followed by a description of the transotic procedure by Jenkins and Fisch.7 Although hearing is also sacrificed in this variation, the facial nerve is only skeletonized. To better preserve facial and auditory function, Al-Mefty, et al., described their experience with the retrolabyrinthine petrosal approach. This provided for improved facial and surgical freedom at each step of the approach for each side of each cadaveric head were made and superimposed, enabling visual comparison and proofing (data not shown). The length of the fifth cranial nerve exposure was simply calculated in millimeters and compared.

Results

The retrolabyrinthine approach provided 108 ± 51 mm² of exposed, visible clivus. This is significantly less than with the transcrusal approach, which provided 449 ± 71 mm². This translates to 21% compared with 89% of the final exposure achieved with a transcochlear approach (Table 2). There was no significant difference among the transcrusal, transotic, or transcochlear clival exposures. In terms of length, the retrolabyrinthine approach provided 17.8 ± 4.8 mm compared with 28.1 ± 5.9 mm with a transcrusal route. Again, the difference among the latter three exposures was insignificant.

Surgical freedom, on the other hand, revealed a gradually increasing trend between exposures, with the largest jump between the transcrusal and transotic variations. The first three steps provided 56, 71, and 91% of the surgical freedom provided for by the final or transcochlear step. The exposure of the fifth cranial nerve reached significance between the retrolabyrinthine and transcrusal variations. The last three exposures each provided a similar view.

Discussion

King and colleagues8,9 first reported a combined presigmoid, transtentorial approach to vestibular schwannomas, thereby paving the way for what is now generally referred to as the petrosal approach: a combined presigmoid, supra- and infratentorial exposure of the petroclival region. A transcochlear exposure involving posterior mobilization of the facial nerve described by House and colleagues5,6 was followed by a description of the transotic procedure by Jenkins and Fisch.7 Although hearing is also sacrificed in this variation, the facial nerve is only skeletonized. To better preserve facial and auditory function, Al-Mefty, et al., described their experience with the retrolabyrinthine petrosal approach. This provided for improved facial and surgical freedom at each step of the approach.

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<table>
<thead>
<tr>
<th>Step of the Approach</th>
<th>Exposed Petroclival Area</th>
<th>Surgical Freedom</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean Area (mm²)‡</td>
<td>Mean Percentage of Final Exposure</td>
</tr>
<tr>
<td>retrolabyrinthine</td>
<td>108 ± 51b</td>
<td>21 ± 9</td>
</tr>
<tr>
<td>transcrusal</td>
<td>449 ± 71b</td>
<td>89 ± 19</td>
</tr>
<tr>
<td>transotic</td>
<td>476 ± 62b</td>
<td>94 ± 16</td>
</tr>
<tr>
<td>transcochlear</td>
<td>514 ± 78b</td>
<td>100</td>
</tr>
</tbody>
</table>

* Values are expressed as means ± standard deviation.
† The extent of surgical freedom was defined by the area of a slice through a cone at a distance of 10 cm from the apex, which was positioned at the AICA, as described in Stereotactic Data Gathering.
‡ Values with dissimilar superscripts (a, b) differ significantly from each other at the level of p < 0.001.
§ Values with dissimilar superscripts (a, b) differ significantly from each other at the level of p < 0.05.
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auditory function, but allowed the surgeon less room to work than either the transotic or transcochlear procedures. McElveen, et al. reported a single case of hearing preservation after surgery performed via a modified translabyrinthine route. Hirsch and colleagues used a similar approach of partial labyrinthectomy in a series of 14 vestibular schwannoma resections in which hearing was preserved. Members of the same group of physicians recently reported their use of this technique in treating 36 neoplastic and vascular lesions of the petroclival area, with preservation of hearing in 81% of their patients. Our experience with a variation of the technique that we call transcrusal has also been favorable, with hearing preservation in six of six patients. The classification scheme we use in this report is based on historical review and describes the degree of temporal bone resection involved. Although well described, the translabyrinthine variation of temporal bone resection is conspicuously absent from our petrosal scheme. The reasons are twofold: historically, the translabyrinthine approach has been reserved for infratentorial temporal bone dissection to gain access to the lateral internal acoustic meatus for vestibular schwannoma resection. Also, petrosal craniotomies are typically used to gain access to lesions that involve both supra- and infratentorial compartments. These lesions do not always invade the porus acusticus. We therefore view the petrosal approach as a series of steps along a continuum, with each named step defining the amount of bone ultimately removed before putting a cranial nerve at risk for loss. The translabyrinthine approach falls between transcranial and transotic. Because hearing is invariably lost once the vestibule is opened, the next logical place to stop would be short of putting the facial nerve at risk. The amount of bone ultimately removed for a particular lesion is dictated by the surgeon’s preference and may fall between steps. Because of the way we classify our approach and for the sake of this study, we determined end points based on potential morbidity.

The translabyrinthine approach is the safest method in terms of cranial nerve morbidity but is limited in terms of surgical view of the upper petroclival region: it provided only 21% of the ultimate transcochlear view. The transcranial variation provides up to 89% of the view afforded by the transcochlear approach. This is very significant in terms of cranial nerve morbidity: the risk of permanent deafness is 100% with the transotic and transcochlear variations, and partial facial paralysis is seen in essentially 100% of patients undergoing the transcochlear variation. Although we see a trend of increasing surgical freedom with each step, it appears that the transcranial variation gives the best results. We use this variation for a variety of lesions in the petroclival region including AICA and middle cerebral artery aneurysms, meningiomas, and clival chordomas, in which hearing preservation is important. We have been able to save hearing in all six of our patients, and in a larger series in up to 81%. We have found that the increased morbidity of the transotic and transcochlear exposures with their requisite compromise of auditory and/or facial function is unnecessary unless the tumor extends into the internal auditory canal or involves the petrous bone itself. Before completing this study in cadavers and treating our six patients, we favored the retrolabyrinthine approach to neoplasms and vascular lesions in this area, but had been frustrated by the lack of exposure in the region of the internal acoustic meatus and porus trigeminus. Brainstem compression certainly aids in the exposure of these structures in larger tumors, but there is always at least a small area of obstruction by which tumor removal is hindered. By removal of the posterior and superior canals, visualization is vastly increased, with tumor resection made more simple and the angle for aneurysm clip application made more direct. From a technical standpoint, we make a trephination in the apex of each canal, fill each end with a wax and bone-dust mixture, and then drill through the remainder of the canals. The preservation of endolymph, which is emphasized in other studies, is more time consuming and did not appear necessary in our cases.

The petrosal approach to the upper and middle clivus is useful but should be used judiciously, because morbidity levels can be high. The retrolabyrinthine approach has limited utility. For tumors with no bone invasion, the transcranial approach provides a much more versatile exposure with a good probability of hearing and facial preservation. The transotic approach provides greater versatility in approaching the AICA but clival exposure is not greatly enhanced. Transcochlear exposure adds little in terms of intradural exposure and should be reserved for patients in whom access to the petrous portion of the CA is necessary.

Conclusions

The petrosal approach to the upper and middle clivus is useful but should be used judiciously, because morbidity levels can be high. Our classification scheme is a simple way of categorizing progressive levels of temporal bone dissection and hence, subsequent morbidity. The transcranial approach in particular provides for a much more versatile exposure with a possibility for hearing and facial nerve preservation. Until more data are gathered that support our preliminary findings, use of this technique should be limited to patients in whom the retrolabyrinthine exposure does not provide enough access to lesions.

References

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