Endoscopic/Microscopic Approach to Sphenopetroclival Complex: An Anatomical Study

ABSTRACT—A dilemma presents itself to the otoneurologist and neurosurgeon when determining the least invasive surgical approach to giant cholesterol cysts (GCC) of the petrous apex of the temporal bone. These lesions can be diagnosed with a fair degree of certainty with imaging studies. Transmastoid and subcochlear approaches may be inadequate to access these lesions, and the transcochlear approach results in the sacrifice of hearing. A minimally invasive, combined microscopic and endoscopic sublabial transsphenoid approach to drain and marsupialize these lesions has been chosen by the authors in those cases that are anatomically possible. The purpose of this article is to establish the feasibility of entering anterior petrous apex cells by way of this approach, and to better conceptualize the anatomy of the Spheno-Petro-Clival Complex (SPC). Ten Fresh cadaveric “whole head” specimens were dissected with, endoscopic/microscopic control, through midline, sublabial, transeptal, and transsphenoidal routes to the petrous apex. The three-dimensional relationships of the sphenoid sinus, petrous apex, and the clivus were further demonstrated by dissections of the same specimens from the posterior fossa. Sagittal cut sections were also performed. After confirming the feasibility of this approach by dissections, the technique was adopted for performing drainage of GCC of the petrous apex in clinical cases.

Recent developments in computer software technology and diagnostic radiology with assisted magnetic resonance imaging (MRI) allow us to diagnose petrous apex lesions with a fair degree of certainty. In addition to these diagnostic advances, the development of endoscopic surgery and surgical tools have nurtured the development of minimally invasive techniques in lesions that are inaccessible. Advances in skull base surgery have also created a need for more detailed anatomical information that would allow safer surgical success to this critical inaccessible region. Many approaches to the

petrous apex have been defined—transtemporal, transcranial and transsphenoidal—but each approach has its own advantages and disadvantages.

The transnasal, transsphenoidal approach has become a standard technique in dealing with pituitary tumors and is routinely performed with minimal morbidity. The first advocate of this approach, Hirsch,¹ received severe criticism due to the key hole surgery. Hamberger et al,² described an approach to the sphenoid sinus through the maxillary and the ethmoid sinuses. However, due to the obliquity of the approach and the

radicality of removing the maxillary and ethmoid sinus, there was concern of injury to the optic nerve. With the introduction of the surgical microscope and better illumination, the pendulum swung back to the midline approach to the sphenoid sinus, designed to overcome external scarring and the obliquity of the dissection. This has become a standard approach to the pituitary for neurosurgeons.^{3,4}

The transsphenoidal approach to cystic lesions of the petrous apex by way of contralateral ethmoidectomy has been clearly described by Montgomery.⁵ However, this approach necessitates external incision, ethmoidectomy, and removal of the middle turbinate. However, it is a relatively narrow angle approach and the main advantage would be due to its obliquity and contralateral exposure, which would overcome the axis of the petrous bone to sagittal plane (55 degrees).

A case report in the literature has documented the use of the endoscope to approach petrous apex lesions transsphenoidally.⁶ This approach is feasible when no bone is present between the cyst and the sphenoid mucosa. However, the main disadvantage is that it is a one-handed approach because of the need to hold the endoscope.

The exact etiology of the GCC of the petrous apex is unknown. However, the literature supports the theory that chronic poor ventilation or obstruction of the eustachian tube may result in formation of cholesterol granuloma.⁷⁻¹² Cholesterol is generated by the catabolism of hemoglobin or by tissue break down. Why fluid continues to accumulate is unclear, but it is responsible for the progressive expansion of the cyst and bone erosion. Canfield¹² reported a case of unexplained coma and meningitis in a patient due to rupture of the GCC of the petrous apex. Despite drainage and treatment, the patient died. Postmortem examination demonstrated a large cystic space with dural defect. The relative incidence of the GCC leading to sudden death is unknown.

clivus is the area below the IX, X, and XI cranial nerves and includes the occipital condyl and the XII cranial nerve.

The complex sphenoid bone also contributes to the Spheno-Petro-Clival Complex (SPC), situated between the middle and posterior skull base region. Posteriorly, the basisphenoid articulates through a synostosis with the occipital bone to form the clivus. The sphenoid sinus is extremely variable in size, shape, and in relation to the sella and surrounding structures, and such variation is due to its unique pneumatization.

The third bone that contributes to the SPC is the petrous part of the temporal bone. Chole,¹⁴ in review of 84 temporal bones, found 9% of the anterior petrous apices were pneumatic, 7% were sclerotic, and 84% were diploic. Arbitrarily, the petrous bone has been divided anatomically by the coronal plane passing through the internal auditory canal into anterior and posterior segments. The anterior segment of the petrous bone is conveniently described as a truncated pyramidal bone having three surfaces and three borders, and houses the internal carotid artery (ICA). The borders and surfaces of the anterior segment of the petrous apex also include the trigeminal ganglion, and the superior and inferior petrosal sinuses. The superior surface forms the floor of the middle cranial fossa and is in relation to the gasserian ganglion, greater superficial petrosal nerve, lesser petrosal nerve, and the branches of the middle meningeal artery. The superior petrosal sinus is in relation to the junction of the superior and posterior surface. The posterior surface is a smooth bone that is in close proximity to the pontine and arterial branches of the vertebrobasilar system, abducent nerve, and beginning of the inferior petrosal sinus. The inferior surface of the petrous apex is irregular and is bounded by the foramen lacerum, petroccipital fissure, carotid canal, and the jugular foramen. The other structures in relation to this surface are the internal jugular vein, ICA and the lower IX, X, XI, and XII cranial nerves.

ANATOMY

The clivus is a specific term designating the dorsal slanting surface of the sphenoid body and the occipital bone from the dorsum sellar to the foramen magnum. However, the clivus is arbitrary divided according to neurovascular structures and has been regionalized into upper, middle, and lower segments.¹³ This type of classification will help to better understand the surgical approach.

The upper clivus is defined by the area of bone above the petrous apex, trigeminal nerve, and the abducent nerve. It includes the dorsum sellae and the postclivoid process. The midclivus region extends from abducent nerve to lower cranial nerves leaving the jugular foramen, posteriorly related to the branches of basilar artery and laterally the inferior petrosal sinus. The lower

MATERIALS AND METHODS

Ten fresh frozen cadaveric heads were dissected by using a sublabial transsphenoidal approach to the anterior cells of the petrous apex with an operating microscope and endoscopic control; these heads provided the material for this study.

These dissections were performed with a high-speed drill and an extra long burr handle. Dissections were performed to optimally expose and display the anatomical characteristic of the area, while simulating the actual procedure. The feasibility of reaching the petrous apex was confirmed and further dissections of the same specimens from the posterior fossa were performed for better definition of the intra cranial structures in the region of petrous apex. After completion of

these dissections, all skull specimens were cut sagittally for remeasurement. Special attention to the anatomy of the sphenopetrous segment of the ICA and related structures in the petrous apex and the sphenoid bone were studied to understand the three-dimensional relationships of the SPC complex. A summary of anthropometric measurements based on the dissections of 10 fresh cadaveric specimens (20 petrous apices) by utilizing the above approach and sagittal sections of the skull is depicted in Figures 1–3 and Tables 1–3, respectively.

Measurements were taken from the anterior inferior nasal spine to the anterior and posterior sphenoidal wall and the clival dura (Fig. 1). The transverse diameter between both ICA were measured proximally (distance between the petrous segment of the ICA) and distally (distance between the ICA in the cavernous segment) (Fig. 2). The petrous apices were measured after sagittal section (Fig. 3). The exposed portion of the anterior petrous cells were measured and pneumatization of the petrous apex are documented in Figure 3.

Anatomical Dissections

The surgical approach to the petrous apex through the midline sublabial transseptal transsphenoidal dissection is an extradural approach. However, for the purpose of better understanding the three dimensional anatomy, we performed extradural and intradural dissections anteriorly through the sphenoid and posteriorly through

Figure 1. Schematic diagram representation of the midline transsphenoidal approach to the petrous apex with emphasis of the ICA at the region of lateral sphenoid wall. (A) Distance between ANS & ASW. (B) Distance between ANS & PSW. (C) Distance between ANS & CD. ANS = anterior nasal spine; ASW = anterior sphenoid wall; PSW = posterior sphenoid wall; CD = clival dura.

Figure 2. Representation of transverse measurement of the proximal (←→) and distal (←→), segments of the ICA.

the retosigmoid approach. Sagittal sectioning was also performed in all 10 specimens.

Extradural Dissection

The cadaveric head was fixed and a standard midline sublabial, transseptal, transsphenoidal approach performed.¹⁵ The anterior wall of the sphenoid sinus and vomerine bone were removed and the pneumatization of the sphenoid sinus were documented. Vertical and horizontal dimension of the sphenoid sinus were measured. For better access of the petrosphenoid segment of the ICA, the inferior wall of the sphenoid sinus was partially removed. Skeltonization of both the ICAs from the petrosphenoid segment to the end point of the ICA was performed with extra long diamond burs, and the

Figure 3. Exposed petrous apex cells medial to the ICA-C.

Table 1. Measurement of Skull Specimens: Sphenoid Sinus: (Sagittal)

<i>Pneumatization Sphenoid Sinus</i>	<i>Distance Between AINS & ASW (cm)</i>	<i>Distance Between AINS & PSW (cm)</i>	<i>Distance Between AINS & CD (cm)</i>	<i>Height of the Sphenoid Sinus (cm)</i>
Presellar	7.5	9.1	9.9	3.0
Sellar	7.0	9.2	9.6	2.5
Presellar	7.0	8.4	9.0	2.8
Sellar	7.0	9.5	9.9	2.5
Sellar	7.0	8.2	8.6	3.0
Presellar	6.5	8.5	9.2	2.5
Sellar	6.4	8.5	9.0	2.8
Sellar	7.0	8.0	9.0	2.8
Sellar	6.5	8.5	8.9	2.8
Presellar	7.5	9.0	9.7	3.0
Mean range	6.4–7.5	8.0–9.5	8.6–9.9	2.5–3.0
Mean average distance	6.89	8.66	9.23	2.77

AINS = Anterior inferior nasal spine; ASW = anterior sphenoid wall; PSW = posterior sphenoid wall; CD = clival dura; ICA = internal carotid artery.

distance between these arteries were measured proximally and distally.

To approach the anterior group petrous cells, the ICA at the junction of petrous and the posterior wall of the sphenoid sinus was identified. Drilling posterior and medial to the ICA, the clival dura was exposed (Fig. 4), and marks the end of extra dural dissection. This clival dura is a key landmark and opens up the anterior petrous apex cells, which are medial to the ICA. With the help of a 30-degree rigid 4-mm endoscope, further cells were exenterated to overcome the axis of the petrous apex with the sagittal plane.

along the dural flap and, cephalically, the trigeminal nerve entering Meckel's cave.

To further enhance the definition of infratentorial structures intradurally, a separate retrosigmoid posterior fossa craniotomy (20 procedures) was performed and the structures documented transsphenoidally were confirmed by this approach. Intradural dissections were not performed when surgically approaching GCC of the petrous apex, but were utilized to better define regional anatomy.

RESULTS AND FINDINGS

Intradural Dissection

To define the neurovascular structures in relation to the petrous apex through the transsphenoidal approach, a laterally based dural flap was created using a sickle knife. This flap was raised laterally to protect the ICA and prevent any violation of important neurovascular structures at the level of the petrous apex. Zero- and 30-degree, 4-mm rigid endoscopes were utilized to visualize the abducent nerve entering the cavernous sinus by Dorello's canal, the inferior petrosal sinus lying

The pneumatization of the sphenoid sinus was, as expected, variable. The sellar type of pneumatization was found in 60% of the surgical specimens the presellar type of the pneumatization in 40% of the specimens, and no conchal type of the sphenoid sinus was found.

The thickness of the posterior wall of the sphenoid sinus varied with respect to the type of pneumatization. In presellar sphenoid, the thickness of the wall was 8 mm (range 6 to 9 mm). In sellar sphenoid, the posterior wall was 4 mm (range 3 to 6 mm) (Table 3). The transverse distance between ICA at the sphenopetro segment,

Table 2. Measurement of Skull Specimens: Petrous Bone of the Temporal Bone

<i>Pneumatization Petrous Apex</i>	<i>Distance Between IAC-Apex of the Petrous Bone</i>		<i>Distance Between IAC and exposed Petrous apex cells</i>		<i>Exposed Petrous Apex Cells</i>	
	<i>Right PA (cm)</i>	<i>Left PA (cm)</i>	<i>Right PA (cm)</i>	<i>Left PA (cm)</i>	<i>Right PA (cm)</i>	<i>Left PA (cm)</i>
Marrow filled	3.0	3.0	2.0	1.5	1.1	1.2
Marrow filled	2.8	2.4	1.8	1.4	0.9	0.9
Sclerotic	2.8	2.5	1.8	1.6	0.9	0.9
Marrow filled	2.4	2.2	1.6	1.2	1.2	1.0
Marrow filled	2.5	2.5	1.6	1.2	0.9	0.9
Pneumatic	2.3	2.8	0.9	1.0	1.2	1.1
Marrow filled	2.6	2.8	1.5	1.5	0.9	0.9
Marrow filled	2.4	2.4	1.3	1.5	0.9	0.9
Sclerotic	2.3	2.2	1.0	0.9	0.9	0.8
Marrow filled	2.2	3.0	1.7	2.0	1.2	1.2
Mean range	2.2–3.0	2.2–3.0	1.0–2.0	1.0–2.0	0.9–1.2	0.8–1.2
Mean distance	2.57	2.53	1.5	1.31	1.1	1.2

IAC = internal auditory canal; PA = petrous apex.

Table 3. Measurement of Skull Specimens: Sphenoid Wall

Sphenoid Pneumatization	Clival Bone Thickness (mm)	Exposed Petrous Apex (mm)	Measurement of ICA	
			Proximal (mm)	Distal (mm)
Presellar	4 (range 3 to 6)	11	18	24
Sellar	8 (range 6 to 9)	12	18	25

however, remains constant at 18 mm, regardless of the type of sphenoid pneumatization.

Pneumatization of the petrous bone has been classified as pneumatic (aerated with mucosally lined cells), diploic (marrow filled), or sclerotic. Differentiation of such pneumatization can be accurately classified by radiological studies. The petrous apex pneumatization was variable in our studies and indicated no correlation between the type of sphenoid pneumatization. The type of petrous apex pneumatization encountered from our cadaveric dissections was marrow or diploic (70%), sclerotic (20%), and pneumatic type (10%). The mean average exposure of the anterior petrous cells through this approach was 11 mm in presellar and in sellar type of 12 mm (Table 3).

The important neurovascular structures in relation to posterior sphenoid wall intradurally at the level of anterior petrous apex from above downward were the trigeminal nerve, abducent nerve, and inferior petrosal sinus (Fig. 5). The basilar artery and its branches were in close proximity, but were variable in position. However, there was no correlation between the type of petrous apex pneumatization and the exposure ultimately obtained from the petrous apex cells by these approaches.

Figure 4. Drilling of the posterior wall of the sphenoid sinus and the solid arrow showing the clival dural angle medial and inferior to the ICA.

CLINICAL EXPERIENCE

Two illustrative cases are briefly described as representative of potential lesions that can be managed by this approach. In both cases, a three-dimensional computer software neurostation and a three-dimensional optical digitizer were used intraoperatively to confirm the surgical position. Utilizing this real-time feedback and the knowledge gained by our dissections, the anterior petrous apex was approached.

Case 1

A 42-year-old White female presented with a hearing loss, diplopia, and occasional tinnitus. On audiological examination 30-dB conductive hearing loss with good speech discrimination scores were observed. The VI cranial nerve function was absent on the ipsilateral side of hearing loss. The remainder of the cranial nerves were intact. Computed tomography (CT) scan showed extensive smooth erosion of the left petrous apex and MRI revealed hyperintense signal of the left petrous apex on T1- and T2-weighted images, confirming GCC of the petrous apex.

Figure 5. Overview of the skull base from above showing, on the left side, the infratentorial erosion commonly caused by the GCC, and, on the right side, the related neurovascular structures.

Case 2

A 42-year-old male presented with unilateral headaches, recurrent pounding tinnitus, and hearing loss of the right ear. Physical examination demonstrated a dark blue tympanic membrane. The remainder of the head, neck, and otoneurological examination was unremarkable. In a span of 2 years, the patient had twice undergone mastoidectomy with the infralabyrinthine approach and subcochlear approach to the petrous apex of GCC, 2 which had failed to decompress or marsupialize the lesion.

Both cases were successfully approached. Upon opening the cyst walls, which were well defined, a black to brown oily fluid with golden crystals of cholesterol granuloma drained profusely. A # 20 rolled silastic sheeting was placed into the drainage sites to prevent stenosis. Both lesions were successfully drained without morbidity and the patients were discharged after an overnight stay without complications.

DISCUSSION

Improved diagnostic imaging and a heightened awareness has led to an increase in the diagnosis of petrous apex lesions, particularly GCC, the most common cystic lesion of this region. However, only those cases causing significant symptoms such as headache, hearing loss, or cranial nerve impairment require drainage. Successful surgical approach requires a detailed three-dimensional understanding of the neurovascular structures of the SPC complex. The SPC region is formed by the petrous part of the temporal bone, posterior wall of the sphenoid sinus, and the clivus. Tumors in this region are intimately associated with important neurovascular structures. The surgical approach to GCC of the petrous apex is dictated by the clinical presentation, local extension, and preoperative radiological evaluation.

In cases of a GCC of the petrous apex, the aim of surgery is to perform a minimally invasive technique to drain and exteriorize the cyst with minimum morbidity. The major advantage of the transsphenoidal approach is the direct access that it gives to the petrous apex, and the full conservation of hearing and vestibular function. The recent advent in radiological imaging techniques, by high-resolution CT and MRI may demonstrate, with a fair degree of accuracy, benign cystic lesions from malignancies. The radiological characteristics of GCC of the petrous apex on MRI demonstrates high signal to T1- and T2-weighted images and nonenhancing with gadolinium is due to cholesterol crystals and chronic haemorrhagic by-products.¹⁶ The cyst wall of the GCC of the petrous apex is composed of fibrous connective tissue and has the capacity to expand and erode bone, in some cases demonstrating remarkable destruction of these petrous apex, clivus, and related skull-base structures.

The sign and symptoms of an expanding lesion in the petrous apex depend on the region of involvement of the temporal bone. The most common symptom is conductive deafness, secondary to serous effusion due to eustachian tube compression. Other lesser symptoms can include headache from pressure or stretching of the dura, facial hypoesthesia caused by the trigeminal nerve involvement, or diplopia due to abducent nerve involvement.

One observation we have made is that GCC of the petrous apex seems to form medial to the ICA in the antero-medial compartment of the petrous apex. The GCC then seems to expand antero-medially and inferiorly. Hence, the anatomical presentation is infratentorial, and erosion of the posterior sphenoid wall and the lateral part of the clivus is a common feature. The senior author (M.L.) has found the transmastoid or subcochlear approach allows for only incomplete drainage of these lesions and further requires the placement of permanent middle ear ventilation tubes. Sacrifice of the cochlea to widely approach these lesions is not generally justified. The posterior fossa and middle fossa approaches are not recommended because of the highly irritative effect of the fluid within the cyst, should it be released into the epidural space or posterior fossa.

The subcochlear approach may provide only limited access to the petrous apex. The distance between the membranous cochlea and the internal carotid artery varies between 0.33 to 3.70 mm.¹⁴ The distance between the jugular bulb and the otic capsule may also be a limiting factor in obtaining access to the petrous apex. Because of these anatomical limitations, we recommend the midline transsphenoidal in selected cases, after thoroughly evaluating the regional anatomy radiologically by CT scan.

During radiological assessment, if the position of the ICA is favorable, a midline transsphenoidal approach to the petrous apex is utilized because it allows more complete access and drainage. As per our dissections, the mean average exposure of the anterior petrous apex was 11 to 12 mm. On the basis of anatomical dissections, one interesting observation was that a correlation did not exist between the degree of pneumatization between the sphenoid and petrous bones, and the ultimate exposure. However, a sellar type of the sphenoid with a thin bony wall presents less difficulty technically than a thicker presellar type of posterior sphenoid wall. Although not encountered clinically or in cadaveric specimens, a conchal type of sphenoid would be a contraindication to this approach.

Partial removal of the inferior wall of the sphenoid sinus is necessary to approach the middle clival space. This corresponds to the region of the petrous apex. Widening the contralateral bony margins of the pyramidal aperture and adjunctive usage of 30-degree endoscope will help to overcome the petrous apex axis. The bony prominence produced by the ICA on the lateral

wall of the sphenoid sinus is positively identified before drilling. By drilling medial and inferior to the ICA, the clival dura is exposed and identified. This key angle marks the end of dissection and allows exenteration of the anterior cells of the petrous apex, which are medial to the petrosphenoid segment of the ICA. The main disadvantage of the midline sublabial transsphenoidal approach is its limited approach inferiorly. This limitation can be overcome by partial removal of the inferior wall of the sphenoid sinus. In addition, our current use of a standard imaging intensifier is extremely helpful in correlating the position of the posterior sphenoid wall, ICA, and the anterior petrous apex. Currently, we are using a stereotactic MRI neuro-navigational surgical guidance system and have found this improvement results in better imaging methods. In addition, an endoscopic conformation of position has also been highly advantageous in providing an extra margin of safety in previously penetrating this accessible region.

CONCLUSIONS

In this anatomical study, the relationships between the neurovascular structures of the sphenopetro-clival complex were evaluated to explore the feasibility and safety of the midline sublabial transseptal transsphenoidal approach to the petrous apex. On the basis of this anatomical research, clinical experience has been obtained utilizing this midline approach.¹⁷

We recommend this approach in selected cases, with the following suggestions and caveats:

1. An experienced skull-base team with intimate knowledge of the relevant anatomical landmarks performs the procedure.
2. The pyriform aperture must be widely exposed.
3. The anterior and inferior walls of the sphenoid sinus must be widely exposed.
4. Positive microscopic and endoscopic confirmation the internal carotid artery in the lateral wall of the sphenoid is essential.
5. Extra length cutting and diamond drills are necessary to penetrate the dense posterior sphenoid wall (clivus).
6. The cholesterol granuloma cyst wall may be fibrous and require adequate opening to establish drainage.
7. A conventional image intensifier, or a neuronavigation system, provides important intraoperative confirmation and positional feed back.

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