Decompression of the Jugular Bulb for Enhanced Infralabyrinthine Access to the Petroclival Region: A Quantitative Analysis

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Abstract

Objectives To describe an enhanced infralabyrinthine approach to petroclival lesions with jugular bulb decompression, and to quantify surgical access using a flat-panel computed tomography image protocol.

Design Retrospective case series and paired comparison of pre- versus post-dissection anatomy.

Setting Tertiary academic medical center.

Participants Four patients presenting with petroclival lesions. Six fresh cadaveric specimens were used for temporal bone dissection.

Main Outcome Measures Axial and coronal dimensions, and access angles of the infralabyrinthine surgical corridor.

Results Decompression of the jugular bulb increased the craniocaudal width of the infralabyrinthine corridor from 0.9 to 7.9 mm to 6.5 to 11.6 mm. The mean increase of 4 mm was statistically significant ($t = 3.7$; $p < .05$). There was also a significant widening of the infralabyrinthine window along the axial dimension by 0.9 to 4.5 mm or a mean of 2 mm ($t = 3.7$; $p < .05$). Angles of access to the petroclival region were wider following jugular bulb decompression, particularly in the coronal plane (mean difference 7.9 degrees; $t = 5.0$; $p < .005$) but less so in the axial plane (mean difference 4.7 degrees; $t = 2.5$; $p = .05$).

Conclusions Jugular bulb decompression enhances infralabyrinthine access to petroclival lesions, permitting the removal of tissue for diagnoses or partial resection, without significant additional morbidity.

Keywords

- petroclival junction
- transtemporal approach
- jugular bulb decompression
- flat-panel computed tomography

Introduction

Although uncommon, lesions of the petrous apex and petroclival junction pose diagnostic and therapeutic challenges because of the intricate radiologic and surgical anatomy of this skull base region. These lesions include expansile non-neoplastic processes such as cholesterol granuloma and

cholesteatoma; primary neoplasms that vary in degree of local and regional invasiveness, such as chondrosarcoma and chordomas; and secondary neoplasms such as breast, gastrointestinal, and renal cancers.^{1,2} Following a thorough radiologic work-up to narrow the differential diagnosis and to eliminate pseudolesions such as fibrous dysplasia and meningoencephaloceles, the direct examination of tissue may

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still be warranted. Beyond tissue diagnosis the goals of surgical excision must consider the potential threat of the lesion as reflected by size and location, histology, growth rate, and invasiveness.

The surgical approach with the lowest risk of morbidity and mortality should be selected to achieve the necessary surgical goals, taking into consideration tissue consistency and ease of removal, radiation sensitivity, and patient factors such as age and comorbidities. Whereas surgical drainage of benign cystic lesions such as the cholesterol granuloma may be accomplished through the narrow access of a transcanal and infracochlear approach, for example,³ even limited biopsy of a solid lesion requires wider access. Tumors in the petroclival region in particular pose technical challenges to the achievement of partial or complete resection because of the need to traverse and sometimes manipulate important neural and vascular structures. A variety of approaches are available for wider access to the petrous apex and petroclival region most commonly to address chondrosarcomas. Open transcranial approaches via the middle and posterior fossae, with the goal of complete resection, have been described and proposed as the management of choice for these tumors.^{4–7} The high prevalence of postoperative complications in these transcranial approaches reflects the increased risk associated with brain retraction and the need to work around critical neurovascular structures.

In a meta-analysis of 560 cases of skull base chondrosarcoma, however, Bloch et al⁸ revealed a superior tumor control rate for patients receiving surgery followed by adjuvant radiotherapy, independent of extent of tumor removal, compared with surgery or radiation alone. Less invasive endonasal approaches have been shown to achieve effective tumor removal, particularly in the cavernous sinus region.⁹

Whereas significant intracranial extension of tumors arising in the petroclival region may warrant transcranial approaches, many lesions are limited to the skull base. In these cases transtemporal and endonasal endoscopic approaches provide surgical access to petroclival lesions without entering the cranial vault. Endonasal approaches, however, are most appropriate with abutment of the lesion against the sphenoid sinus and favorable placement of the internal carotid artery.^{9,10} Transmastoid access to the petrous apex and medial structures, in contrast, is obstructed by the jugular bulb, facial nerve, labyrinth, and the petrous portion of the internal carotid artery (ICA). In a deaf ear, the translabyrinthine approach provides direct access to the petrous apex.¹ More anterior access to the petroclival junction may require mobilization of the facial nerve, transcochlear extension of the dissection,¹⁰ and repair of a cerebrospinal fluid (CSF) leak using a fat graft.

Previously described transtemporal approaches to the petrous apex¹ with the goal of hearing preservation include, but are not limited to infralabyrinthine, infracochlear,¹¹ and subarcuate¹² approaches. Giddings et al were the first to describe the infracochlear approach in 1991.³ The infracochlear approach to cholesterol granulomas is frequently described, but visualization is limited, and the use of instrumentation for tissue dissection or biopsy is restricted by the

narrow dimensions of the external auditory canal and infracochlear aperture. More anterior and medial lesions of the petrous apex and petroclival junction require even wider access windows that can accommodate the identification of critical structures and the visualization and removal of pathology.

The transmastoid infralabyrinthine approach was described by Dearmin in 1937¹³ and has advantages of hearing preservation, preservation of facial nerve function, and maintenance of the posterior wall of the external auditory canal. Wider access at the mastoid becomes severely restricted more deeply, however, by the jugular bulb that may severely limit or prevent access to the petrous apex in as many as 50% of cases based on cadaveric temporal bone dissection^{14,15} or in 74% of cases based on computed tomography (CT) imaging.¹⁶ Some reports have highlighted the feasibility and safety of decompressing and retracting the jugular bulb to improve infralabyrinthine drainage of cholesterol granulomas.^{17–19} The role of the infralabyrinthine approach enhanced by decompression and displacement of the jugular bulb in the management of other apical and petroclival lesions, however, has not been widely reported.

This report describes the implementation of jugular bulb decompression and retraction to expand infralabyrinthine access for the biopsy and decompression of petroclival tumors with minimal to no intracranial extension. In addition to examining the clinical experience and outcome of this technique in a small cohort of patients, we set out to quantify the impact of jugular bulb decompression and retraction on infralabyrinthine access to the petroclival junction in several randomly selected cadaveric temporal bones using measurements on flat-panel computed tomography (FPCT) images. This study also sets out to establish radiologic methods that could be used preoperatively to assess the infralabyrinthine access afforded by decompression of the jugular bulb.

Methods

The Surgical Procedure

The extended infralabyrinthine dissection provides a viable approach to tumors at the petroclival junction such as that shown on CT and magnetic resonance imaging (MRI) in ►Fig. 1. A wide complete mastoidectomy is performed paying particular attention to the decompression of the sigmoid sinus and up to a centimeter of dura in the retrosigmoid region, if needed. The amount of retrosigmoid dura that is decorticated depends on the position of the sigmoid sinus. A more anteriorly and laterally positioned sinus will require greater decortication to achieve more anteromedial exposure to the petrous apex. Following identification of the mastoid segment of the facial nerve, the sigmoid sinus is followed distally and into the retrofacial region where the jugular bulb is identified. The inferior limb of the posterior semicircular canal (SCC) is defined and blue lined. This landmark serves as the superolateral limit of the infralabyrinthine dissection. The retrofacial cell tract is opened, and the vertical segment of the fallopian canal is skeletonized. The presigmoid dura is exposed to maximize access to the infralabyrinthine corridor.

Fig. 1 Preoperative temporal bone imaging of representative case. (A–C) A right-sided petrous apex lesion (asterisk) abuts the internal carotid artery (ICA) and is hyperintense on T2-weighted axial magnetic resonance images. (D–F) Preoperative computed tomography images at corresponding axial levels. Erosion of the posterior cortical plate of the petrous pyramid (arrowhead) with minimal extension into the posterior fossa.

The jugular bulb is further defined to its most superior dome (►Fig. 2). The blue line of the inferior limb of the posterior SCC is followed anteriorly until the posterior ampulla is identified. The jugular bulb is fully decorticated and decompressed as far laterally as the facial nerve and as far medially as the dura of the posterior fossa. Using a Freer elevator (Sklar Corp., West Chester, Pennsylvania, United States) or Rhoton no. 7 (Medline Industries, Mundelein, Illinois, United States), the jugular bulb is elevated from the remaining anterior and medial cortical bone of the jugular fossa. A flattened piece of bone wax measuring ~ 1 cm in diameter is placed over the jugular bulb and firmly applied to the surrounding bone. In this way the jugular bulb is retracted inferiorly, thereby widening infralabyrinthine access (►Fig. 2).

The dissection is continued into the space anterior and medial to the jugular fossa. In this location the ICA is identified close to its genu anterior-medial to the cochlea. The

petrous apex cells medial to the carotid artery are exenterated to gain access to the medial petrous apex and petroclival region. Just anterior to the jugular bulb the cochlear aqueduct is encountered. The radiologic appearance of an extended infralabyrinthine dissection used to biopsy the chondrosarcoma in ►Fig. 1, is shown on FPCT in ►Fig. 3. To enhance access medially and anteriorly, the facial nerve can be mobilized distal to the second genu, and the cochlea can be blue lined. After tumor removal, the bone wax is removed from the jugular bulb, which is allowed to reexpand to its natural position. The opening to the cochlear aqueduct can be sealed to manage any CSF leak by tightly packing fascia within the infralabyrinthine space.

Clinical Case Review

Between 2006 and 2014, the senior author used the infralabyrinthine approach in four cases to biopsy and decompress destructive petroclival tumors with limited intracranial

Fig. 2 Intraoperative dissection of representative case. (A) Surgical access. The posterior semicircular canal is blue lined (arrow) and the jugular bulb identified (asterisk). The facial nerve (FN) and sigmoid sinus (SS) are skeletonized. The jugular bulb is freed from surrounding bone by blunt dissection (B). Bone wax is used to retract the jugular bulb (arrowhead in C). HSC, horizontal semicircular canal.

Fig. 3 Postoperative flat-panel computed tomography images in the (A) axial and (B–D) serial coronal planes of a representative case show the access window (asterisks) and surgical corridor. Anatomical landmarks in the axial plane (arrow indicates facial nerve; SS, sigmoid sinus) denote the anterior and posterior borders. The inferior limb of the posterior semicircular canal (arrow in C, D) and the jugular bulb (jb) define the superior and inferior borders, respectively, in the coronal plane (B–D). co, cochlea; ICA, internal carotid artery.

extension. The medical records and imaging studies were reviewed with an emphasis on technical details and clinical outcomes.

The Temporal Bone Study

Cadaveric temporal bones were randomly selected for this study. They underwent an FPCT scan prior to dissection. These temporal bones were then subjected to the extended infralabyrinthine approach described previously followed by repeat imaging. The dissection identified and preserved key landmarks including the posterior semicircular canal, vertical segment of the facial nerve, cochlear aqueduct, petrous ICA,

and the jugular bulb (► **Fig. 4**). The end point of dissection was a maximally widened infralabyrinthine corridor including decompression and retraction of the jugular bulb without mobilization of the facial nerve or violation of the labyrinth. The medial access of these dissections was limited by the length of available drill burrs.

Flat-Panel CT Imaging and Analysis

Temporal bone cadaver specimens underwent FPCT (DynaCT, Siemens, Erlangen, Germany) evaluation on a biplane neuroangiography system (Axiom Artis Zee, Siemens) using commercially available software (Syngo DynaCT, Siemens). A 20-

Fig. 4 Cadaveric dissection. (A, B) A representative cadaveric dissection identifies the structures encountered during access to the petrous apex (PA). The posterior semicircular canal (arrow) is blue lined. The facial nerve (FN) and sigmoid sinus (SS) are skeletonized. Bone wax is used to retract the decompressed jugular bulb (arrowhead). The cochlear aqueduct (asterisk) is identified and preserved. An opening into the PA is demonstrated in (B). FR, facial recess; HSC, horizontal semicircular canal.

second FPCT without contrast was performed for each specimen using the following parameters: 109 kV, small focus, 200-degree rotation angle, and 0.4-degree/frame angulation step. Postprocessing was performed on a commercially available workstation (Leonardo DynaCT, Inspace 3D software; Siemens). Secondary reconstructions were created using Hounsfield units (HU) kernel type and sharp image characteristic.

Multiplanar two-dimensional reconstruction images of the temporal bone specimens were created by first locating the posterior semicircular canal in the axial plane and subsequently aligning parallel and perpendicular axes in the coronal and sagittal planes, respectively. The coronal and sagittal axes were maintained in an orthogonal relationship and then rotated until the axial plane was positioned along the long axis of the retrofacial-infralabyrinthine access window and deeper surgical defect or corridor. This created a coronal oblique image of the surgical corridor and the posterior semicircular canal.

In the axial plane, the facial nerve and ICA formed the anterior border; the posterior border was formed by the posterior fossa dura (►Fig. 5A). The superior border in the coronal plane was limited by the inferior limb of the posterior semicircular canal while the inferior border was the superior dome of the jugular bulb (►Fig. 6A). A line through the midpoint of the most medial aspect of the surgical corridor bisecting the infralabyrinthine opening was used to establish an orthogonal measure of aperture width at the facial nerve in the axial plan (►Fig. 5B, C) and at the inferior limb of the posterior SCC in the coronal plane (►Fig. 6B, C). The surgical angles of freedom gained from the access window and surgical corridor were measured between the limiting borders anteriorly and posteriorly, and superiorly and inferiorly, in the axial and coronal planes, respectively. All measurements were repeated three times, and the median values and standard deviations were reported. Paired *t*-test analysis was conducted to compare pre- and post-dissection dimensions of the infralabyrinthine corridor.

Results

Clinical Outcomes

Four patients underwent a transmastoid infralabyrinthine approach to lesions of the petrous apex and petroclival junction, three of whom required decompression and retraction of the jugular bulb (►Table 1). In representative case 3, a 54-year-old man was initially evaluated for headache and found to have an erosive petroclival lesion on MRI. There was erosion of cortical bone with minimal extension of disease into the prepontine compartment of the posterior fossa. Partial encasement of the ICA was identified, and a decision was made to perform the extended infralabyrinthine approach with jugular bulb decompression for tumor biopsy and decompression. Preoperative imaging showed a T2 hyperintense lesion (►Fig. 1A–C). The erosive changes from the lesion were demonstrated in the preoperative CT (►Fig. 1D–F). A rigidly fixed stereotactic frame was used for intraoperative CT navigation. Access to the lesion was achieved as previously described (►Fig. 2). A partial resection was achieved of the lateral aspect of the tumor. Following pathologic review, the lesion was found to be a clear cell neoplasm, presumed to be a low-grade chondrosarcoma, and he was treated with adjuvant proton beam radiation. Postoperative FPCT shows the access achieved using the expanded infralabyrinthine approach (►Fig. 3). The axial angle of access was 20 degrees and the coronal angle was 11.6 degrees. The coronal (craniocaudal) dimension of the access window was 9.1 mm from the posterior SCC to the decompressed jugular bulb. The postoperative axial dimension of this access window was 4.9 mm. The jugular bulb was allowed to return to its native position following decompression and dissection of the lesion, so postoperative measurements were taken from the remaining bony margin to approximate its intraoperative position.

In two other patients (cases 1 and 2), additional access was achieved for greater tumor removal, with limited transposition of the vertical segment of the facial nerve. As shown in ►Fig. 7 from case number 1, all bone around the nerve was

Fig. 5 Axial flat-panel computed tomography images of procedural access. Representative axial images of a dissected (A, B) and undissected (C) cadaveric temporal bone specimen were used to measure the access window. The anterior-lateral limit was the facial nerve (arrow) and the posterior-lateral limit the posterior fossa tegmen. The anteroposterior dimension, depth, and angle of access were measured (B). The predicted access of an undissected image (C) was based on fixed landmarks (the facial nerve, internal carotid artery, and posterior fossa dura).

Fig. 6 Coronal flat-panel computed tomography images of procedural access. Representative coronal images of a dissected (A, B) and undissected (C) cadaveric temporal bone specimen were used to measure the access window. The craniocaudal dimension, depth, and angle of access were measured (B). The superior-lateral limit was the inferior limb of the posterior semicircular canal (arrow) and the inferior-lateral limit the decompressed jugular bulb (jb). In the undissected specimen, the inferior-lateral limit was the apex of the jugular bulb in its native position.

circumferentially drilled away from the lateral semicircular canal to the stylomastoid foramen followed by elevation and lateral retraction of the digastric muscle from its mastoid insertion. Normal facial function was conserved in both cases without transient weakness. Tumor removal was subtotal to complete in case number 1 with no remaining gross tumor

seen on rigid endoscopy or with subsequent imaging performed on the first postoperative day (►Fig. 8). In case 2, only a portion of the tumor was removed for limited decompression and tissue diagnosis, and it was followed by postoperative proton beam therapy. In case 4, the infralabyrinthine corridor was sufficiently large to allow for complete removal

Table 1 Clinical features of four cases of chondrosarcoma of the petrous pyramid surgically treated using an infralabyrinthine approach

	Age (y), gender, side	Tumor characteristics	Presenting signs and symptoms	Surgical details	Postoperative course (follow-up period)
Case 1	26, female, left	1.7 × 1.0 × 1.4 cm mass at jugular bulb extending into petrous apex with small extension into CPA; chondrosarcoma, grade 2	Mild hearing loss; hoarseness; paralyzed left vocal fold; left trapezius atrophy and arm weakness	FN partially mobilized; CSF leak repair. Tumor fully resected	Hearing unchanged, normal facial function, no CSF rhinorrhea or other complications, no radiotherapy (follow-up transferred after 2 mo)
Case 2	32, male, right	3 × 2 × 2.7 cm mass within petrous apex with extension to the clivus and into IAC; chondrosarcoma, grade 2	Sudden onset right facial weakness; mild hearing loss; dizziness	FN partially mobilized; jugular bulb decompressed. Tumor partially resected	Hearing unchanged, normal facial function, no complications, Proton beam radiotherapy, slight subsequent growth without new symptoms (7 y currently)
Case 3	54, male, right	3.1 × 1.5 × 1.8 cm mass eroding into the right clivus and carotid canal; clear cell neoplasm (Fig. 1)	Sudden right-sided hearing loss and associated vertigo	Jugular bulb decompressed without mobilization of the FN. Tumor partially resected	Hearing unchanged, no complications, proton beam radiotherapy (12 mo currently)
Case 4	29, female, left	1.9 × 2.1 × 1.6 cm mass at jugular fossa with extension to carotid canal; chondrosarcoma, grade 2	Intermittent left hearing loss; middle ear mass	Retrofacial dissection without jugular bulb decompression or mobilization of FN. Subtotal resection of tumor	Hearing unchanged, no complications, radiotherapy (18 mo currently)

Abbreviations: CPA, cerebellopontine angle, CSF, cerebrospinal fluid; FN, facial nerve; IAC, internal auditory canal.

Fig. 7 Mobilization of the vertical segment of the facial nerve in case 1 to expand infralabyrinthine access to the petrous apex and petroclival junction. (A, B) Circumferential removal of bone inferior to the lateral semicircular canal including the stylomastoid foramen. This technique is less traumatic to the nerve than elevation from the Fallopian canal. (C) Lateral mobilization of the vertical segment by liberating the digastric muscle from its mastoid and soft tissue attachments and tacking it to the parotid fascia, thereby expanding access to the jugular bulb (JB). (D) Inferior retraction of the decompressed JB (by suction) provides expanded access for removal of the tumor (black arrowhead) and visualization with endoscopes. DM, digastric muscle; FN, facial nerve; HSC, horizontal semicircular canal; SMF, stylomastoid foramen.

Fig. 8 T1-weighted magnetic resonance images (MRIs) with gadolinium enhancement performed preoperatively and on postoperative day number 1, showing near-complete removal of left petroclival chondrosarcoma.

of gross disease without jugular bulb decompression or facial nerve mobilization. The gelatinous consistency of the tumor facilitated its removal using curettes and suction.

Cadaveric Studies

Fresh cadaveric temporal bones were used to determine the infralabyrinthine access achieved with decompression of the jugular bulb. The dissection identified and preserved key landmarks including the posterior semicircular canal, vertical seg-

ment of the facial nerve, cochlear aqueduct, petrous ICA, and the jugular bulb (► Fig. 4). The sigmoid sinus was decompressed and retrosigmoid decortication performed as needed to improve access and to maintain dissection trajectory toward the petrous apex and petroclival junction. Bone wax was used to retract the jugular bulb. Once the jugular bulb was decompressed and retracted, the depth of dissection was often limited by the length of burrs available in the temporal bone laboratory and not the dimensions of the extended infralabyrinthine window.

Imaging obtained prior to dissection of the specimens showed variable access window dimensions. The axial dimension, defined as the distance between the posterior border of the vertical segment of the facial nerve and the posterior fossa dura, ranged from 1.8 to 7.7 mm. The craniocaudal (coronal) dimension, defined as the distance from the inferior border of the posterior semicircular canal to the dome of the jugular bulb, ranged from 1.7 to 8.8 mm. Decompression of the jugular bulb increased the craniocaudal distance by 0.9 to 7.9 mm to 6.5 to 11.6 mm (►Fig. 9). The resulting mean increase of 4 mm was statistically significant using the paired *t* test ($t = 3.7$; $p < .05$). The dissection also produced a

significant widening of the infralabyrinthine window along the axial dimension by 0.9 to 4.5 mm or a mean of 2 mm ($t = 3.7$; $p < .05$) (►Fig. 10).

The angles of access were estimated in dissected specimens based on the most medial point of dissection and boundaries of the infralabyrinthine access window. These angles were compared with those estimated in undissected specimens relative to the natural position of the jugular bulb. There was variable improvement in the angles of access to the petroclival region in the axial plane (0.15–12.67 degrees) and coronal plane (2.89–14.3 degrees). Differences were significant in the coronal plane (mean difference: 7.9 degrees;

Fig. 9 Changes in the coronal dimension of the infralabyrinthine access window following decompression of the jugular bulb in cadaveric specimens. On average there is a 4-mm widening of this dimension.

Fig. 10 Changes in the axial dimension of the infralabyrinthine access window following decompression of the jugular bulb in cadaveric specimens. On average there is a 2-mm widening of this dimension.

$t = 5.0$; $p < .005$) but less so in the axial plane (mean difference: 4.7 degrees; $t = 2.5$; $p = .05$).

Discussion

In a small series of patients we demonstrated the feasibility and safety of an infralabyrinthine approach for the biopsy and partial resection of lesions in the petrous apex and petroclival junction. This approach can be used with and without decompression of the jugular bulb, improving access without the need for craniotomy. The cadaveric study has further quantified the expanded access afforded by decompression of the jugular bulb and demonstrates the generalizability of the technique. This study also describes and demonstrates a novel approach utilizing FPCT imaging of the temporal bone for the planning of transtemporal approaches to the petrous apex and petroclival junction.

The transmastoid infralabyrinthine approach was described by Dearmin in 1937¹³ and has advantages of hearing preservation, preservation of facial nerve function, and maintenance of the posterior wall of the external auditory canal. Wider access at the mastoid becomes severely restricted more deeply, however, by the jugular bulb in half of the temporal bones dissected by Jacob and Rupa,¹⁵ and in 40% by Haberkamp.¹⁴ This report demonstrates the feasibility of widening this surgical corridor with decompression and retraction of the jugular bulb, supporting similar findings in other studies.^{17–19} The mean vertical dimension in temporal bones with undisturbed jugular bulbs (5.28 mm) is in close agreement to that reported by Cömert et al.¹⁷ (5.79 mm), Jacobs and Rupa¹⁵ (4.6 mm), and Haberkamp¹⁴ (4.99 mm).

Cömert et al¹⁷ were able to increase infralabyrinthine exposure by decompressing the jugular bulb in many cases, achieving unimpeded access to the petrous apex in 73% of all temporal bone specimens. Compared with dimensions reported in the current temporal bone series (7×9.25 mm), a slightly larger mean surgical aperture was achieved by Cömert et al following decompression of the jugular bulb (8.64×11.16 mm). The dissection described by Cömert et al, however, included removal of the posterior external auditory canal wall. Careful mobilization of the vertical segment of the facial nerve using the technique presented in ▶Fig. 7 and guided by Brackmann's observations,²⁰ can further expand infralabyrinthine access with low risk of facial weakness and without the need to remove the ear canal wall. The feasibility and safety of decompressing the jugular bulb for improved drainage of the petrous apex¹⁹ was reported. Couloigner et al²¹ also performed decompression of the jugular bulb in 13 patients for treatment of Ménière disease and pulsatile tinnitus with no adverse effects.

The role of the infralabyrinthine approach enhanced by decompression and displacement of the jugular bulb in the management of apical and petroclival lesions other than cholesterol granuloma has not been widely reported, however. This approach offers the opportunity to obtain tissue for histologic diagnosis and varying levels of gross tumor removal without the morbidity associated with more extensive skull base and transcranial resections. In particular, avoiding the

manipulation of the lower cranial nerves, often necessary in a transcranial approach to the posterior fossa, provides a clear advantage related to the potential postsurgical transient or permanent dysfunctions and associated complications.

In their extensive review of the English literature that encompassed 560 patients, Bloch et al⁸ reported markedly and significantly lower 5-year recurrence rates for patients treated with surgery followed by radiation therapy (9%) compared with either surgery (44%) or radiation alone (19%). Analysis of available data demonstrated a clear statistically significant benefit in recurrence-free survival for patients receiving postoperative radiation regardless of the degree of resection. Overall, the data therefore suggest a significant additive benefit of surgery and radiation and questionable benefit of complete resection. They furthermore report comparable overall tumor recurrence rates for patients with gross total versus subtotal resection after postoperative radiation therapy was given, suggesting that a gross total resection does not improve recurrence-free survival if adjuvant radiation therapy is given.

Tumor debulking with the plan for adjuvant radiotherapy is therefore a reasonable treatment strategy for skull base chondrosarcomas, negating the need for more complete tumor removal using more morbid open techniques. Higher rates of recurrence in mesenchymal compared with conventional tumor subtypes,⁸ however, may require more extensive tumor removal prior to radiation therapy in these rare cases. Although grade III tumors had higher recurrence rates compared with grades I and II, this difference did not achieve statistical significance. Unlike histologic type, tumor grade may therefore have little influence on prognosis and treatment planning. Furthermore, the vast majority of tumors present with grade I or II histology.

Published treatment outcome data for chondrosarcoma therefore support surgical goals that can be readily achieved using an infralabyrinthine approach enhanced as needed by decompression of the jugular bulb and mobilization of the vertical facial nerve. The lack of evidence that complete resection of these tumors imparts a survival or quality-of-life advantage over tumor debulking with adjuvant radiotherapy,⁸ particularly in cases with minimal to no intracranial extension, places into question the utility of more extensive transcranial approaches.

Rigid endoscopes have been increasingly utilized to effect minimally invasive approaches to skull base and intracranial lesions, particularly chondrosarcomas that are relatively soft with minimal if any soft tissue invasion.⁹ A 2010 report speaks to the feasibility of achieving > 95% removal of chondrosarcomas located in the superior aspect of the petrous apex, petroclival and cavernous sinus regions using extended endonasal approaches.⁸ As an alternative approach, the transmastoid infralabyrinthine corridor may provide direct access to more inferior lesions within the petrous apex and petroclival junction without the need for postoperative management of an open sinonasal or mastoid cavity. The comparison of transtemporal and transnasal surgical anatomy to the petrous apex using a large CT database found easy surgical access via the lateral approach in 37% and via the nasal

approach in 40%.¹⁶ Easy access via one or the other approach, however, did not correlate strongly with ease via the other approach.

Transnasal and lateral extracranial approaches are therefore complementary and should both be considered on a case-by-case basis guided by the specific anatomy. In the occasional case for which both approaches are feasible, the occurrence of a CSF leak can be more readily addressed with tight packing of fibromuscular grafts within the bony confines of the infralabyrinthine defect, or fat grafting of the mastoid if needed. Alternatively, the transnasal approach may be preferred if extensive facial nerve mobilization and/or cochlear compromise are required of a lateral approach.¹⁰

As reported, FPCT imaging of the temporal bone can be used specifically to study the infralabyrinthine anatomy relative to the pathology of interest. Using specific landmarks and cross-sectional planes, the size and orientation of an infralabyrinthine corridor can be estimated in advance of surgery. This information may assist in planning for appropriate instrumentation to effect the safest and most complete tumor removal possible. It is our impression that the expanded infralabyrinthine approach provides a transmastoid surgical corridor that may afford even deeper and more refined dissection with the assistance of endoscopy, specially designed tools, image navigation,¹¹ and robotic technology.²²

Wider angles of freedom afforded by decompression of the jugular bulb and possibly the partial mobilization of the vertical facial nerve are likely to facilitate the use of endoscopes with appropriate instrumentation, navigation, and possibly robotic assistance. Potential future benefits include improved access to deeper skull base or intracranial structures. The use of this imaging protocol for intraoperative navigation would be a helpful advance and could potentially complement endoscopic techniques for deeper skull base dissection. For example, the advantage of image navigation has been reported for infralabyrinthine surgery of the petrous apex.¹¹ The recent report of robot-assisted image-guided drainage of a petrous apex cholesterol granuloma via an infralabyrinthine approach²² furthermore elucidates the potential for further technological developments aided by radiologic planning and enhanced surgical access as reported here.

Limitations to this study include the difficulty of comparing dimensions and angles despite using fixed anatomical landmarks to define the anterior and posterior as well as superior and inferior borders on the axial and coronal planes, respectively. Additionally, the measurements obtained on the preoperative FPCT images may have underestimated those obtained on the dissected specimens. Coronal measurements in post-dissected specimens, for example, may underestimate the maximum access achieved during dissection with the use of bone wax and supplemental pressure used to retract the jugular bulb by instrumentation.

These limitations may also explain the smaller vertical dimension achieved following decompression of the jugular bulb compared with Cömert et al.¹⁷ Furthermore, these measurements were made directly of the dissected anatomy compared with the use of FPCT images. Accurate comparisons

of angles of freedom were challenging due to the lack of a standard medial landmark. The medial aspect of the surgical corridor served as the apex of the measurement for the angle of freedom in dissected specimens. This was estimated based on the intersection between the lines defining the anterior and posterior and superior and inferior borders of the access window in the axial and coronal planes, respectively.

Conclusion

The transmastoid infralabyrinthine surgical corridor to the petrous apex and petroclival junction offers an effective approach with low morbidity for drainage, biopsy, and resection of pathology in this region. Decompression of the jugular bulb enhances the infralabyrinthine aperture as well as the angles of freedom with which instrumentation can be used safely to access these lesions. Limited mobilization of the facial nerve can further increase surgical access. FPCT imaging can be used to assess the utility and feasibility of the infralabyrinthine approach to access petroclival lesions using anatomical landmarks as described in this report. Endoscopic guidance supplemented by navigation and other technologies render this a promising approach for deeper skull base and intracranial access.

References

- 1 Isaacson B, Kutz JW, Roland PS. Lesions of the petrous apex: diagnosis and management. *Otolaryngol Clin North Am* 2007; 40(3):479–519, viii
- 2 Boardman JF, Rothfus WE, Dulai HS. Lesions and pseudolesions of the cavernous sinus and petrous apex. *Otolaryngol Clin North Am* 2008;41(1):195–213, vii
- 3 Giddings NA, Brackmann DE, Kwartler JA. Transcanal infracochlear approach to the petrous apex. *Otolaryngol Head Neck Surg* 1991; 104(1):29–36
- 4 Samii A, Gerganov V, Herold C, Gharabaghi A, Hayashi N, Samii M. Surgical treatment of skull base chondrosarcomas. *Neurosurg Rev* 2009;32(1):67–75; discussion 75
- 5 Sekhar LN, Schessel DA, Bucur SD, Raso JL, Wright DC. Partial labyrinthectomy petrous apicectomy approach to neoplastic and vascular lesions of the petroclival area. *Neurosurgery* 1999;44(3): 537–550; discussion 550–552
- 6 Tzortzidis F, Elahi F, Wright D, Natarajan SK, Sekhar LN. Patient outcome at long-term follow-up after aggressive microsurgical resection of cranial base chordomas. *Neurosurgery* 2006;59(2): 230–237; discussion 230–237
- 7 Crockard HA, Cheeseman A, Steel T, et al. A multidisciplinary team approach to skull base chondrosarcomas. *J Neurosurg* 2001;95(2): 184–189
- 8 Bloch OG, Jian BJ, Yang I, et al. Cranial chondrosarcoma and recurrence. *Skull Base* 2010;20(3):149–156
- 9 Moussazadeh N, Kulwin C, Anand VK, et al. Endoscopic endonasal resection of skull base chondrosarcomas: technique and early results. *J Neurosurg* 2015;122(4):735–742
- 10 Mason E, Van Rompaey J, Carrau R, Panizza B, Solares CA. Anatomical and computed tomographic analysis of the transcochlear and endoscopic transclival approaches to the petroclival region. *Laryngoscope* 2014;124(3):628–636
- 11 Caversaccio M, Panosetti E, Ziglinas P, Lukes A, Häusler R. Cholesterol granuloma of the petrous apex: benefit of computer-aided surgery. *Eur Arch Otorhinolaryngol* 2009;266(1):47–50

- 12 Lee A, Hamidi S, Djalilian H. Anatomy of the transarcuate approach to the petrous apex. *Otolaryngol Head Neck Surg* 2009;140(6):880–883
- 13 Dearmin R. A logical surgical approach to the tip cells of the petrous pyramid. *Arch Otolaryngol* 1937;25:314–320
- 14 Haberkamp TJ. Surgical anatomy of the transtemporal approaches to the petrous apex. *Am J Otol* 1997;18(4):501–506
- 15 Jacob CE, Rupa V. Infralabyrinthine approach to the petrous apex. *Clin Anat* 2005;18(6):423–427
- 16 Iseli TA, Yahng J, Leung R, Briggs RJ, King JA, Phal PM. Anatomic comparison of nasal versus lateral surgical access to the petrous apex. *Clin Anat* 2013;26(6):682–687
- 17 Cömert E, Cömert A, Cay N, Tunçel U, Tekdemir I. Surgical anatomy of the infralabyrinthine approach. *Otolaryngol Head Neck Surg* 2014;151(2):301–307
- 18 Goldofsky E, Hoffman RA, Holliday RA, Cohen NL. Cholesterol cysts of the temporal bone: diagnosis and treatment. *Ann Otol Rhinol Laryngol* 1991;100(3):181–187
- 19 Mosnier I, Cyna-Gorse F, Grayeli AB, et al. Management of cholesterol granulomas of the petrous apex based on clinical and radiologic evaluation. *Otol Neurotol* 2002;23(4):522–528
- 20 Brackmann DE. The facial nerve in the infratemporal approach. *Otolaryngol Head Neck Surg* 1987;97(1):15–17
- 21 Couloigner V, Grayeli AB, Bouccara D, Julien N, Sterkers O. Surgical treatment of the high jugular bulb in patients with Ménière's disease and pulsatile tinnitus. *Eur Arch Otorhinolaryngol* 1999;256(5):224–229
- 22 Balachandran R, Tsai BS, Ramachandra T, et al. Minimally invasive image-guided access for drainage of petrous apex lesions: a case report. *Otol Neurotol* 2014;35(4):649–655