CE: D.C.; ON-17-161; Total nos of Pages: 11;

ON-17-161

Otology & Neurotology
xx:xx–xx © 2017, Otology & Neurotology, Inc.

Petrous Apex Cholesterol Granulomas: Outcomes, Complications, and Hearing Results From Surgical and Wait-and-Scan Management

AQ1 *Golda Grinblat, *Ashish Vashishth, †Francesco Galetti, *Antonio Caruso, and *Mario Sanna

AQ2 *Department of Otology and Skull Base Surgery, Gruppo Otologico, Piacenza, Rome; and †Faculty of Medicine and Surgery – Azienda Ospedaliera Di-Messina, Messina, Italy*

Objective: 1. To analyze the surgical outcomes in the management of petrous apex cholesterol granulomas (PACG) with a brief literature review.
2. To evaluate the importance of wait-and-scan management option.
Study Design: Retrospective review.
Setting: Quaternary referral center for otology and skull base surgery.
Subjects and Methods: Charts of 55 patients with at least 12 months of follow-up were analyzed for demographic, clinical, audiometric, and radiological features. Patients were divided into surgical group (SG) (n = 31) and wait-and-scan (n = 24) (WS) group. Surgical approach was chosen as per hearing status and PACG extension and relation to nearby neurovascular structures and included either drainage by transmastoid-infralabyrinthine approach (TM-IL)/transcanal-infracochlear approach (TC-IC) or resection by infratemporal fossa type B approach (ITF-B). The combination of ITF-B with trans-otic (TO) approach or TO approach solely was used in unserviceable hearing cases. Postoperative outcomes and complications were evaluated in SG.
Results: Postoperative symptom relief was observed in 24 patients (77.4%). Diplopia and paresthesia recovered in each case and improvement in headache, dizziness, tinnitus, and hearing loss was observed in 87.1% cases. Serviceable hearing was preserved in 24 of 26 cases. Postoperative complication rate was 32.2% including incidences of profound hearing loss, facial nerve paresis, carotid artery injury and intraoperative CSF leaks. Revision surgery was required in 3 (9.6%) cases, after TM-IL approach.
Conclusion: Surgical drainage is preferable to more aggressive resection procedures, with the latter reserved for recurrent lesions or lesions with severe hearing loss/involvement of critical neurovascular structures. ITF-B approach provides adequate cyst and neurovascular control for resection, while avoiding brain retraction. An initial wait-and-scan approach can be used in most patients where symptoms and imaging justify so. **Key Words:** Cholesterol granuloma—Infracochlear—Infralabyrinthine—Infratemporal fossa approach—Petrous apex—Transotic.

Otol Neurotol 38:xxx–xxx, 2017.

Petrous apex cholesterol granuloma (PACG) is one of the most common lesions of the petrous apex, characterized by benign, slow growing, and cystic nature (1–6). Although an uncommon lesion in general, PACG was found to be much more common than petrous bone cholesteatoma, a much more aggressive pathology, in a previous study (7).

Being a pseudocyst rather than a true cyst (8,9), PACG is filled with brownish thick fluid, composed of blood degradation products in the form of hemosiderin and cholesterol, where the latter incites foreign-body granulomatous reaction. This ongoing chronic inflammation is fueled by incoming blood supply, the source of which has been described in the literature as the exposed bone marrow at the petroclival junction (10). Regardless of the pathophysiologic mechanism (10,11), surgical treatment is dictated by growing/symptomatic lesions and is broadly divided into drainage and resection procedures (1–5,8,12–17). Otherwise, an initial wait-and-scan policy has been advocated (1–3,6,17) as another form of management.

In the present study, an attempt to provide surgical selection criteria, as per preoperative symptomatology, hearing, and imaging status was made, with a reflection on surgical outcomes/complications and comparison with the literature, as well as discussion of the wait-and-scan policy.

METHODS

Of the 4621 lateral skull base surgeries performed from February 1991 to December 2015, medical records of 56

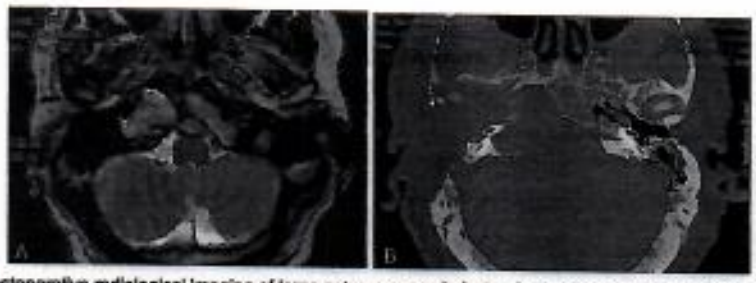
AQ3 Address correspondence and reprint requests to Ashish Vashishth, M.S., D.N.B., Department of Otology and Skull Base Surgery, Gruppo Otologico, Piacenza, Rome, Italy;
E-mail: drashishvashishth@gmail.com, golda87@hotmail.com

The current research article was funded by grant from The Mario Sanna Research Foundation.

AQ4 The authors disclose no conflicts of interest.
DOI: 10.1097/MAO.0000000000001578

CE: D.C.; ON-17-161; Total nos of Pages: 11;

ON-17-161



AQ7 AQ8 **FIG. 1.** Pre- and postoperative radiological imaging of large petrous apex cholesterol granuloma involving petrous carotid artery treated using infratemporal fossa type B approach.

patients diagnosed with PACG at our referral center were reviewed. One patient with simultaneous endolymphatic sac tumor and PACG was excluded from the study cohort to avoid confounding bias. Patients included in the study had at least 12 months of follow-up.

This yielded a study population of 55 patients. Charts were analyzed for demographic, clinical, audiometric, and radiological features in all the cases. Surgical approaches with outcomes and complications/revision surgery were evaluated in the surgery group (SG).

Hearing results were evaluated as per the modified Sanna Classification of hearing for the evaluation of the results of treatment (18,19). Audiometric studies included four-frequency (500, 1000, 2000, and 4000 Hz) pure-tone average (PTA) for bone-conduction (BC), air-conduction (AC), and speech discrimination scores (SDS).

FN (facial nerve) function was graded pre- and postoperatively according to the House–Brackmann (HB) grading system.

A high-resolution computed tomography (HRCT) scan of the temporal bone and magnetic resonance imaging (MRI) with and without gadolinium were obtained and compared with postoperative imaging during follow-up. In cases where preoperative imaging was suggestive for carotid canal involvement\erosion, angiography was performed. Carotid canal involvement\erosion was defined as canal encircling of at least 180 degrees by PACG, internal carotid artery (ICA) stenosis, or antero-lateral displacement (Fig. 1). Change in size of PACG was defined by increase or decrease by 2 mm in any axial dimension. The surgical approach was chosen as per preoperative hearing status and PACG location (anterior or posterior petrous apex), extension and relation to nearby neurovascular structures. Our treatment philosophy has changed over the previous years (with more patients managed on observation and serial scanning) and the decision to operate was taken after consideration of patient symptoms, their temporal progression, and imaging characteristics. Patients with small-sized lesions with stable symptoms in the absence of neurovascular involvement were offered symptomatic treatment with follow-up and imaging. Surgical treatment was advocated for patients with symptom progression, increasing size, and involvement of critical neurovascular structures such as labyrinth, petrous carotid, and posterior or middle fossa dura. The surgical procedures included drainage by transmastoid-infralabyrinthine (TM-IL) or transcanal-infracochlear approach (TC-IC) and resection procedures. Drainage procedures were consistent in their application and were based on relative position of jugular bulb with the infralabyrinthine cell tract. TC-IC approach was chosen for small cysts in primary drainage procedures on confirming the presence of infracochlear cell tract. In most other instances, a TM-IL approach was opted for wider access and drainage tube placement. Silicone stent was used for patients undergoing drainage procedure. In instances of high jugular bulb, surgical lowering was performed (TM-IL only) after confirmation of patency of the opposite venous drainage. In the resection category, the hearing preservation procedure constituted the infratemporal fossa type B (ITF-B) approach (Fig. 2). The combination of ITF with TO or solely TO approach was chosen in patients with unserviceable hearing. Serviceable hearing was defined as per modified Sanna classification (18) with PTA thresholds <30 dB and SDS >70%. Larger lesions with involvement of either carotid canal, posterior cranial fossa (PCF) and\or middle cranial fossa (MCF) dura or otic capsule- internal auditory canal (IAC) were treated by resection procedures, while in smaller lesions without wide involvement of nearby structures, drainage procedures were used. The above-mentioned procedures have been described in detail elsewhere (19–23). In all the cases, FN function was monitored intraoperatively.

Outcome measures included postoperative symptom relief, intraoperative and postoperative complications, hearing and FN status function postoperatively, and revision surgeries, if any.

A review of the literature was done using a PubMed Search using relevant search words.

This study was approved by the Institutional Review Board of the hospital for ethical research.

FIG. 2. Intraoperative image demonstrating control of petrous carotid during infratemporal fossa type B approach.

CE: D.C.; ON-17-161; Total nos of Pages: 11;

ON-17-161

TABLE 1. *Patient characteristics at presentation*

Surgery Group (SG) and Wait-and-Scan (WS) Group		
	SG (n=31)	WS Group (n=24)
Age (years-mean, range)	41.1 (15–75)	34.6 (14–61)
Sex		
Male n (%)	20 (62.5)	11 (45.8)
Female n (%)	11 (37.5)	13 (54.2)
Side		
Right n (%)	17 (54.8)	8 (33.3)
Left n (%)	14 (45.2)	16 (66.7)
Symptomatology n (%)[b]		
Paresthesia	7 (22.6)	5 (20.8)
Diplopia	12 (38.7)	1 (4.2)
Tinnitus	17 (54.8)	4 (16.6)
Hearing loss	19 (61.3)	4 (16.6)
Vertigo\dizziness	22 (70.9)	11 (45.8)
Headache	21 (67.7)	20 (83.3)
Without symptoms[a]	0 (0)	2 (8.3)
Symptom duration (mo, range)	17.7 (2–204)	9.0 (4–36)
Previously operated elsewhere	2 (6.3%)	0 (0)
Follow-up duration (mo, range)	51.5 (12–180)	49.1 (16–252)

[a]Two cases of incidental finding.
[b]28 (90.3) in SG and 15 (62.5) in WS group had multiple symptoms.

RESULTS

Patient characteristics and demographics are shown in Table 1.

Imaging Analysis

Overall mean diameter of PACG on imaging in SG and WS (wait-and-scan) group, resection and drainage groups and the involvement of neurovascular structures is demonstrated in Table 2.

A stable\smaller diameter was measured in all cases after drainage procedures and in 23 of 24 (95.8%) cases in WS group. Reduction of diameter was observed in WS group as late as post 20 years of follow-up with accompanying symptom relief.

All the patients with aerated PA reported symptom relief (see Table 2).

Hearing Analysis

Table 3 shows the overall mean pre- and postoperative PTA-AC, PTA-BC, ABG, and SDS in SG in 26 of 31 patients, as 5 (16.1%) patients had severe or profound deafness preoperatively. Figure 3 displays the pre- and postoperative scatter grams of pure-tone thresholds and speech discrimination scores.

Two patients after TM-IL approach developed profound hearing loss. In the remaining 21 patients after the TM-IL approach, hearing improved postoperatively in all the parameters.

All profoundly deaf patients underwent resection procedures because of extensive disease and large cyst diameters (Table 4).

At the time of diagnosis in the WS group, four patients complained of hearing loss. The mean initial PTA-AC, PTA-BC, ABG, and SDS in this subset of patients were 35.6 ± 5.8 dB, 19.7 ± 2.8 dB, 15.9 ± 8.5 dB, and $95.5 \pm 2.1\%$, respectively. On the last follow-up, their hearing improved in all the above-mentioned parameters by 11.3 dB, 2.9 dB, 8.4 dB, and 3.5%, respectively.

Symptom Relief Outcomes Are Provided in Table 5

All the patients in resection group had total symptom relief whereas symptom relief rate varied in drainage and wait-and-scan group.

In WS group, hearing loss, tinnitus, and dizziness had a higher tendency for a spontaneous recovery. Refusal for surgery led to persistence of diplopia in one patient, though the lesion remained stable through a 42-month follow-up. There were no signs of preoperative facial nerve (FN) involvement in our series (see Table 6).

TABLE 2. *CT/MRI characteristics of patients*

Initial Findings				
	PACG Diameter[a] (mm)	ICA[b] n (%)	PCFD\MCFD[c] Compression n (%)	IAC[d]\Otic Capsule Involvement n (%)
Surgical group (removal\drainage) (n=31)	40.4\22.7	16 (51.6)	13 (41.9)	20 (64.5)
Wait-and-scan group (n=24)	16.1	1 (4.2)	5 (20.8)	2 (8.3)
Findings at the Last Follow-up				
		Stable\Smaller[e] n (%)	Increased n (%)	Aeration n (%)
Surgical group (removal\drainage) (n=31)		18 (58.1)\13 (41.9)	0 (0)	14 (60.8)[f]
Wait-and-scan group (n=24)		14 (58.3)\9 (37.5)	1 (4.2)	2 (8.3)

[a]The largest mean diameter in any axial dimension.
[b]Internal carotid artery involvement, at least 180 degrees engulfed by PACG\positioned antero-laterally\ stenotic.
[c]Posterior\middle cranial fossa dura.
[d]Internal auditory canal\otic capsule were referred as inner ear in the text.
[e]Smaller finding is defined when diameter is decreased by at least 2 mm in any axial dimension in follow-up imaging.
[f]Observed for drainage group only.

TABLE 3. *Hearing results*

Overall Hearing Status in SG	Preoperative	Postoperative
Severe\profound SNHL n (%)	5 (16.1)	7 (22.5)
PTA AC (mean, Std)	33.6 dB (±14.3)	30.8 dB (±13.3)
PTA BC (mean, Std)	20.75 dB (±9.9)	18.5 dB (±7.9)
ABG (mean, Std)	12.8 dB (±8.8)	12.3 dB (±10.0)
SDS (mean, Std)	94.5% (±9.2)	96.9% (±4.09)

	Resection (n = 8)		Drainage (n = 23)		
Hearing Status According Surgery Subgroup	Preoperative	Postoperative	Preoperative	Postoperative	Delta[d]
Severe\profound SNHL n (%)[a]	5 (62.5%)	5 (62.5%)	0 (0%)	2 (8.6%)[b]	
PTA AC (mean, Std)	28.4 dB (±6.6)	54.2 dB (±11.2)	34.3 dB (±14.8)	27.5dB[c] (±9.7)	6.8 dB
PTA BC (mean, Std)	18.8 dB (±5.3)	20.4 dB (±4.6)	21.0 dB (±10.3)	18.2 dB (±8.3)	2.8 dB
ABG (mean, Std)	9.6 dB (±3.7)	33.7 dB (±12.7)	13.2 dB (±9.2)	9.3 dB (±4.3)	3.9 dB
SDS (mean, Std)	94.6% (±7.5)	90% (±0)	94.5% (±9.4)	97.9% (±3.4)	3.4%

[a]Severe\profound SNHL: sensorineural hearing loss.
[b]Two patients with normal preoperative hearing had profound SNHL after TM-IL approach.
[c]In 21 patients.
[d]Difference between preop. and postop. drainage surgeries.

Complications and Revision Surgery

Table 4 describes the surgical approaches and postoperative characteristics. Duration of surgery for the resection and drainage procedures was 4.6 (3.9–7) and 2.7 (1.5–3.3) hours, respectively. Postoperative hospital stay for the resection and drainage group was 5.6 (4–7) and 3.4 (2–4) days, respectively.

Gross total resection was accomplished in six of eight (75%) resection procedures. The orbito-zygomatic extension was used in the ITF type B approach in one case where preoperative imaging demonstrated broad involvement of horizontal segment of petrous carotid and most of clivus.

In one patient during resection (ITFB + TO approach), the ICA wall underwent injury at the area of the anterior foramen lacerum. Immediate packing with a muscle and definite endovascular treatment was done after 2 days, the details of which can be found in our previous publication. No permanent neurologic sequelae were observed postoperatively (9). In another patient, presence of calcified adherent capsule on the clivus and dura mandated near total capsular removal to avoid morbidities. No recurrence of lesion or preoperative symptoms was observed in either of the patients on last follow-up.

An intraoperative CSF leak occurred in three patients who underwent the TM-IL approach for the drainage and was subsequently managed in the same sitting. No postoperative CSF leak was observed in any patients.

Two patients undergoing TM-IL approach drainage had profound hearing loss postoperatively. The patient with immediate hearing loss underwent revision surgery and is discussed later. In the other case, the postoperative hearing loss was delayed after 2 months of an uneventful surgery. A detailed CT examination with a senior neuroradiologist could not demonstrate any inner ear trauma. Both were symptom-free at last follow-up after 60 and 96 months, respectively.

Four of 31 (12.9%) patients undergoing surgery developed postoperative facial nerve paresis. Three out of four patients had grade V/VI facial palsy post ITF-B procedure, which recovered to gr I/II within 1 year. One patient after TM-IL approach developed a grade II facial paresis that recovered to grade I within 1 year. None of the patients had any structural damage to facial nerve intraoperatively, demonstrated by the eventual good recoveries, and from postoperative imaging. The details of the following patients have been elaborated previously and

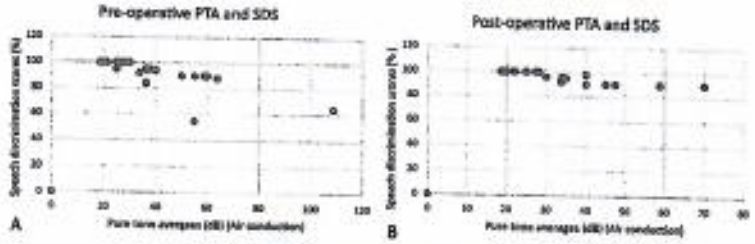


FIG. 3. Pre- and postoperative scatter grams demonstrating pure-tone average thresholds and speech discrimination scores.

CE: D.C.; ON-17-161; Total nos of Pages: 11;

ON-17-161

TABLE 4. *Surgical and postoperative characteristics*

Surgical approach n (%)	
Resection	
ITF-B	3 (9.7)
ITF-B with OZ	1 (3.2)
TO	1 (3.2)
ITF-B+TO	3 (9.7)
Total	8 (25.8)
TR	6\8 (75%)
Drainage	
IL	20 (64.5)
TC-IC	3 (9.7)
Total	23 (74.2)
Intraoperative complications n (%)	
Resection	ICA laceration 1 (3.2)
Drainage	CSF leak 3 (9.7)
Total	4 (12.9)
Postoperative complications n (%)	
Facial nerve paralysis	4 (12.9)
Profound SNHL	2 (6.4)

ICA indicates internal carotid artery; IL, infralabyrinthine approach; ITF-B, infratemporal fossa approach type B; OZ, orbitozygomatic extension; SNHL, sensorineural hearing loss; TC-IC, transcanal-infracochlear approach. In all but three cases with CSF-leak silicone stent was introduced; TO, transotic approach; TR, total resection.

no facial nerve palsy was observed postoperatively since 2007 (9).

Revision Surgery Was Required in Three Patients

Case 1: A large cyst occupied the infralabyrinthine region reaching the occipital condyle with capsule adherent to the PCF dura. TM-IL approach was initially used for cyst decompression followed by uneventful postoperative recovery and total symptom resolution. A delayed follow-up due to reappearance of diplopia mandated revision surgery using the same approach. The previous drainage tube was found blocked by connective tissue and was liberated after decompressing the cyst cavity with insertion of another tube.

Case 2: A CSF leak from cochlear aqueduct injury during primary TM-IL approach was managed intraoperatively using obliteration. Endoscopic trans-sphenoid decompression was done 3 months later to avoid CSF leak from cochlear aqueduct and the patient remained symptom free on the last follow-up (20 months).

Case 3: Primary TM-IL approach was complicated with a small CSF leak from the inferior wall of the IAC and was immediately managed by fat and muscle obliteration, although the patient exhibited profound hearing loss immediately postoperatively. ITF-B with TO approach was used 3 months later with gross total removal.

DISCUSSION

PACGs can produce clinical symptoms by compression of the fifth through eight cranial nerves and nearby neurovascular structures (1–2). Accordingly, management is determined by disease extension and hearing status. Surgical approaches described in the literature are broadly divided into drainage and resection procedures (1–5,8,12–17). When dealing with large lesions with broad involvement of surrounding structures, surgical policy must be governed by the choice of the most direct approach while avoiding retraction of brain tissue or critical neurovascular structures at the cranial base. ITF-B with or without translabyrinthine or TO approaches provide a wide exposure and excellent control of neurovascular structures, but at the expense of hearing, ear canal closure and mastication issues.

However, in lieu of the slow growing, benign and cystic nature of these lesions (1–6), decompression and drainage tube placement seems to be an excellent treatment option in majority of cases, obviating hearing loss or other adverse effects of the more radical approaches. Furthermore, in cases of asymptomatic or minimally symptomatic patients (mild headache/ non-specific occasional dizziness) with stable lesions, an initial wait-and-scan policy has been advocated previously (1–3,6,17), and has been found to be true in our subset of patients as well (Table 2).

Symptom Relief

Postoperative symptom relief reported in the literature ranges between 45.5% and 100% (77.4% in the present series) (Tables 5 and 6). This is comparable with the results (82.4% symptom relief) by Brackmann et al. (8),

TABLE 5. *Symptom relief characteristics*

Symptom Relief	WS Group	Surgery Group	
		Resection	Drainage
Headache	9\20 (45%)	8\8 (100%)	12\13 (92.3%)
Dizziness	10\11 (90.9%)	5\5 (100%)	15\17 (88.2%)
Paresthesia	2\5 (40%)	3\3 (100%)	4\4 (100%)
Hearing improvement	3\4 (75%)	a	11\13 (84.6%)
Tinnitus	4\4 (100%)	5\5 (100%)	10\12 (83.3%)
Diplopia	0\1 (0%)	5\5 (100%)	7\7 (100%)

[a]Two patients did not complain of HL. Five patients had severe/profound SNHL preoperatively. Preoperative mixed HL remained the same postoperatively after ITF-B approach in one case.

TABLE 6. *Open surgical approaches for petrous apex cholesterol granuloma—the review of literature*

		Surgery							Radiologic Follow-up			
Author, Year	No. of Patients	Procedures Drainage n (%)	Procedures Removal n (%)	Symptom Relief n (%)	Hearing Status Preop (PTA)	Hearing Status Postop (PTA)	Complications Intraoperative and Postoperative	(%)	Symptom Recurrence Revision Surgery n (%)	Reduced/Stable n (%)	Increased n (%)	Aeration n (%)	Follow-up (mo)
Thedinger (1) et al., 1989	10	1 SOC, 2 TC-IC, 3 IL, 4 TS 10 (100)	0 (0)	8 (80)	NA	NA	1 Diplopia, 2 FN palsy, 2 Sinus otitis media	50	6 (60) 5 (50)	9 (90)	1 (10)	NA	47
Fong et al. (12), 1995	26	9 IL, 7 TC-IC, 5 MCF, 4 TLA. 25 (100)	0 (0)	13 (81) (n = 16)	17.3dB	33.2 dB	1 meningitis, 1 CSF leak, 1 TM perforation,1 otitis abscess	16	3 (12) 3 (12)	18 (100) (n = 18)	NA	5 (27) (n = 18)	55.2
Brodsky et al. (13), 1996	11	8 IL, 2 TC-IC, 1 TLA 11 (100)	0 (0)	5 (45.5)	13.7dB (n = 9) TD (n = 2)	34dB (n = 7) TD (n = 3) (HFS = 10)	1 meningitis, 2 CSF leak, 2 profound SNHL (1 cochlea injury, 1 labyrinth injury) 4 hearing deterioration	81.8	0 (0) 0 (0)	7 (100) (n = 7)	NA	NA	29.5
Eisenberg et al. (2), 1997	10	0 (0)	2 Petrosal, 8 MCF 10 (100) (10 TR)	10 (100)	NA	NA	1 seizures 2 years postop., 1 CSF leak, 1 CN3 weakness	30	0 (0) 0 (0)	4 (100) (n = 4)	NA	NA	66.1
Cristante et al (14), 2000	8	0 (0)	8 MCF 8 (100) (5 TR, 3 NTR)	8 (100)	27.2dB (n = 5) TD (n = 3)	27.2dB (n = 5) TD (n = 3)	1 FN palsy, 1 subgalial hematoma	25	0 (0) 0 (0)	18 (100)	0 (0)	18 (100)	61.1
Bonderman et al. (8), 2002	34	18 TC-IC, 7 IL, 7 MCF, 1 TLA, 1 TO		28 (82.4)	34dB (n = 31) TD (n = 3)	35.2dB (n = 34)	1 FN palsy, 1 profound SNHL, 1 TM perforation, 2 wound infection	14.7	5 (14.7) 5 (14.7)	20 (95.3) (n = 21)	1 (4.7) (n = 21)	5 (23.8) (n = 21)	62.9
Mosnier et al.(3), 2002	8	5 IL, 2 TC-IC, 1 TO 8 (100)	0 (0)	8 (100)	NA	NA	2 FN palsy	25	0 (0) 0 (0)	8 (100)	0 (0)	2 (29)	36
Castillo et al. (15), 2008	17	10 MCF, 3 IL, 2 TC-IC, 1 TLA, 1 T-CO, 1 TS		9 (52.9)	27dB (n = 12)	23dB (n = 9)	2 profound SNHL	12	7 (41.2) 4 (23.5)	NA (n = 13)	NA (n = 13)	0 (0) (n = 13)	56.7
Ilea et al. (6), 2012	17	13 TC-IC, 3 IL,1 MCF 17 (100)	0 (0)	10 (58.8)	34dB (n = 12)	48dB (n = 12)	NA	NA	7 (41.2) 7 (41.2)	15 (100) (n = 15)	0 (0)	4 (23.5)	90.7

TABLE 6 (Continued)

Author, Year	No. of Patients	Surgery: Procedures Drainage n (%)	Surgery: Procedures Removal n (%)	Symptom Relief n (%)	Hearing Status Preop (PTA)	Hearing Status Postop (PTA)	Complications Intraoperative and Postoperative	(%)	Symptom Recurrence Revision Surgery n (%)	Radiologic Follow-up: Reduced/-Stable n (%)	Radiologic Follow-up: Increased n (%)	Radiologic Follow-up: Aeration n (%)	Follow-up (mo)
Kawase et al. (5), 2012	17	1 IL 1 (5.9)	16 MCF 16 (94.1) (15 TR, 1 STR)	15 (93.7) (n = 16)	NA	NA	1 death (occlusion of ICA), 1 epidural infection	11.8	1 (5.9) 1 (5.9)	14 (87.5) (n = 16)	2 (12.5) (n = 16)	NA	48
Rihani et al. (16), 2014	8	5 TC-IC, 2 IL, 1 TC-IC + IL 8 (100)	0 (0)	4 (50)[a]	28.5dB	22.2dB (n = 6) TD (n = 2)	1 CSF leak, 1 wound cellulitis, 2 profound SNHL	50	0 (0) 0 (0)	NA	NA	NA	NA
Stevens et al. (17), 2017	14	6 TC-IC, 7 IL,1 MCF+IL 14 (100)	0 (0)	(48%)	32.6dB (n = 10)	36.8dB (n = 10)	1 local wound infection, 2 TM perforation, 1 temporary headache	28.6	3 (21.4) 3 (21.4)	NA	NA	NA	49.2
Current Study	31	3 TC-IC, 20 IL 23 (74.2)	4 ITPA-B, 1 TO, 3 ITPA-B+TO 8 (25.8) (6 TR)	24 (77.4)	30.75dB (n = 26) TD (n = 5)	18.5dB (n = 24) TD (n = 7)	4 FN palsy, 2 profound SNHL, 1 ICA laceration, 3 CSF leak	32.2	2 (6.4) 3 (9.6)	31 (100) (n = 31)	0 (0) (n = 31)	14 (60.8) (n = 23)[e]	51.5

[a]Unclear (authors advocate drainage).
[b]Unclear.
[c]In terms of hearing improvement only.
[d]No number-of-patients available.
[e]Aeration is observed for the drainage group only.
CN5 indicates cranial nerve V; CSF, cerebrospinal fluid; FN, facial nerve; HPS, hearing preservation surgery; ICA, internal carotid artery; IL, infra-labyrinthine; ITP-B, infratemporal fossa type B approach; MCF, middle cranial fossa approach; NA, non-availability; NTR, near-total resection; PTA, pure tone average; SNHL, sensorineural hearing loss; SOC, sub occipital; STR, sub-total resection; TC-IC, transcanal-infracochlear; T-CO, transcochlear approach; TD, total deafness; TLA, translabyrinthine approach, Petrosal: petrosal approach; TM, tympanic membrane; TO, transotic approach; TR, total resection; TS, trans-sphenoid approach.

employing mainly drainage procedures. In another study, Kusumi et al. (5) mentioned a relief rate of 93.7%, employing mostly MCF approach with vascularized galeal flap as a resection procedure. However, no surgical selection criteria or preoperative involvement of petrous carotid artery or hearing status were described with employment of MCF approach in most cases. Craniotomy, temporal lobe retraction, prolonged intensive care unit stay, possible intracranial complications and seizures requiring lengthy anti-epileptic treatment are known morbidities of MCF approach. Furthermore, no preoperative mean duration of symptoms was mentioned in this series, as symptom duration is inversely proportional to the symptom relief. In the present study, the mean symptom duration was 17.7 months.

Space occupying lesions expanding at the borders of petrous apex have the propensity to create pressure on the middle or posterior fossa dura (3,6), causing pain sensation. Headache was resolved in all but one patient in our series with total recovery of facial paresthesia and diplopia. Similar results have been reported in most other series (2,3,5,8,12,14,15). This may be attributed to the better neural recovery of the trigeminal ganglion and abducens nerve following surgical decompression as compared to other cranial nerves. Also, this is suggestive of the lasting relief of dural pressure by cyst decompression using drainage procedures. Somewhat less success was seen with complaints of dizziness, tinnitus and hearing loss (Table 5), also recently observed by Stevens et al. (17) where none of the patients in their series had any relief from these postsurgical drainage, perhaps reflecting more fragile inner ear apparatus and cochleo-vestibular nerve, as well as higher rate of inner ear/IAC involvement seen in present series. (Table 2). The same study suggested no statistical differences between stent/drainage tube placement with regards to symptom resolution but all recurrences in the above study occurred in cases where no stent was placed. In the present study, stent was placed in all cases of drainage procedures. We feel the association of stent placement with long term results is controversial, although stents may improve early postoperative symptom relief and possible reduction in inflammation due to increased drainage, but eventual obstruction by connective tissue.

Hearing Results

Postoperatively, the mean PTA across the literature varied between 20.2 dB and 48 dB, and SDS varied between 85.5% and 100%, with reported data missing in certain series (1–5,12,17) (Table 6). Brackmann et al. (8) reported PTA of 26.2 dB with SDS of 93% for 24 out of 34 cases postoperatively. Similarly, Hoa et al. (4) reported PTA of 48 dB in 12 out of 17 cases postoperatively. Similar results were observed in present series with the mean PTA-BC and PTA-AC of 18.5 dB and 30.8 dB respectively. SDS of 96.9% was observed in 24 patients with serviceable hearing. The comparable hearing results in the present study can be attributed to a higher percentage of the much wider infra-labyrinthine approach used as compared to the narrower infracochlear approach used in previous series that leads to presumably lesser decompression, particularly when draining multiloculated cysts with thicker contents.

Complications

Complication rate in open techniques for PACG treatment varied tremendously among the series, between 11.8 and 81.8% (Table 6).

Facial Nerve

The incidence of FN palsy after PACG surgery was observed between 2.9 and 25% of cases. Though the incidence is 12.9% (4/31 patients) in the current study, all patients recovered to near normal facial nerve function within 1 year postoperatively. The TM-IL approach is bound by mastoid segment of facial nerve anteriorly and could be affected by thermal damage by the drill or minimal exposure, both of which can lead to minimal postoperative facial paresis with complete eventual recovery. Though no definite association of the ITF-B approach exists with postoperative facial nerve palsy, extensive drilling with thermal damage, transection of middle meningeal artery compromising the vascular supply to geniculate ganglion, and stretch trauma to the geniculate ganglion and greater petrosal nerve could all possibly contribute to the same. All the three cases preoperatively had gross involvement of horizontal petrous carotid artery needing more than usual middle fossa retraction. Although no cases of facial nerve palsy have been observed since 2007, no specific measures taken could be retrospectively ascertained, apart from observing extra caution around the region of facial nerve.

Hearing Loss

Profound hearing loss reported after hearing preservation surgery for treating PACG varies between 2.9 and 25% of cases (Table 6). The reason for profound unexplained postoperative deafness has not been explained in few series (8,15,16).

Comert et al. (24), in their anatomical study on the TM-IL approach, described the region bound by the inferior border of the cochlea, the posterior wall of vertical carotid, and the cochlear opening of the cochlear aqueduct (CA) as the region most prone to surgical complications. As the inferior cochlear vein (ICV) runs intimately parallel to CA, their integrity seems to be at risk in infra-labyrithine or infra-cochlear approach (24). Since the ICV drains blood from the modiolus, interference with outflow can potentially lead to spiral ganglion neuronal degeneration and delayed hearing loss (25). Injury to either CA or ICV before opening of PACG capsule can potentially lead to inflammatory response in the inner ear due to contamination with cyst contents, consequently resulting in hearing loss (27).

Other Complications

The presence of CSF leak was observed between 4 and 18% in the literature with incidents of meningitis (13)

CE: D.C.; ON-17-161; Total nos of Pages: 11;

ON-17-161

and re-exploration (2). In the present series, no postoperative CSF leak was observed in any case despite three cases having an intraoperative CSF leak which was successfully managed during surgery.

The universal finding in revision surgery after drainage procedures is blockage of draining tube by granulation tissue (1,3,4,8,12). Hence, in the event of an initial hearing preservation surgery, repetition of the procedure with tube replacement can be undertaken, as described in one of our revision cases. In cases where hearing preservation is of no concern, radical surgery in the form of TO approach, in case of more posteriorly situated lesion, or ITF-B with TO approach, if PACG is positioned more anteriorly with broad ICA or clivus involvement, can be undertaken. Though ITF-B approach involves mandibular condyle displacement and retraction, none of our patients in the postoperative period had significant long-term mastication complaints. Furthermore, ITF-B approach provides control of both vertical and horizontal petrous ICA as far as anterior foramen lacerum without significant brain retraction.

The variability in incidence of revision surgery for PACG (0 to 50%) might be reflected by great variation of surgical techniques, with some used for both drainage and resection (Table 6). In few series (8,12,15), MCF drainage required redrainage via either TM-IL or TC-IC approach. We agree with others (1,12,27–29) that MCF approach does not provide permanent drainage/aeration and provides poor control of the vertical petrous ICA (30), with control of horizontal ICA only possible by sacrifice of mandibular nerve, Eustachian tube and greater superficial petrosal nerve, along with significant temporal lobe retraction. Kusumi et al. (5) despite gross-total resection using MCF approach reported two recurrences with one revision surgery for the same.

Though petrous apex pathologies, particularly PACGs, have been predominantly surgically managed using lateral or superior corridors, medial drainage through the transnasal endoscopic trans-sphenoidal approach has been successfully used for drainage by many authors (31,32). In cases of favorable anatomy of cyst bulging inside the sphenoid sinus wall with good pneumatization, the approach has led to comparable results. In other instances, the need for ICA lateralization and transpterygoid approach (32) seems incomparable given the relatively simple TM-IL route for drainage. The postoperative issues such as blockage of drainage seem the same on long-term with recent indications of nasoseptal flap repair for the same (33). The single case in the present series that was subsequently managed using trans-sphenoidal approach had, in our opinion, a favorable anatomy for the same, and wherever feasible, the same seems to be a valid option for drainage, particularly in the presence of a high jugular bulb.

Follow-up Imaging Results

Across the literature, though discrepancy was noted between changes in cyst diameter and rate of revision surgery (0–50%) (Table 6), high correspondence was observed between symptom recurrence (mean 25.9%) and revision surgery (mean 22.4%) rate (Table 6). Accordingly, we agree with Castillo et al. (15) that revision surgery should be governed primarily by symptomatology, with follow-up imaging having supplementary role, unless imaging provides evidence of major vessel erosion (Table 6).

Wait-and-Scan Policy—a Natural Course of PACG

Due to slow and indolent natural growth history of PACG, a wait-and-scan approach has been suggested by many authors (1–3,6,15,17) and was seen in the present series as well. The possible explanation could be spontaneous drainage or cessation of inflammatory process or vascular supply (10,34). Delayed growth, however, has been reported (35) and hence mandates a long-term follow-up. Surgical treatment in the form of an initial drainage procedure can be undertaken in the presence of significant increase in size of lesion in accordance with symptoms.

Limitations and Recommendations

Given the small number of cases in resection group, it was not possible to compare results between two surgical subgroups, as well as the comparison between surgery and wait-and-scan group due to different lesion parameters. Further prospective studies formulating protocols for treatments are desirable, though difficult due to the uncommon nature of these lesions. A multicenter trial is encouraged in view of these findings.

CONCLUSION

The present series represents one of the largest series on this subject to the best of our knowledge. For patients with PACG requiring surgery, drainage is preferable to more aggressive resection procedures. Resection can be undertaken in cases of recurrence after drainage and in the presence of hearing loss where wide approaches such as ITF-B, TLA, TO provide excellent control to these lesions. When deciding the need for surgery, careful correlation of patient symptoms to current pathology must be made and serious consideration given to the wait-and-scan policy in the absence of any significant radiological neurovascular involvement.

REFERENCES

1. Thedinger BA, Nadol JB Jr, Montgomery WW, Thedinger BS, Greenberg JJ. Radiographic diagnosis, surgical treatment, and long-term follow-up of cholesterol granulomas of the petrous apex. *Laryngoscope* 1989;99:896–907.
2. Eisenberg MB, Haddad G, Al-Mefty O. Petrous apex cholesterol granulomas: Evolution and management. *J Neurosurg* 1997;86:822–82.
3. 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;23:522–8.
4. Hon M, House JW, Linthicum FH. Petrous apex cholesterol granuloma: Maintenance of drainage pathway, the histopathology of surgical management and histopathologic evidence for the exposed marrow theory. *Otol Neurotol* 2012;33:1059–65.

5. Kusumi M, Fukushima T, Mehta AI, Cunningham CD 3rd, Friedman AK, Fujii K. Middle fossa approach for total resection of petrous apex cholesterol granulomas: Use of vascularized galeofascial flap preventing recurrence. *Neurosurgery* 2013;72 (ONS suppl 1):77–86.
6. Sweeney AD, Osetinsky LM, Carlson ML, et al. The natural history and management of petrous apex cholesterol granulomas. *Otol Neurotol* 2015;36:1714–9.
7. Arriaga MA, Brackmann DE. Differential diagnosis of primary petrous apex lesions. *Am J Otol* 1991;12:470–4.
8. Brackmann DE, Toh EH. Surgical management of petrous apex cholesterol granulomas. *Otol Neurotol* 2002;230:529–33.
9. Sanna M, Dispenza F, Mathur N, D Stefano A, De Donato G. Otoneurological management of petrous apex cholesterol granuloma. *Am J Otolaryngol* 2009;30:407–14.
10. Jackler RK, Cho M. A new theory to explain the genesis of petrous apex cholesterol granuloma. *Otol Neurotol* 2003;24:96–106.
11. Hiraide F, Inouye T, Miyakogawa N. Experimental cholesterol granuloma. Histopathological and histochemical studies. *J Laryngol Otol* 1982;96:491–501.
12. Fong BP, Brackmann DE, Telischi F. The long-term follow-up of drainage procedures for petrous apex cholesterol granulomas. *Arch Otolaryngol Head Neck Surg* 1995;121:426–30.
13. Brodsky JA, Robertson JH, Shea JJ 3rd, Gardner G. Cholesterol granulomas of the petrous apex: Combined neurosurgical and otological management. *J Neurosurg* 1996;85:625–33.
14. Cristante L, Puchner MAJ. A keyhole middle fossa approach to large cholesterol granulomas of the petrous apex. *Surg Neurol* 2000;53:64–71.
15. Castillo MP, Samy RN, Isaacson B, Roland PS. Petrous apex cholesterol granuloma aeration: Does it matter? *Otolaryngol Head Neck Surg* 2008;138:518–22.
16. Rihani J, Kutz JW Jr, Isaacson B. Hearing outcomes after surgical drainage of petrous apex cholesterol granuloma. *J Neurol Surg B skull base* 2015;76:171–5.
17. Stevens SM, Manning A, Persak ML, Samy RN. Long-term symptom-specific outcomes for patients with petrous apex cholesterol granulomas: Surgery versus observation. *Otol Neurotol* 2017;38:253–9.
18. Kanzaki J, Tos M, Sanna M, Moffat DA, Monsell EM, Berliner KI. New and modified reporting systems from the consensus meeting on systems for reporting results in vestibular schwannoma. *Otol Neurotol* 2003;24:642–8.
19. Sanna M, Mancini F, Russo A, Taibah A, Falcioni M, Di Trapani G. The Translabyrinthine Approaches.*Atlas of Acoustic Neurinoma Microsurgery*. Stuttgart: Georg Thieme Verlag; 2011. pp. 60–140.
20. Sanna M, Khrais T, Mancini F, Piazza P, Russo A, Taibah A. *Atlas of Microsurgery of Lateral Skull Base*. Stuttgart: Georg Thieme Verlag; 2008.
21. Giddings NA, Brackmann DE, Kwartler JA. Transotal infracochlear approach to the petrous apex. *Otolaryngol Head Neck Surg* 1991;104:29–36.
22. Silverstein H. Infracochlear/transcochlear approach to the petrous apex. In: Silverstein H, editor. *Surgical Techniques of the Temporal Bone and Skull Base*. Philadelphia, PA: Lea and Febiger; 1992. pp. 217–26.
23. Wilson DF, Hodgson RS. Transmastoid infralabyrinthine approach to petrous temporal bone. *Skull Base Surg* 1991;1:188–90.
24. Comert E, Comert A, Cay N, Tuncel U, Tekdemir I. Surgical anatomy of the infralabyrinthine approach. *Otolaryngol Head Neck Surg* 2014;151:301–7.
25. Guo R, Zhang H, Chen W, Zhu X, Liu W, Rask-Anderson H. The inferior cochlear vein: Surgical aspects in cochlear implantation. *Eur Arch Otorhinolaryngol* 2016;273:355–61.
26. Gopen Q, Rosowski JJ, Merchant SN. Anatomy of the normal human cochlear aqueduct with functional implications. *Hear Res* 1997;107:9–22.
27. Goldofsky E, Hoffman RA, Holliday RA, Cohen NL. Cholesterol cysts of the temporal bone: Diagnosis and treatment. *Ann Otol Rhinol Laryngol* 1991;100:181–7.
28. Amedee RG, Marks HW, Lyons GD. Cholesterol granuloma of the petrous apex. *Am J Otol* 1987;8:48–55.
29. Gherini SG, Brackmann DE. Cholesterol granuloma of the petrous apex. *Laryngoscope* 1985;95:659–64.
30. Oghalai JS, Driscoll CLW. *Atlas of Neurotologic and Lateral Skull Base Surgery*. Berlin, Heidelberg: Springer-Verlag; 2016.
31. Paluzzi A, Gardner P, Fernandes-Miranda JC, et al. Endoscopic endonasal approach to cholesterol granuloma of the petrous apex: A series of 17 patients: Clinical article. *J Neurosurg* 2012;116:792–8.
32. Zanation AM, Snyderman CH, Carrau RL, Gardner PA, Prevedello DM, Kassam AB. Endoscopic endonasal surgery for petrous apex lesions. *Laryngoscope* 2009;119:19–25.
33. Karligkiotis A, Bignami M, Terranova P, et al. Use of pedicled nasoseptal flap in the endoscopic management of cholesterol granulomas of the petrous apex. *Int Forum Allergy Rhinol* 2015;5:747–53.
34. Pfister MH, Jackler RK, Kunda L. Aggressiveness in cholesterol granuloma of the temporal bone may be determined by the vigor of its blood source. *Otol Neurotol* 2007;28:232–5.
35. Thorne MC, Gebarski SS. Rapid expansion in a previously indolent cholesterol cyst: A need for lifelong follow-up. *Otol Neurotol* 2005;27:124–6

Uncited Reference

AQ5

(26)