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Evaluation of Subtotal Petrosectomy Technique in Difficult Cases of Cochlear Implantation

Golda Grinblat[a, b] Diana Vlad[b, c] Antonio Caruso[b] Mario Sanna[b]

[a]Department of Otorhinolaryngology, Hillel Yaffe Medical Center Affiliated to the Technion University Haifa, Hadera, Israel; [b]Gruppo Otologico, Quaternary Referral Center for Otology, Neurotology and Skull Base Surgery, Piacenza, Italy; [c]Second Department of Otolaryngology, University of Medicine and Pharmacy Cluj-Napoca, Cluj-Napoca, Romania

Keywords

Subtotal petrosectomy · Blind sac closure · Middle ear obliteration · Chronic ear disease · Cochlear implantation

Abstract

Objectives: To assess the validity of the subtotal petrosectomy (STP) technique in problematic cases of cochlear implant (CI) surgery, and review indications, outcomes, and related controversies. ***Study Design:*** This is a retrospective review of data from a private quaternary referral center of otology and skull base surgery. ***Patients and Methods:*** A review of patients who underwent CI with STP (STP-CI) as the leading approach was performed. Demographics, indications, surgical details, and main outcomes were evaluated. The surgeries performed were usually single-stage procedures encompassing a comprehensive mastoidectomy, blind sac closure of the external auditory canal (EAC), and mastoid obliteration with autologous fat. ***Results:*** A total of 107 cases were included. Mean follow-up was 7.1 years (range 1–13 years). The most frequent indication for STP-CI was chronic otitis media with/without cholesteatoma (32.7%), followed by open mastoid cavity (26.1%), and cochlear ossification (17.7%). Other difficult conditions where STP facilitates successful implantation include inner-ear malformations, temporal-bone trauma, unfavorable anatomic conditions, and revision surgery. A planned staged procedure was performed in 3 cases. The rate of major complications was 5.6% ($n = 6$). Three patients developed postauricular wound dehiscence which eventually resulted in device extrusion. No cases of recurrent/entrapped cholesteatoma, EAC breakdown, or meningitis were encountered. This is the largest single-center series of STP-CI reported in the literature. ***Conclusions:*** When CI is intended in technically challenging cases or associated with a high risk of complications, STP is effective and reliable. Safe implantation and excellent long-term outcomes can be achieved provided surgical steps are properly followed. Single-stage procedures can be performed in most cases, even when there is active middle-ear disease.

Introduction

Patient eligibility for cochlear implantation (CI) has dramatically expanded in the last decades due to ongoing technological progress and increasing accessibility.

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karger@karger.com
www.karger.com/aud

Golda Grinblat, MD
Department of Otorhinolaryngology, Hillel Yaffe Medical Center
Affiliated to the Technion University, Haifa
169 Shalom Street, 38100 Hadera (Israel)
goldagrinblatmd@gmail.com

Alongside this development, otologists are faced with a growing class of patients for which classic posterior tympanotomy (PT) may be technically challenging or there is a high risk of complications, e.g., in chronic otitis media (COM), previous open mastoidectomy, and inner-ear malformations (IEM). These conditions have been addressed with various surgical techniques; over time, subtotal petrosectomy (STP) has stood out as an efficient and reliable procedure [Gray et al., 1995; Issing et al., 1998; Kim et al., 2004; Leung and Briggs, 2007; Postelmans et al., 2009; Barañano et al., 2013; Free et al., 2013; Vincenti et al., 2014a; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017]. There are multiple benefits with this procedure including the eradication of middle-ear/mastoid disease, a safe/stable environment for CI, wide surgical exposure, an accurate identification of anatomical landmarks, enhanced array stability, optimal management of intraoperative adverse findings (e.g., cerebrospinal fluid [CSF] leak or meningoencephalic herniation [MEH]), and the elimination of the need for life-long cavity care. The main principles of this surgical technique are: secure double-blind sac closure of the external auditory canal (EAC) in 2 layers (i.e., the inverted EAC skin and the tragal cartilage), extensive drilling out of all mastoid cell tracts, comprehensive removal of tympanomastoid disease and mucosa, occlusion of the eustachian tube (ET), and obliteration of the remnant mastoid cavity [Sanna et al., 2019].

Although results published thus far of STP with CI (STP-CI) are encouraging [Postelmans et al., 2009; Barañano et al., 2013; Free et al., 2013; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017], most include small case series and a particular focus on COM cases. The validity and widespread acceptance of this method as current standard practice as well as clear indications for STP in CI have yet to be established. We present the largest single-center series up to date, aiming to report and analyze the role of STP in CI, encompassing 107 cases, including a comprehensive description of current indications and controversial aspects that have arisen.

Materials and Methods

A retrospective case review of all CI performed in a quaternary referral center between January 1983 and December 2017 was carried out. Primary/staged STP was the leading approach for 129 ears, following the surgical technique described in our previous publications [Sanna et al., 2008; Free et al., 2013; Prasad et al., 2017; Vashishth et al., 2018a]. Surgical extensions done with curative

Table 1. Clinical and surgical characteristics of patients

Age (mean ± SD)	56.8±18.6 years	
Median age		
Pediatric patients (6.54%)	7 (range 2–16) years	
Adult patients (93.45%)	100 (range 18–86) years	
	n	%
Sex		
Male	66	61.68
Female	41	38.31
Hearing loss		
Unilateral	8	7.47
Bilateral	99	92.5
Surgical history		
TPL/MPL	11	10.2
CWD/RMC	28	26.1
RLAB[a]	1	0.93
CI/explantation	4	3.73
ABI	3	2.8
Implanted ear		
Left	52	48.5
Right	51	47.6
Bilateral	4	3.73
Active disease		
CMOM	7	6.54
CCOM	13	12.1
CWD/RMC[a]	4	3.73
Single-stage procedure	99	92.5
Two-stage procedure	8	7.47
Not intended	5	2.8
COM	2	
RMC[a]	1	
ORN	1	
CSF fistula	1	
Intended		
CMOM[b]	1	
CCOM[c]	1	
RMC[d]	1	
Cochlear ossification		
RWO	16	14.9
BTO	12	11.21
Partial	9	8.41
Complete	3	2.8
Electrode insertion		
RW	79	73.8
Drill-out	28	26.16
Scala vestibuli	3	2.8
Complete insertion	100	93.45
Intraoperative findings		
Exposed dura/MEH	6	5.6
FN dehiscence	17	15.88

TPL, tympanoplasty; MPL, myringoplasty; CWD, canal wall down; RMC, radical mastoid cavity; RLAB, retrolabyrinthectomy; CI, cochlear implantation; ABI, auditory brainstem implant; CMOM, chronic mucous otitis media; CCOM, otitis media with cholesteatoma; COM, chronic otitis media; ORN, osteoradionecrosis; CSF, cerebrospinal fluid; RWO, round window ossification; BTO, basal-turn ossification; RW, round window; MEH, meningoencephalic herniation; FN, facial nerve.

[a] Three more cases presented with epithelium attached to the exposed middle/posterior fossa dura.

[b] CMOM with profuse purulence.

[c] Cholesteatoma with intraoperative uncertainty regarding complete disease removal.

[d] RMC with extensive granulation tissue.

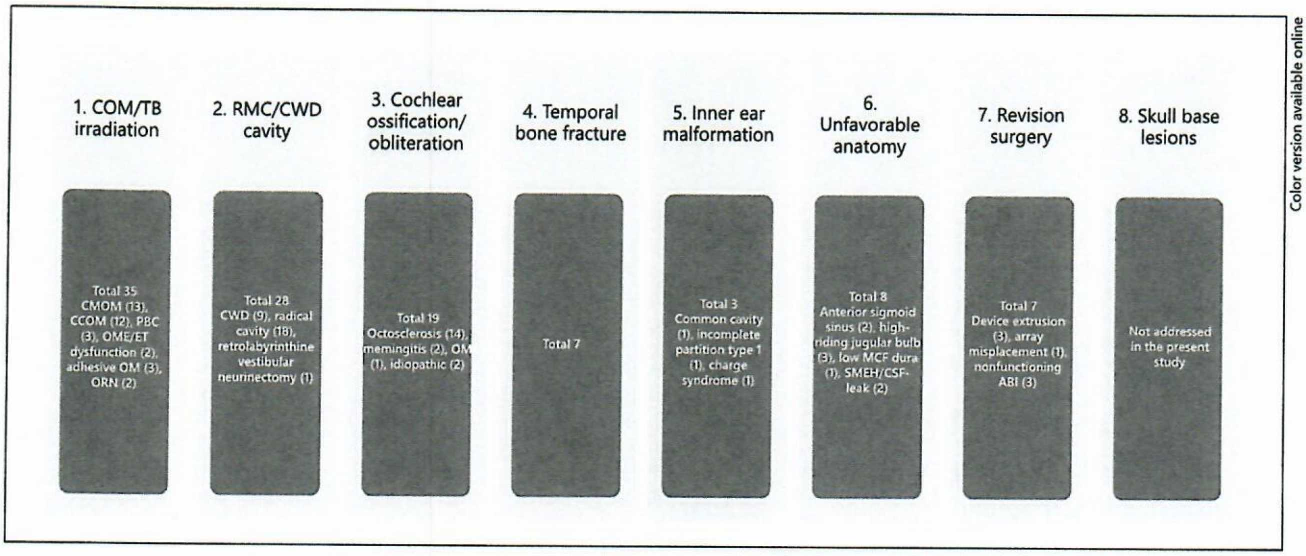

Fig. 1. Indications for STP as the leading approach for CI and findings in the study cohort of 107 cases. COM, chronic otitis media; TB, temporal bone; CMOM, chronic mucous otitis media; CCOM, otitis media with cholesteatoma; PBC, petrous bone cholesteatoma; OME, otitis media with effusion; ET, eustachian tube; OM, otitis media; RMC, radical mastoid cavity; CWD, canal wall down; MCF, medial cranial fossa; CSF, cerebrospinal fluid; ABI, auditory brainstem implant.

intent such as partial/total labyrinthectomy, and Fallopian tube or middle fossa plate exposure were included in this series. Patients that underwent a lateral skull base procedure and those with <1-year/insufficient follow-up were excluded.

Clinical charts were reviewed for demographic characteristics, etiology, and history of hearing loss (HL), indications for STP, preoperative imaging studies, operative reports, and postsurgical outcomes. Preoperative audiological assessment included pure-tone audiometry, speech discrimination tests, and auditory brainstem responses. Cochlear patency and the extent of tympanomastoid disease were evaluated by means of high-resolution computed tomography (HRCT) and magnetic resonance imaging (MRI).

For bilateral HL, the worse-hearing side was chosen for implantation. CI was staged considering disease activity and surgical findings. Implant electrodes were inserted routinely via the round window (RW). All cavities were obliterated with an abdominal fat graft. Electrode placement was confirmed by intraoperative radioscopy or postoperative CT scan. Patients were usually discharged by postoperative day 3. Radiological follow-up was assessed by HRCT during a 10-year period, annually for the first 3 years and then once every 2 years. Audiological follow-up was conducted after switch-on at 1, 3, 6, 9, 12, and 18 months postoperatively, and then once annually. Postoperative speech performance was evaluated according to the standard protocol used at the Gruppo Otologico, and it included perception score levels in the categories of vocal identification, recognition (words and phrases), and comprehension (questions) in percentages. All major and minor ensued complications [Cohen and Hoffman, 1991] and applied management were noted.

A systematic search was additionally conducted using the Medline/PubMed databases to identify papers written in English concerning STP-CI, using the keywords "subtotal-petrosectomy," "cochlear implant," and "mastoid obliteration" (MO). Single-center reports that involved patient overlap [Free et al., 2013; Polo et al., 2016; Vashishth et al., 2017, 2018a, 2018b], series comprising < 10 cases, and an absence of EAC closure or MO during the surgical technique were excluded.

Results

Clinical Features

A total of 107 ears (in 103 patients), were included. Table 1 features patients' demographic and clinical characteristics. Mean age at implantation was 56.8 ± 18.6 years (range 2–86 years). Seven pediatric cases were encountered (age range 2–16 years) and 3 presented an IEM. Thirty-five cases were excluded as per the exclusion criteria.

Indications for STP

The most frequent indication for STP was COM, counting 35 (32.7%) cases. This represents a heterogenous group that comprises several middle-ear pathologies underlined in Figure 1. Out of 13 patients with chronic mucosal otitis media (CMOM), 7 presented with active middle-ear disease and underwent a single-stage implantation. Three cases of petrous bone cholesteatoma, with erosion up to the fundus of the internal auditory canal,

Table 2. Summary of major and minor complications encountered in this series and their management

Type	Complication	Age/sex	Primary pathology	Single-/ two-stage	Disease activity	Time of onset	Management
Major	Postauricular fistula/ R/S exposure	41 years/M	radical cavity	single	inactive	12 months	Resuturing of dehiscence, followed by cavity infection and explantation after 12 months; ipsilateral reimplantaion after 7 days due to primary array removal due to granulation tissue around RW
	Cavity infection/ retroauricular retraction	67 years/M	radical cavity	single	inactive	20 months	Musculoperiosteal occipital flap/cavity adhesiolysis; cavity infection and explantation after 2 months. Contralateral reimplantation after 7 days
	Postauricular fistula/ R/S extrusion	63 years/M	radical cavity	single	inactive	11 months	Explantation, followed by 2 debridement interventions for exuberant granulation tissue; ipsilateral reimplantation after 3 years
	Cavity infection/ postauricular fistula	17 years/M	cholesteatoma	single	active	4 months	Explantation and ipsilateral reimplantation after 4 months
	Postauricular fistula/ revision, followed by bilateral FNS	51 years/M	cochlear ossification (OS)	single	inactive	9 months	Explantation followed by reimplantation 1 year later; the patient developed FNS after reimplantation that was managed by selective switching-off of electrodes
	Array mispositioning in the SSC	46 years/F	cochlear ossification (OS)	single	inactive	intraoperative	Confirmed by postoperative CT scan; reinsertion in the ST the next day
Minor	Vertigo ($n = 3$)	43–57 years/ not available	–	single	inactive	postoperative	Vestibular rehabilitation, symptom resolution within maximum 1 year
	Subcutaneous CSF collection[a]	2 years/M	common cavity	single	inactive	immediate postoperative	Sterile puncture and head bandage; no residual effects
	Gusher	66 years/M	cochlear ossification (OS)	single	inactive	intraoperative	Periosteum RW packing

R/S, receiver/stimulator; M, male; RW, round window; FNS, facial nerve stimulation; OS, otosclerosis; F, female; SSC, superior semicircular canal; ST, scala tympani; CT, computed tomography; CSF, cerebrospinal fluid.
[a] These complications were also discussed in detail in Free et al. [2013] and Vashishth et al. [2017, 2018a, 2018b]

required additional translabyrinthine drilling for disease clearance, and CI was done at the same sitting.

The second indication ($n = 28$) was previous canal wall down (CWD)/radical mastoid cavity (RMC). Four patients were found to have residual cholesteatoma and middle cranial fossa (MCF) dura exposure/MEH was encountered in 5 cases. Cochlear ossification (CO) of variable extent was the third reason for STP to be performed in 19 (16.9%) subjects, but 9 additional cases presented with associated cochlear obliteration.

Revision surgery/reimplantation was required in 7 cases initially implanted in other clinics. Four patients with CI were referred to us due to array misplacement or device extrusion (DE) following local complications. The first had a CO with accidental electrode inset in the petrous carotid canal. He was subsequently operated on at our center, and STP facilitated patency identification of the scala tympani (ST) and full electrode insertion. The initial array was transected and left in place. Another patient developed adhesive otitis media (AdOM) after CI, which gradually led to infection and device removal. We achieved effective reimplantation by concurrent STP. Three additional cases with nonfunctioning auditory brainstem implants (ABIs), performed for cochlear-nerve hypoplasia, complete CO, and trauma of the temporal bone (TB) were successfully rehabilitated with CI via STP.

Staged Procedure

Eight patients underwent 2-step surgery (Table 1). The period between STP and CI ranged from 2 months to 3 years. The procedure was deliberately staged in 3 cases, i.e., CMOM with profuse purulence, cholesteatoma, and RMC with extensive granulation. CI was performed after 2–9 months and provided a stable, safe cavity. In the remaining

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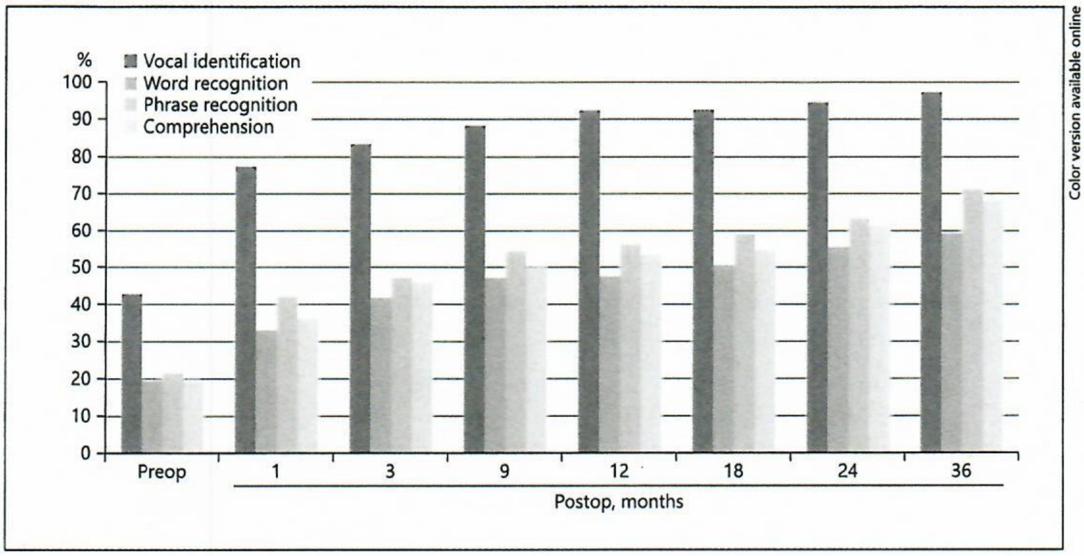

Fig. 2. Postoperative speech performance after STP-CI. Vocal identification, word and phrase recognition, and comprehension scores gradually improved in time.

cases, CI was not envisioned at primary surgery and was indicated as the patients' hearing deteriorated further. Patients with bilateral CI were also sequentially implanted.

Intraoperative Particularities

Average operative time was 2.4 h. Full electrode insertion was achieved in 91.5% cases. Drilling-out procedures were required in 28 ears (26.4%). All the arrays were placed in the ST except for 3 scala vestibuli (SV) insertions, required due to a lack of ascending basal-turn patency.

Two intraoperative gushers and 1 array misplacement inside the superior-semicircular canal were encountered (Table 2). The latter was confirmed at routine perioperative imaging check-up and mended forthwith.

Audiological Results

The postoperative speech scores in terms of vocal identification, word recognition, phrase recognition, and comprehension were 92.4, 47.5, 56.4, and 53.6%, respectively, at the end of the first postoperative year. All parameters continued to gradually improve until the 3rd postoperative year when a score plateau was observed (Fig. 2).

Follow-Up and Complications

Mean follow-up period was 7.1 years (range 1–13 years). For the entire cohort, 5 major postoperative complications occurred: 1 cavity infection and 4 retroauricular fistulas with DE (Table 2). All were single-stage procedures without any apparent signs of infection. We did not encounter any recurrent cholesteatomas or EAC breakdowns in the series.

Table 3 presents a brief comparison of previously published series of STP-CI [Issing et al., 1998; Leung and Briggs, 2007; Barañano et al., 2013; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017].

Discussion

Introduction of the STP technique in CI surgery has permitted the resolution of difficult cases that were previously contraindicated. This procedure has gradually been recognized as a valuable tool and indications for conducting it are still developing. The postoperative auditory results are similar to those obtained with classic PT, without any negative effect on postoperative performance. We have reported here the largest series of STP-CI ever analyzed at a single medical center. We now discuss our experience regarding the indications, complications, and pending controversies associated with this technique.

Indications for STP-CI

COM/Osteoradionecrosis of the Temporal Bone

Although the incidence of COM in CI recipients is relatively rare (2.2–10.9%) [Yoo et al., 2014], this category

Table 3. Brief comparison of published studies on combined subtotal petrosectomy and cochlear implantation (STP-CI)

First author [year]	Cases, *n*	Adult or pediatric cases	Indications (*n*)	Disease activity, *n*	Single-/two-stage STP-CI (*n* of indications)	Interval between stages, months	Obliteration material (*n*)	Follow-up duration	Complications, *n*	Type of complication
Issing [1998]	14	adult/ pediatric	COM (10), RMC/CWD (2), TB fracture cholesteatoma (1), revision surgery (1)	active (8)/ inactive (6)	single-stage (10) two-stage (4)	6	fat graft	28 months (mean)	4	retroauricular fistula (2), seroma (1) wound-healing disorder (1)
Leung [2007]	17	adult	COM (8), RMC/CWD (8), unfavorable anatomy (1)	active (13)/ inactive (4)	single-stage (7) two-stage (10)	6	fat graft (2), temporalis muscle flap (15)	1–7 years	5	meningitis (1), device failure (1), array migration (1), middle-ear effusion before CI (1), breakdown of EAC before CI (1)
Barañano [2013]	39	adult/ pediatric	COM (28), RAOM (7), RMC/CWD (2), unfavorable anatomy (1), revision surgery (5)	active (4)/ inactive (9	single-stage (10) two-stage (29)	n.a.	fat graft (12), temporalis muscle flap (26), bone pate (1)	n.a.	6	wound abscess/device explantation (3), air pocket (1), canal granulation (1), electrode extrusion (1)
Bernardeschi [2015]	26	adult	COM (22), IEM (1), TB fracture (1), progressive HL (2)		single-stage (all)	n.a.	fat graft	–	7	recurrent cholesteatoma (1), array extrusions (2), array malposition (1), device failure (1)
Polo [2016] (multicenter)	110 (32 from our center)	adult/ pediatric	COM (27), RAOM (2), RMC/CWD/STP (35), CO (13), IEM (10), TB fractures (9), others* (11)	n.a.	single-stage (108) two-stage (2)	n.a.	n.a.	1–15 years	7 major 6 minor	device extrusion (5), device failure (1), facial nerve palsy (1), vertigo (2), retroauricular fistula (1), seroma (1), subcutaneous CSF collection (1)
Szymański [2016]	19	adult	COM (5), RMC (7), IEM (3), CO (1), ORN (1)	active (5)/ inactive (14)	single-stage (14) two-stage (5)	6–11	fat graft (15), temporalis muscle flap (2)	1-10 years	0	–
Casserly [2016]	16	adult	Mastoid cavity (9), CSOM (5), unfavorable anatomy (2)	active (5)/ inactive (11)	single-stage (4), two-stage (12)	n.a.	fat graft (5), temporalis muscle flap (10)	8 months to 7 years	1	EAC fistula (1)
Altuna [2017]	12	adult/ pediatric	COM (6), RMC (3), reimplantation (2), ORN (1)	n.a.	all single-stage	n.a.	fat graft (9), temporalis muscle flap (3)	1–3 years	1	infection/explantation (1)
Our study	107	adult/ pediatric	COM (35), ORN (2), RMC/CWD (28), CO (19), IEM (3), TB fractures (7), unfavorable anatomical conditions (8), revision surgery (7)	active (7)	single-stage (98) two-stage (8 [3 of which were deliberate])	2–9	fat graft	1–13 years	5 major 6 minor	Postaurocular fistula/device extrusion (3), cavity infection (1), device extrusion/bilateral FNS (1), array mispositioning in the SSC, vertigo (3), subcutaneous CSF collection (1), gusher (1)

COM, chronic otitis media; RMC, radical mastoid cavity; HL, hearing loss; CO, cochlear ossification; ORN, osteoradionecrosis ; CWD, canal wall down mastoidectomy; TB, temporal bone; EAC, external auditory canal; IEM, inner-ear malformation; RAOM, recurrent acute otitis media; STP, subtotal petrosectomy; CSF, cerebrospinal fluid; CSOM, chronic suppurative otitis media; FNS, facial nerve stimulation; SSC, superior semicircular canal; n.a., not available.

has expanded over time to include several distinct middle-ear pathologies, namely: CMOM, COM with cholesteatoma (CCOM), otitis media with effusion (OME)/ET dysfunction, AdOM, and chronic eosinophilic otitis media. Ensuring a disease-free, stable cavity prior to implantation is of paramount importance, otherwise there is a high risk of disease recurrence, implant extrusion, and severe infective complications (labyrinthitis and meningitis). STP specifically serves this purpose by meticulous debridement of the tympanomastoid pathology and mucosa, isolating the remnant cleft form further infectious breach by closure of the ET/EAC.

For CMOM cases, some authors advocate the use of simple tympanoplasty (TPL)/tympanomastoidectomy with CI, usually performed in 2 stages [Axon et al., 1995; Incesulu et al., 2004; Roehm and Gantz, 2006; Leung and Briggs, 2007; Hellingman and Dunnebier, 2009; Postelmans et al., 2009; Vincenti et al., 2014b; Yoo et al., 2014]. This approach may be hazardous due to the possibility of disease relapse [Vincenti et al., 2014b], or biofilm persistence [Lyu and Park, 2017] with consequent infection. Specifically, additional surgery is frequently required in such cases to control the disease [Barañano et al., 2013], including STP, MO, or EAC closure. We also performed TPL and second-stage CI in several predictable tympanic membrane (TM) perforations, but here, rigorous patient selection is essential and the best permanent outcome is achieved with STP. The MCF approach has also been proposed to avoid entirely an infected middle ear [Colletti et al., 1998]. The complications inherent to this procedure and the ongoing auricular pathology must still be investigated, making it less appealing.

There is wide acceptance of STP when CI is planned for cases of cholesteatoma [Postelmans et al., 2009; Barañano et al., 2013; Free et al. 2013; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017]. The procedure ensures thorough disease clearance, greater surgical exposure, and the optimal management of unwanted intraoperative findings like CSF leak, MEH, dural and/or facial nerve (FN) dehiscence, and labyrinthine/cochlear erosion [Vashishth et al., 2018a]. Drilling can be safely extended to adjacent sites when needed, as in the PBC cases already mentioned. Atelectatic otitis media is associated with a high risk of developing cholesteatoma or array extrusion [Xenellis et al., 2008]. Simple TM reinforcement is therefore not prudent in CI and STP is indicated [Altuna et al., 2017]. We refer here to the case referred to us which ultimately resulted in DE due to atelectasis.

Few reports have underlined the role of SPT when CI is performed in recurrent acute otitis-media (RAOM), OME, and ET dysfunction [Barañano et al., 2013; Polo et al., 2016; Altuna et al., 2017]. This is particularly relevant for the pediatric population who would benefit most from a more definitive solution that eliminates the need for continued microscopic/paraclinic follow-up, possible additional interventions, and a delay in CI/speech acquisition [Barañano et al., 2013]. Altuna et al. [2017] reported that in 1/3 cases, DE was caused by ET dysfunction. Nonetheless, considering the radicality of the procedure, we would advise using it only in the presence of additional unfavorable factors like the failure of ventilation tubes, a cleft palate, or immunodeficiency. One study also reported favorable outcomes in HL resulting from eosinophilic otitis media after the removal of all eosinophilic mucosa and ET/EAC closure to prevent the entry of foreign inflammatory stimuli, and CI [Sugimoto et al., 2017].

TB irradiation in various malignancies can result in profound sensorineural HL (SNHL) and osteoradionecrosis [Sharon et al., 2014]. Though problematic, due to the increased risk of infection, FN injury after bone softening, and CO, CI is successful when combined with STP [Sanna et al., 2016; Szymański et al., 2016; Altuna et al., 2017]. As the life expectancy of oncological patients has got longer, the indication for CI done via STP could increase in this population. Leonetti et al. [2010] recorded 0% osteoradionecrosis of the TB (vs. 12%) by performing prophylactic STP in 221 patients treated for parotid tumors. Although it may seem overstated, this strategy could be considered in selected cases to prevent debilitating disease and ensure safe CI.

RMC and CWD Techniques

As discussed in previous reports [Cohen and Hoffman, 1991; Postelmans et al., 2009; Barañano et al., 2013; Free et al. 2013; Vincenti et al., 2014b; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017; Vashishth et al., 2018a], CI in an open mastoid cavity is best addressed by STP. Initial implantation efforts encountered a high rate of complications [Free et al., 2013] owing to: the risk of array extrusion through the thin epithelial lining [Issing et al., 1998; Free et al., 2013], external exposure and infection [Altuna et al. 2017], and damage to the epithelium/electrode following regular cavity-cleaning maneuvers [Sanna et al., 2016]. Various surgical strategies have been proposed as a means of safe implantation including: cleft obliteration with bone chips and posterior-wall reconstruction [Tamura et al., 1997; Kojima et al., 2010]; partial obliteration and covering the electrode with full-thickness skin, cartilage, muscle, or periosteal flaps [Kiefer and von Ilberg, 1997; Meyerhoff et al., 1988; Schlöndorff et al., 1989; Babighian, 1993; El-Kashlan et al., 2003]; reinforcing the neotympanum with a silastic block [Lyu and Park, 2017]; and a transcanal [Jang et al., 2012], subfacial [Olgun et al., 2005], or MCF approach [Colletti et al., 1998]. Despite the reasonable argument for deploying these techniques (e.g., the ease of monitoring a cholesteatoma relapse) and the favorable outcomes reported, they also present several drawbacks: the lack of proper endorsement due to the limited number of cases, the high risks associated with electrode exposure/migration, the technically difficult and time-consuming reconstruction of the posterior wall [Postelmans et al., 2009], and the ongoing middle-ear disease experienced with bypass techniques. We feel that STP is the most consistent, and also it can be performed simultaneously to CI in most cases.

Cochlear Ossification/Obliteration

Carrying out CI via PT in the setting of CO confers a greater risk of electrode misplacement or harming essential nearby structures like the FN, internal carotid artery, or jugular bulb [Bernardeschi et al., 2015]. STP is recommended to facilitate wider access to the RW and safety during intrinsic drill-out procedures [Polo et al., 2016; Vashishth et al., 2017, 2018b]. The remote case referred to, that involved array mispositioning in the carotid canal, endorses the latter aspect and proves that limited approaches cannot provide sufficient local control. Theoretically, STP could also contribute to improving audiological outcomes by assuring a higher probability of full array inset, reduced trauma to the electrodes and intracochlear structures, and fewer complications [Vashishth et al., 2018b].

We observed otosclerosis to be the main etiology (73.6%) for CO. This pathology poses specific problems like FN stimulation (FNS) caused by transotic transmission or insufficient ST patency [Burmeister et al., 2017]. Electrode adjustment or use of perimodiolar arrays can address FNS [Burmeister et al., 2017], and SV insertion has proved a valid alternative when there is obstruction of the ST [Lin et al., 2006; Coelho and Roland, 2012]. Although STP is indicated in grade III/IV CO, our center developed a low threshold for the procedure [Vashishth et al., 2017], extending it to lower grades for a safer operative setting but also due to the possibility of the extent of ossification being underestimated on radiological findings.

Array insertion was not possible in 2 cases owing to absence of cochlear lumen, and a conversion to an ABI was undertaken. Nevertheless, CO, even complete CO, cannot be considered a primary indication for ABI [Colletti et al., 2009].

Inner-Ear Malformations

In a recent meta-analysis, Farhood et al. [2017] found IEM to be associated with a high rate of gusher (39.1%) and FN anomalies (34.4%). Confronted with an aberrant morphology, an intricate electrode insertion, a high risk of developing postoperative CSF leak/meningitis, and an inconsistent FN course, many groups advocate the use of STP for secure CI [Colletti et al., 1998; Free et al., 2013; Szymański et al., 2016]. Others uphold that CI is achievable via PT, resorting to fascial packing and performing electrode arrays to address intraoperative obstacles [Papsin and Gordon, 2008; Isaiah et al., 2017]. Nonetheless, CI was found to be challenging in 24% of cases that involved incomplete/difficult insertion, array kinking, and cochlear drill-out [Isaiah et al., 2017]. We believe that the surgical approach should be selected based on the specific type of malformation and the surgeon's experience. STP provides better control of the impairments mentioned above, but further development of specialized arrays and the use of intraoperative fluoroscopy [Perez et al., 2014] or CT [Kim et al., 2018], will perhaps mean its practice becomes more limited.

Fracture of the TB with Involvement of the Otic Capsule

TB trauma can cause profound SNHL in up to 8% of cases [Khwaja et al., 2012]. Otic capsule fracture also implies a life-long exposure to CSF leak/meningitis since fracture lines heal only by fibrous bonding that creates an intracranial connection [Free et al., 2013; Bernardeschi et al., 2015; Polo et al., 2016]. To overcome this and additional technical difficulties like posttraumatic CO or anatomy distortions [Serin et al., 2010], it is advisable to use SPT for CI. As we encountered, some surgeons primarily use ABIs for posttraumatic HL rehabilitation as they are afraid that complete CO, cochlear nerve (CN) damage, or postoperative complications (meningitis and FNS) may occur [Medina et al., 2014]. This notion is unfounded because great force is necessary to induce CN rupture; a promontory stimulation test [Serin et al., 2010] can appreciate CN function and other impediments can be managed by STP.

Revision Surgery

Cochlear reimplantation (CR) has been shown to be a safe procedure with outcomes comparable to initial CI performance [Reis et al., 2017]. Revision surgery can be typically elaborate and also accompanied by local pathological changes like middle-ear inflammation/infection, CO after otic capsule violation, and the exposure of ana-

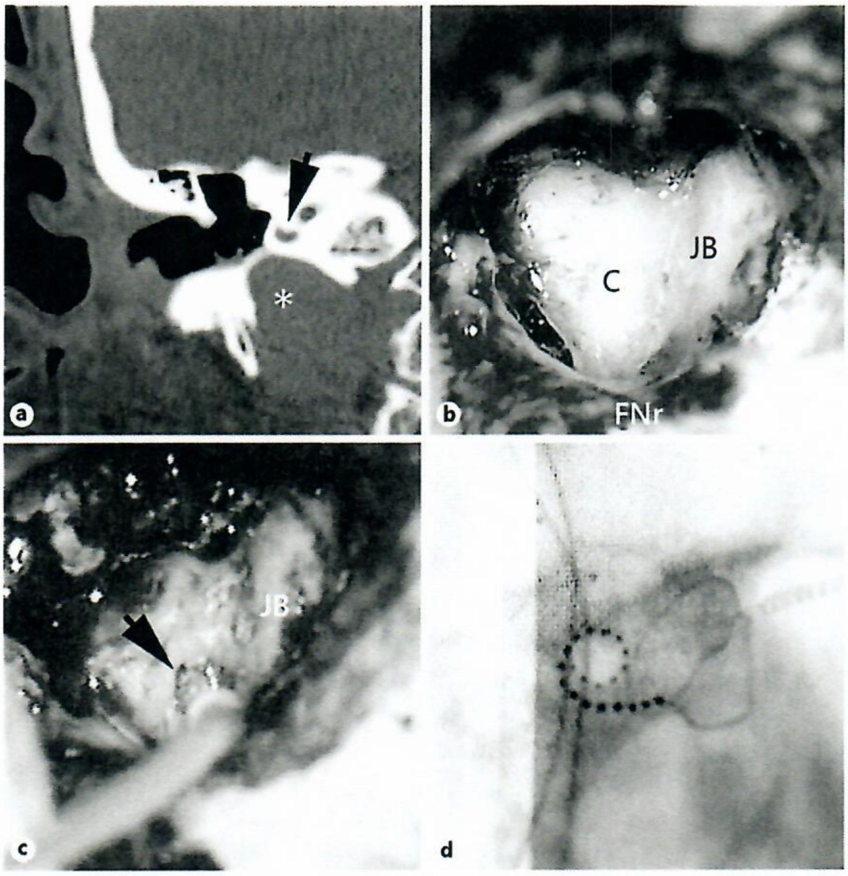

Fig. 3. Example of a case of high jugular bulb (JB) and chronic mucous otitis media with a history of tympanoplasty and a current indication for CI. **a** Preoperative CT scan showing the high JB (white asterix) in direct contact with the basal turn of the cochlea (black arrow). **b** Intraoperative image of the middle-ear cleft after STP. Note the JB touching the cochlea (C), the absent round window niche, and the lowered facial nerve ridge (FNr). **c** A cochleostomy was drilled out in the basal turn (black arrow) and electrode-array insertion was achieved. **d** Image of intraoperative control radioscopy showing the array inside the cochlea.

tomical structures that puts them at risk. We prefer the STP approach, particularly after implantation conducted at other centers or the failure of multiple attempts at array insertion. CI was achieved uneventfully in our previously discussed revision cases, and outcomes were favorable at the clinical and audiological follow-up. Enlarging candidacy criteria for CI, concurrent with a lengthened time of device use by recipients, may lead to an increase in revision/reimplantation surgery [Manrique-Huarte et al., 2016], so STP is a valuable tool to master and apply in difficult situations.

Unfavorable Anatomical Conditions

In structurally complex cases, including those with vascular/nervous variations, STP confers substantial advantages to CI in relation to surgical exposure and intraoperative control. Access to the RW via the facial recess may be hazardous or even impossible in a very anterior sigmoid sinus, a high jugular bulb (Fig. 3), and with FN or ICA anomalies. Likewise, in the presence of a sclerotic mastoid or spontaneous CSF leak/MEH, STP with MO ensures proper management [Leung and Briggs, 2007; Free et al., 2013;]. The alternative transcanal [Hans and Prasad, 2015] and transattical approaches [Vaca et al., 2015] have been proposed, but they can involve a higher risk of array misplacement [Bernardeschi et al., 2015] and local vascular control is absent. The choice of technique remains at the surgeon's discretion. We favor SPT to achieve straightforward CI, protect anatomical structures, and avoid possible life-threatening complications.

Skull Base Lesions with Preservation of the CN and Cochlea

Although not the specific aim of our paper, we propose that CI is a possibility for hearing revalidation in certain skull base lesions/nontumoral diseases that entail an otic capsule breach but with preservation of the CN and the cochlea [Sanna et al. 2016] (e.g., NF-2, otosclerosis with reluctant vertigo, and B class paragangliomas with SNHL). These approaches are a combination of STP with further labyrinthectomy or procedures that extend to the skull base.

Complications

Significant complications associated with STP-CI include: DE due to flap difficulties or infection, EAC breakdown, recurrent/entrapped cholesteatoma, FN paralysis, and meningitis [Postelmans et al., 2009; Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016]. Consistent with previous reports [Gray et al., 1995; Issing et al., 1998; Leung and Briggs, 2007; Postelmans et al., 2009; Vincenti et al., 2014a; Casserly et al., 2016; Polo et al., 2016; Altuna et al., 2017], we recorded a low rate of major complications (5.6%). Particular for this series was the high occurrence in the RMC group, i.e., 2 postauricular fistulas and 1 cavity infection/retroauricular retraction. As these patients had undergone multiple previous interventions, it is reasonable to assume that wound dehiscence/infection could be the consequence of excessive fibrous healing and vascular compromise [Postelmans et al., 2009; Vashishth et al., 2018a]. The use of an extended temporalis flap [Szymański et al., 2016; Yung, 2016] with a retroauricular S-shape incision [Szymański et al., 2016] would seem more appropriate here. Another causal possibility is biofilm persistence that could lead to disease flare-up, even in clinically inactive cholesteatoma [Lyu and Park, 2017] or after a long time [Bernardeschi et al., 2015]. Comprehensive exclusion of all tympanomastoid mucosa, secure closure of the ET/EAC, and proficient antibiotic coverage are paramount for good surgical outcomes.

Although reports of recurrent/inclusion cholesteatoma are scarce [Gray et al., 1995; Basavaraj et al., 2005; Bernardeschi et al., 2015], all patients should undergo long-term HRCT evaluation due to the risk of silent disease with adverse progression. Basavaraj et al. [2005] noted cholesteatoma recurrence 9 years after STP and CI. Some authors endorse CT use only when there are symptoms (pain, discharge, and wound breakdown) or known residual disease [Leung and Briggs, 2007; Vincenti et al., 2014a; Casserly et al., 2016], so as to avoid irradiation exposure. Nonetheless, eradication of subclinical disease carries less threat for the implant. Although MRI after CI is impaired due to the presence of major artifacts [Barañano et al., 2013; Casserly et al., 2016; Polo et al., 2016], HRCT has proven to be reliable for cholesteatoma detection as obliteration fat creates an interface between soft tissues, and lesion expansion and/or bone erosion are suggest disease progression [Gray et al., 1995; Issing et al., 1998; Leung and Briggs, 2007; Free et al. 2013; Vincenti et al., 2014a; Altuna et al., 2017]. We did not observe any recurring cholesteatoma cases, and we feel that a thorough surgical technique carries more value than staging procedures.

Closure of the EAC is an essential surgical step that can lead to several complications if not properly executed, like cavity infection, DE, and inclusion cholesteatoma. It also eliminates the need for life-long cavity care and water avoidance [Postelmans et al., 2009]. The procedure is feasible even in meatoplasty cases, and although some authors associate it with an esthetic disadvantage [Lyu and Park, 2017], we did not register any complaints in this regard, and observed that it can be even less obvious than the previous large opening [Szymański et al., 2016].

Although underreported in STP-CI cases, we registered 3 cases of persistent imbalance postimplantation, that subsided with vestibular rehabilitation. Evaluation of vestibular function is particularly important in patients with a history of tympanomastoid surgery, when selecting on which side to perform the CI, due to the risk of bilateral vestibular function deterioration [Sugimoto et al., 2018]. This can result in serious balance difficulties and an impaired quality of life. Preoperative evaluation of vestibular function should be pursued, especially for RMC.

Cavity Obliteration

Various materials have been used for cavity obliteration after radical mastoidectomy and CI. Autologous fat graft and temporalis muscle flap remain the most common procedures [Gray et al., 1995; Issing et al., 1998; Kim et al., 2004; Leung and Briggs, 2007; Postelmans et al., 2009; Barañano et al., 2013; Free et al. 2013; Vincenti et al., 2014a Bernardeschi et al., 2015; Casserly et al., 2016; Polo et al., 2016; Szymański et al., 2016; Altuna et al., 2017]. Synthetic materials involve a risk of ossification which impedes revision surgery [Vincenti et al., 2014a]. Our policy has been to use autologous abdominal fat for a broad range of interventions, including skull base surgery, with optimal results. It has several benefits: good availability, a low metabolic rate, resistance to necrosis [Postelmans et al., 2009; Vincenti et al., 2014b], its volume and consistency are maintained [Vashishth et al., 2018a] and it has intrinsic immunoreactive properties [Vincenti et al., 2014b], can be easily removed for a reintervention or staged procedure [Hellingman and Dunnebier, 2009], the array is stable, and it contributes to the management of CSF leak/MEH. One drawback is that it may hinder cholesteatoma detection on radiological follow-up but, as previously argued, HRCT is efficient even in this situation. Some authors opt for a nonobliterative procedure [Xenellis et al., 2008] or do it selectively [Sugimoto et al. 2018]. However, all cavities eventually get obliterated with soft tissue/fibrosis [Vashishth et al., 2018a], forfeiting the advantages provided by MO. Overall, similar results are obtained with fat grafts or vascularized tissue flaps [Leung and Briggs, 2007; Postelmans et al., 2009; Casserly et al., 2016; Altuna et al., 2017]. We would opt for the latter in cases of RMC with a history of multiple ear surgeries and as salvage surgery for wound dehiscence.

Staging of Procedures

Staging STP and CI has been a matter of much debate. Suggestions for progressive implantation [Szymański et al., 2016] are: suppurative/continuously draining otitis media, previous TM surgery with instable disease, cholesteatoma, and TB irradiation. Generally, the recommended time between procedures is 1–6 months for COM [Barañano et al., 2013; Polo et al., 2016] and 6–12 months for CCOM [Leung and Briggs, 2007; Polo et al., 2016; Szymański et al., 2016]. Although one would expect there to be a low rate of complications with gradual implantation, this was not upheld when we reviewed the literature [Postelmans et al., 2009]. We practice 2-stage CI in cases of frank purulence or uncertainty regarding complete cholesteatoma removal. No complications were encountered so far in our series in cases of active middle-ear inflammation, extended cholesteatoma, or previous TB irradiation when concurrent STP and CI were performed. Undergoing a second surgery implies additional hospitalization, anesthesia, fat-harvesting, and delay of implant use. Not all mastoid is exposed the second time, so residue can still escape surgical exploration [Szymański et al., 2016], and cholesteatoma can relapse even after years of a disease-free status. Surgery may be done successfully in 1 stage if proper surgical inspection, exigent surgical practice, and good antibiotic coverage are respected. Careful selection of cases and surgical experience are also mandatory prerequisites.

Conclusion

STP with blind sac closure of the EAC and MO is the preferred approach in difficult cases of CI, and it provides audiological results similar to those obtained with classic PT. Even though associated with a low risk of adverse events, a meticulous surgical technique and routine HRCT follow-up are mandatory. Cavity obliteration can be performed with autologous fat. Successful CI can be achieved as single-stage procedure, even when there is active middle-ear disease. Patients with an open mastoid cavity are at a higher risk of experiencing adverse events. Although the trend in surgery is towards minimally invasive procedures, and STP sometimes appears to be a radical strategy in some situations, CI represents a distinct situation that requires careful weighing-up of the risks and benefits.

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Statement of Ethics

The study was conducted in accordance with the ethics standards of the Gruppo Otologico Medical Center research committee and the Declaration of Helsinki and its later amendments. Informed consent was obtained from all subjects.

Disclosure Statement

The authors have no conflicts of interest to declare.

Author Contributions

All authors contributed to the concept and design of the work, interpretation of data, work on the draft, and critical revision for important intellectual content. The final version was approved for publishing by all authors. They all take accountability for all aspects of the work by ensuring that questions related to the accuracy or integrity of any part of it were appropriately investigated and resolved.

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