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Subtotal Petrosectomy for Cochlear Implantation: Lessons Learned After 110 Cases

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Abstract

Objectives: The purpose of this study was to review the indications for subtotal petrosectomy for cochlear implantation, report our management of complications, as well as review those technical factors that are critical for successful implantation.
Methods: Patients (n = 104) that underwent subtotal petrosectomy with closure of the external auditory canal and obliteration of the cavity with abdominal fat in combination with cochlear implantation were analyzed.
Results: The most frequent indication for subtotal petrosectomy was the existence of a previous canal wall down technique. Postoperative complications occurred in 13 patients (11.83%). Extrusion of the device took place in 5 cases (4.55%).
Conclusions: Subtotal petrosectomy in cochlear implantation permits obtaining a cavity isolated from the external environment, and when needed, it improves the access and visibility during the surgical procedure. Subtotal petrosectomy is a safe technique, with a low rate of complications.

Keywords

subtotal petrosectomy, middle ear obliteration, cochlear implants, chronic ear disease, cochlear implantation

Introduction

Subtotal petrosectomy (SP) is a surgical procedure that can be employed in difficult cases of cochlear implantation (CI). This procedure involves a closure of the external auditory canal (EAC) and the Eustachian tube and obliteration of the surgical cavity with abdominal fat.[1] The advantages of SP that make it an ideal procedure in difficult situations in CI are manifold. First, it allows isolation of the surgical cavity from the external environment, thereby leading to a low risk of postoperative infections. Second, it permits a better sealing of cerebrospinal fluid leaks, thereby reducing the risk of secondary meningitis. Third, SP provides an excellent exposure of the promontory and the round window, enabling the surgeon to perform additional procedures, if necessary, like a drill out in case of difficulty in insertion. In a pediatric population, there are also other indications that can be considered, including recurrent acute otitis media (RAOM) and otitis media with effusion (OME), which will be discussed in this study.

Subtotal petrosectomy is contraindicated in candidates who undergo CI with a residual hearing that is susceptible to electroacoustic stimulation, due to the fact that closure of the EAC impedes electroacoustic stimulation.

The use of SP for CI is associated with a very low rate of complications,[2] which can be basically divided into 3 categories: (1) infection of the abdominal fat, (2) dehiscence of the EAC closure, and (3) development of cholesteatoma in the obliterated cavity.

The aim of this study was to review the indications for SP for CI, report our management of complications, and review the technical aspects that are critical for a successful implantation.

Material and Methods

This multicenter retrospective study was conducted following the principles stated in the Declaration of Helsinki. All patients that underwent CI in combination with SP in 3

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tertiary referral centers and one quaternary referral center between April 2004 and October 2013 were included in the study. The surgical technique of CI in combination with SP is further described elsewhere.[1]

Some of the patients in the study have been reported elsewhere previously.[2,3] Eligible patients were identified from the cochlear implant databases of each center. Data including clinical indication for SP, imaging findings, surgical features, and complications were collected. Complications were classified according to the consensus reporting proposed by Hansen et al.[4]

All patients underwent otological examination and preoperative audiological assessment, including pure tone average (PTA; average of 0,5-1-2-4 KHz), speech discrimination score, and auditory brainstem responses. All patients underwent both gadolinium-enhanced magnetic resonance imaging (MRI) and high-resolution computed tomography (HRCT) of the temporal bone. A postoperative HRCT at 1, 3, 5, and 10 years was performed to detect the eventual development of entrapped cholesteatoma in the obliterated cavity.

In addition, a systematic review of the English literature was conducted with the search engine Pubmed with the key terms *subtotal petrosectomy*, *middle ear obliteration*, and *cochlear implant* to identify all publications in which subtotal petrosectomy in combination with CI had been performed.

Results

Patients Demographics

Between April 2004 and October 2013, 110 CI were placed in combination with SP in 104 patients. All implantations were performed simultaneously with SP except in 2 cases. There were 98 unilateral implantations and 6 bilateral implantations. Mean age was 52.2 years (range, 1-86 years). Sixty-five (62.5%) were males and 39 (37.5%) were females. In 55 cases (50%), the cochlear implant was placed in the right ear and in 55 cases (50%) in the left ear. Mean follow-up was 28.5 months (range, 12-108 months). Eight patients were lost in the follow-up; all of them had been implanted unilaterally.

Indications for Subtotal Petrosectomy

Indications for SP included a wide spectrum of pathologies as shown in Table 1. In this table, a review of the largest series published is presented as well, which will be discussed later.

The most common indication for SP in combination with CI in our series was the performance of a previous canal wall down technique (33 cases, 30%).

The second most frequent group was patients with middle ear disease (29 cases, 26.37%). Under the term *middle ear disease*, we have grouped all the entities that could affect the middle ear function and negatively influence the clinical outcome of the CI. These entities included RAOM, OME, tympanic membrane perforation or retraction, chronic supurative otitis media (CSOM), and cholesteatoma chronic otitis media (CCOM) (Table 1). All these cases were implanted simultaneously to SP, except for 1 patient with bilateral CCOM, who was bilaterally and sequentially implanted in a staged procedure.

The third most common indication, with 13 patients (11.82%), was cochlear ossification. In 6 cases, a total ossification of the round window (RW) was encountered (Figure 1A), associated with a sclerotic mastoid. The remaining 7 patients presented with different degrees of ossification of the basal turn that required cochlear drill out techniques (Figure 1B). In all cases, complete insertion of the electrode array was achieved.

Other indications for SP included temporal bone fracture, inner ear malformations, unfavorable anatomical conditions, Meniere's disease, and previous ear surgery.

Intraoperative Problems

Intraoperative problems took place in 7 cases (6.37%) and are detailed in Table 2.

Postoperative Complications

Postoperative complications occurred in 13 patients (11.83%). Seven patients experienced major complications (6.37%), and 6 patients had minor complications (5.46%). Details of patients with their complications are described in Table 3 and in a supplementary file.

Discussion

Cochlear implants are an effective method for rehabilitation of profound sensorineural hearing loss, with a low rate of complications.[4] In former times, CI was significantly limited by certain middle ear pathologies and anatomical variations.[5] In 1988, Fisch and Mattox[6] systematized the surgical steps of SP. Five years later, Parnes et al[7] were the first to employ this surgical technique simultaneously to CI, allowing for the first time hearing rehabilitation in cases considered non-candidates for CI before.

In the past 2 decades, SP has been an essential tool in the field of middle ear surgery and implantology. Since the first CI in 1960,[8] indications for CI have extended progressively over the years both from an audiological and clinical point of view. Parallel to the constantly increasing audiological indications, the inherent advantages of SP have been the key to allow CI in special situations such as middle ear disease[2] or in combination with neurotological procedures.[9]

The different clinical indications for SP for CI and their most critical aspects are detailed in the following.

Table 1. Review of the Literature on the Largest Series of Patients Treated With Subtotal Petrosectomy in Cochlear Implantation.

			Indication SP														
Reference (Year)	No. of Patients	No. of Ears	RAOM	OME	CCOM	CSOM	Previous CWD Mastoidectomy	TM Perforation/ TM Retraction	Previous SP	Inner Ear Malformations	Temporal Bone Fractures	Cochlear Ossification/ Fibrosis	Unfavorable Anatomical Conditions	Others	Staging	Complications	Follow-up
Parnes et al (1993)	1	1	0	1	0	0	0	0	0	0	0	0	0	—	Single stage: 1	NR	15 mo
Gray and Irving (1995)	4	4	0	0	2	2	0	0	0	0	0	0	0		Second stage: 4	NR	NR
Axon et al (1997)	5	5	0	0	2	0	3	0	0	0	0	0	0	—	Single stage: 2 Second stage: 3	No	NR
Bendet et al (1998)	5	7	0	0	0	0	1	1	0	1 (Mondini)	1		1	Bilateral middle ear adenoma: 2	Single stage: 5 Second stage: 2	No	NR
Issing et al (1998)	14	14	0	0	6	2	2	0	0	1 (Mondini)	1	0	0	Inflammatory pseudotumor: 2	Single stage: 10 Second stage: 4	Seroma: 1 Retroauricular fistula: 2 Explantation: 1	28 mo
Kim et al (2004)	2	2	0	0	0	0	2	0	0	0	0	0	0	—	Single stage: 2	No	12-47 mo
Leung and Briggs (2007)	17	17	0	0	0	8	8	0	0	0	0	0	1	—	Single stage: 7 Second stage: 10	Opened Eustachian tube: 1 Breakdown EAC closure: 1 Mastoiditis: 1 Implant migration: 1	3-11 y

(continued)

Table 1. (continued)

Reference (Year)	No. of Patients	No. of Ears	Indication SP												Staging	Complications	Follow-up
			RAOM	OME	CCOM	CSOM	Previous CWD Mastoidectomy	TM Perforation/ TM Retraction	Previous SP	Inner Ear Malformations	Temporal Bone Fractures	Cochlear Ossification/ Fibrosis	Unfavorable Anatomical Conditions	Others			
Free et al (2013)	31	32	0	0	0	4	13	0	4	2 (CHARGE syndrome, incomplete partition type I)	4	5	0	—	Single stage: 32	Electrode extrusion: 1 Subcutaneous cerebrospinal fluid leakage: 1	18-96 mo
Barañano et al (2013)	36	39	7	3	5	14	2	2	0	0	0	0	5	—	Single stage: 10 Second stage: 27	Abcess: 3 Subcutanous emphysema: 1 Granulation EAC: 1 Explantation: 6	NR
Present study	104	110	2	0	9	14	33	4	2	10	9	13	3	Meniere disease:2 Previous surgery:8 Head trauma (without fracture):1	Single stage: 103 Second stage: 2	Table 3	1-180 mo

Abbreviations: CCOM, cholesteatoma chronic otitis media; CSOM, chronic supurative otitis media; CWD, canal wall down; EAC, external auditory canal; NR, not recorded; OME, otitis media with effusion; RAOM, recurrent acute otitis media; SP, subtotal petrosectomy; TM, tympanic membrane.

Figure 1. (A) HRCT scan, left temporal bone. Ossification of the RW secondary to chronic otitis media. Note that the tympanic membrane is thickened and retracted. (B) HRCT scan, left temporal bone. Ossification of the RW and basal turn of the cochlea secondary to otosclerosis. Cochlear drill out was required to insert the electrode. HRCT, high resolution computed tomography; RW, round window.

Indications

Previous Canal Wall Down Technique

The existence of a previous canal wall down technique has been the most frequent indication for SP in our series (30%). Subtotal petrosectomy is the preferred technique in these cases, widely supported by the experience of numerous groups.[2,10-14] The rationale for the use of SP in these cases is to obtain an isolated cavity with low risk of infections and diminish the risk of extrusions. In cases of open cavities with cochlear implants, the possibility of repeated infections in the cavity constitutes a high risk of meningitis and labyrinthitis[15] and secondary damage to the electrode array. In addition, there is an increased risk of electrode extrusion[14] and a higher probability of trauma to the electrode array if revision surgery is needed.[16] Thus, SP is strongly recommended to diminish the incidence of these complications in cases of a previous canal wall down technique.

Numerous techniques have been proposed as an alternative to SP in these cases.[14,17-21] Some authors[14,17] propose partial obliteration of the cavity to protect the electrode, employing the combination of different materials such as musculocutaneous flaps, periosteal flaps, or tragal cartilage. In other cases, the posterior wall of the EAC has been reconstructed and the cavity obliterated with a Palva flap.[18] These obliterative techniques are aimed to protect the electrode array but do not eliminate the risk of infections in the cavity and device extrusions and do not constitute an optimal alternative to SP.

Colletti et al[20,21] proposed the classical middle fossa approach for CI in patients with an open cavity in order to bypass the middle ear cavity. This approach does not eliminate the risk of infections in the cavity and exposes the patient to the additional unnecessary risks of the craniotomy and temporal lobe compression. Thus, we do not recommend middle fossa approach for CI.

Chronic Middle Ear Disease

The second most common indication for SP in this series was the presence of chronic middle ear disease (26.37%). The problems derived from CI in patients with chronic middle ear disease are mainly infection involving the implant and extrusion of either the electrode or the receiver. The basic principles for safe implantation in these circumstances are to eradicate the disease and obtain a closed, clean, isolated cavity.[10] Subtotal petrosectomy makes feasible these objectives with an important decrease in the rate of recurrence of the primary disease and keeps isolated the electrode reducing extrusion rate.[15]

In cases of CSOM, our philosophy is to perform CI and SP simultaneously; only in the presence of an active purulent infection we consider delaying CI to a second stage. Some groups[19,22,23] propose performing first a preliminary surgery (myringoplasty or tympanoplasty) to create a stable and dry middle ear, followed by CI 3 to 6 months later. These alternative techniques entail several drawbacks: first, the possibility of failure of the preliminary surgery, with the subsequent need for a revision surgery and delayed time to implantation; second, the risk of recurrence of the disease once the cochlear implant has been placed, with secondary extrusion of the electrode through the tympanic membrane and the risk of damage to the electrode if revision surgery is needed. Thus, in order to avoid these undesirable complications and shorten the time to implantation, we stand for treatment of the primary pathology with SP and CI in a single stage in the majority of the cases.

In cases of CCOM, many authors[10,11,15,16] advocate for routinely performing CI in a second stage after SP to reduce the risk of residual cholesteatoma. Given that SP provides a wide exposure, facilitating removal of all the disease, our recommendation is to perform CI and SP in a single stage.[12,24] Nevertheless, if an infiltrative cholesteatoma is encountered or there is any doubt about complete removal of the matrix, implantation should be postponed at least 12 months. From our series of 9 cases of CI in CCOM, only in 2 cases (same patient bilaterally) CI was performed in a second stage due to infiltrative cholesteatoma. No residual cholesteatoma has been found in our series to date.

The use of SP in combination with CI as primary management of patients with RAOM or OME has not been clearly established in the literature. Several studies endorse the use of ventilation tubes in the management of pediatric patients with RAOM and OME candidates to CI.[25,26] However, the early use of SP with CI in children prone to

Table 2. Summary of intraoperative findings and complications and their management.

Case	Complication	Sex Age (y)	Presumable Cause	Management and Further Complications
1	Gusher, electrode array in the IAC	M 3	Cochlear hypoplasia	Reposition of the electrode array 1 week after implantation Device failure and reimplantation 6 months later
2	Gusher	M 2	Common cavity	Subcutaneous CSF collection on immediate postoperative period. CSF sterile puncture and compression bandage 7 days
3	Gusher	F 24	Vestibular aqueduct dilatation	SP (no additional treatment)
4	Gusher	F 4	Incomplete partition type II	SP (no additional treatment)
5	Gusher	M 7	Incomplete partition type II	SP (no additional treatment)
6	Gusher	M 13	Incomplete partition type III	SP (no additional treatment)
7	Intraoperative CSF leak	F 61	IAC opened during surgery	IAC sealed with temporalis muscle

Abbreviations: CSF, cerebrospinal fluid; IAC, internal auditory canal; SP, subtotal petrosectomy.

otitis media eradicates the disease definitively and solves the hearing problem in a single surgery, shortening the time to hearing rehabilitation. In addition, it eliminates the risk of middle ear disease in implanted ears and subsequent possible serious complications such as meningitis or labyrinthitis and the need for future surgeries with risk of damage to the electrode.[13] We have placed cochlear implants in a single stage together with SP in 2 patients of 1 and 9 years with RAOM refractory to ventilation tubes, with no further complications.

Inner Ear Malformations

In patients with inner ear malformations, anomalies in the trajectory of the facial nerve and middle ear malformations are not uncommon, which hampers the identification of the anatomical landmarks for implantation.[27] In addition, inner ear malformations are commonly associated with a CSF leak of perilymph gusher.[28,29] Besides, meningitis may arise with and without CI in this special group of patients since the high CSF pressure often produces a leak in 1 of the windows.[12,15,30]

Because of the above mentioned factors, the use of SP is strongly recommended for implantation in malformed ears. First, it allows a better exposure of all the anatomical structures of the middle ear, facilitating implantation in cases with associated middle ear malformations or facial nerve trajectory anomalies. Second, Eustachian tube sealing and obliteration of the cavity with abdominal fat are the most effective way to isolate the inner ear from the external environment. As a result, the possibility of CSF leak and meningitis is significantly reduced.

From our series of 10 CI in malformed ears, there was only 1 major complication (case No, 1), which consisted in the accidental insertion of the electrode array inside the IAC. This patient was surgically revised 1 week later, and the electrode array was repositioned, but 6 months later, the device failed and the patient was ipsilaterally reimplanted. From the remaining patients, an intraoperative CSF gusher was encountered in 5 cases (Table 2); among them, only 1 had further complications, which consisted of a subcutaneous CSF collection detected 1 week after implantation and successfully managed conservatively. No episodes of meningitis have arisen in this group to date.

Cochlear Ossification/Fibrosis

Although in mild to moderate cases drill out procedures may be performed through a posterior tympanotomy with or without transcanal approach combination,[31] the authors advocate the use of SP in most of these cases. Isolate RW ossification does not generally necessitate SP per se, yet we did employ this approach in 6 of our cases in which there was a difficult anatomical access due to a sclerotic mastoid (Figure 1A).

The rationale for supporting the use of SP is mainly to avoid unnecessary risks that exist during drill out procedures done through a posterior tympanotomy like a damage to the facial nerve or other important structures. Subtotal petrosectomy provides an adequate approach to safely drill out the cochlea and to identify and control landmarks such as the internal carotid artery and the jugular bulb (JB). In the eventuality that CI was impossible with an SP, the procedure could then be easily switched to a translabyrinthine approach for an auditory brainstem implant (ABI) in the same sitting by merely enlarging the same approach.[32]

Temporal Bone Fractures

Temporal bone fractures affecting the otic capsule are invariably associated with a permanent risk of CSF leak

Table 3. Summary of Major and Minor Complications and Their Management.

Type	Case	Complication	Sex Age (y)	Onset	Presumable Cause	Management
Major complications	1	Device failure	M 3	6 mo	Electrode array inside IAC, repositioned 1 week after implantation	Ipsilateral reimplantation.
	8	Extrusion	F 68	24 mo	Foreign body reaction	2 years after implantation, revision surgery for extrusion of the receiver (reposition of the receiver). A few months later explantation and contralateral reimplantation with SP.
	9	Extrusion	M 41	14 mo	Infection	5 months after implantation, revision surgery for partial extrusion of the electrode array The scar reopened, and the electrode array extruded. He was explanted 14 months after implantation. After 1 week of systemic and local administration of antibiotics through a mastoid drainage, he was ipsilaterally reimplanted.
	10	Extrusion	M 15	4 mo	Infection, CCOM	Tympanoplasty was performed elsewhere 3 years before for CCOM. A residual cholesteatoma was detected, for which an SP in combination with CI was performed. 4 months later the electrode array extruded through the postauricular incision. Upon revision, granulation tissue was formed, filling the cavity. Explantation was done, leaving the tip of the electrode inside the cochlea. Programmed for ipsilateral reimplantation.
	11	Extrusion	M 48	15 mo	Infection	Bilateral cholesteatoma underwent bilateral SP in combination with simultaneous bilateral binaural cochlear implantation. Postoperative bilateral retroauricular infection with left partial extrusion of the receiver Left temporal muscle flap with reopening of the scar. Finally, he was explanted 15 months after implantation. 17 months later, he was reimplanted on the right ear.
	12	Extrusion	F 49	2 wk	Foreign body reaction	Retroauricular dehiscence with partial extrusion of the receiver resolved with temporalis muscle flap.
	13	Permanent facial palsy (grade III)	F 78	Immediate postoperative	Uncovering facial nerve, CSOM	Corticosteroids; recovered to grade II within 17 mo.
Minor complications	14	Vertigo	M 54	Immediate postoperative	Unknown	Vestibular depressants and antiemetics; recovered within 48 h.
	15	Vertigo	F 68	Immediate postoperative	Unknown	Vestibular depressants and antiemetics; recovered within 48 h.
	16	Transient facial palsy (grade III)	M 3	4 days	Unknown	Corticosteroids; recovered grade I within 1 mo.
	17	Retroauricular dehiscence	M 53	Intermediate postoperative	Multiple surgeries	Direct closure under local anaesthesia.
	18	Subcutaneous seroma	M 73	Intermediate postoperative	Unknown	Puncture and compression bandage.
	2	Subcutaneous collection CSF	M 2	Immediate postoperative	Common cavity, gusher	Puncture and compression bandage.

Abbreviations: CCOM, cholesteatoma chronic otitis media; CI, Cochlear implantation; CSOM, chronic supurative otitis media; CSF, cerebrospinal fluid; IAC, internal auditory canal; SP, subtotal petrosectomy.

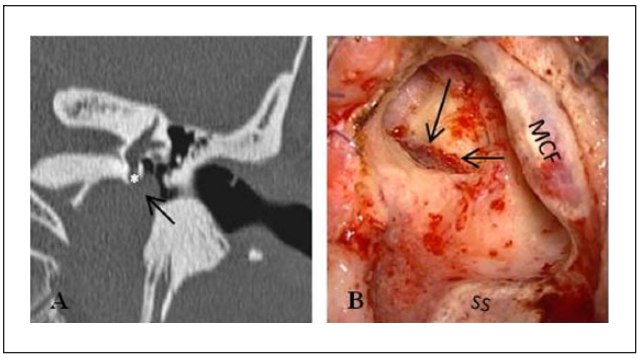

Figure 2. (A) HRCT scan, left temporal bone. High jugular bulb (black arrow) in contact with the RW (white asterisk). (B) Same patient, a subtotal petrosectomy has been performed, obtaining an excellent control and visibility of all middle ear structures. The high jugular bulb (long black arrow) and the RW niche (short black arrow) can be seen. HRCT, high resolution computed tomography; MCF, middle cranial fossa; RW, round window; SS, sigmoid sinus.

and meningitis. It is known that the bone of the otic capsule does not heal with new bone formation but with a thin layer of fibrous tissue that constitutes the only barrier between the central nervous system and the middle ear.[33] Thus, a fracture involving the otic capsule creates a communication between the central nervous system and the middle ear with an increased risk of CSF leak and meningitis.[34]

This risk can be minimized by using an SP in association with cochlear implant insertion.[2,6,12,15,34,35] Subtotal petrosectomy offers an optimal isolation of the inner ear spaces and the cochlear implant from the external environment. In fact, we did not have a single case of meningitis or CSF leak after CI in temporal bone fractures in this series.

Unfavorable Anatomical Conditions

In the presence of unfavorable anatomic conditions such as contracted or sclerotic mastoid and anterior sigmoid sinus, we support the use of SP as it provides wide exposure of the entire promontory.[10,12,13] We also recommend SP in cases of high JB in contact with the RW (Figures 2A, 2B), to avoid damage to the JB while performing the posterior tympanotomy or inserting the electrode.

These cases, although very uncommon, represent a potential danger to the nervous and vascular structures of the middle ear and must be approached adequately.

Some alternatives to SP in difficult anatomical situations have been proposed, such as the intact posterior meatal skin canal wall down technique[36] or the transattical approach.[37] These alternatives are not hassle-free but may have a role in cases of residual hearing.

Contraindications

Subtotal petrosectomy is not recommended in patients with residual hearing to electroacoustic stimulation as closure of the EAC precludes acoustic stimulation through the canal itself.[38]

In case of an active middle ear infection, the surgery must be planned in 2 stages.[39] We recommend a first surgical time consisting of SP with eradication of the pathology and a second stage for CI 3 to 6 months later.

Likewise, in the presence of a cholesteatoma wherein a complete excision of the matrix cannot be assured, the CI can be performed in a second stage. To detect residual cholesteatoma, we recommend a time interval of at least 12 months between the first and the second surgery.

Entrapped Cholesteatoma and Follow-up

Entrapped skin or matrix and possible long-term development of cholesteatoma are the main risks that need to be addressed on the long-term follow-up of these patients; it must also be considered that postoperative imaging using MRI gives artifacts and will make follow-up on the primary pathology more difficult.

In our institutions, follow-up is performed with HRCT at 1, 3, 5, and 10 years to check entrapped cholesteatoma. The radiological interface created by the fat in the cavity increases the diagnostic efficacy of HRCT for residual and entrapped cholesteatoma.[2] If HRCT is not conclusive, MRI up to 1.5 T can be safely performed with the CI in place.[40] Ultimately, if distortions of the image hamper visualization of the area of interest, the magnet can be removed under local anaesthesia and replaced immediately after the MRI.

In this series, we have not had a single case of residual or entrapped cholesteatoma after CI in combination with SP to date.

Conclusions

Subtotal petrosectomy with blind sac closure of the EAC and obliteration of the cavity with abdominal fat is a useful alternative technique in difficult cases of CI. In the past 2 decades, the introduction of SP has been instrumental in allowing CI in patients previously considered to be ineligible for implantation. The distinct advantages of SP are that it allows obtaining a cavity isolated from the external environment, thereby reducing the risk of infections, and when needed, it provides excellent exposure of the promontory and surrounding areas, improving the access and maneuverability during the surgical procedure. Overall, SP is a safe surgical technique associated with a low rate of complications. Follow-up with HRTC is mandatory to check entrapped cholesteatoma.

Declaration of Conflicting Interests

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