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The Role of Subtotal Petrosectomy in Cochlear Implant Surgery–A Report of 32 Cases and Review on Indications

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Objective: To report and review 32 cases of subtotal petrosectomy (SP) in cochlear implant (CI) surgery and to define the indications and contraindications for this procedure
Study Design: Retrospective case review + case reports.
Setting: Tertiary skull base center.
Patients: Cochlear implant database: 32 subtotal petrosectomies in 31 patients.
Interventions: Subtotal petrosectomy with blind sac closure of the external auditory canal, closure of Eustachian tube, and abdominal fat obliteration in combination with cochlear implantation.
Results: Indications for SP in CI surgery were as follows: chronic otitis media (n = 4), previous radical cavity (n = 13), previous subtotal petrosectomy (n = 4), ossification of the cochlea (n = 5), malformation of the inner ear (n = 2), and temporal bone fracture (n = 4). One patient was simultaneously bilaterally implanted; 2 cases were revisions. All procedures were performed in 1 stage. In 2 cases, complications were encountered (6%), one of which lead to reoperation (3%). None of the patients was explanted.
Conclusion: Subtotal petrosectomy combined with cochlear implantation is a procedure required in specific situations and lowers the risk of repetitive ear infections, CSF leakage, and meningitis by closing off all connection with the external environment. Additionally, it gives excellent visibility and access in difficult anatomy or in drill-out procedures. The complication rate of 6% is comparable with normal cochlear implantation. Preservation of residual hearing can be considered the only absolute contraindication as an open external meatus is necessary for use of electroacoustic stimulation. Risks of the SP+CI procedure are infection of the abdominal fat, breakdown of the blind sac closure, and entrapped cholesteatoma. Follow-up with CT imaging is therefore mandatory. **Key Words:** Blind sac closure—Cochlear implant—Implant extrusion—Malformation—Meningitis—Obliteration—Ossification—Radical cavity—Retrofenestral otosclerosis—Subtotal petrosectomy—Temporal bone fracture.

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Cochlear implantation represents a well-established method for hearing rehabilitation in patients with severe-to-profound hearing loss. Surgical risks are fairly low, and good results are achieved in a high percentage of cases (1–3). Issing et al. and Bendet et al. described subtotal petrosectomy (SP) with blind sac closure of the external auditory canal (EAC), closure of the Eustachian tube, and obliteration with abdominal fat being used in cases of cochlear implantation in the presence of a previous radical cavity and/or in chronic infections of the middle ear. Also, they described this procedure for cochlear implantation in malformed cochleae with high risks of CSK leakage or as salvage procedure in cases with repeating episodes of meningitis. SP thus expands the possibilities for CI surgery (4–8). The objective of this procedure is to create an environment with less risk of infection, better possibilities for sealing off any CSF leakage, and less risk of developing meningitis. However, SP may be adopted with significant advantages in additional situations concomitant with cochlear implantation as is illustrated in this paper. The second objective of

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TABLE 1. *Demographics of study participants*

All participants number = 31	
Sex	
Male	22
Female	9
Age (range)	2–72 yr
Follow-up time (range)	18–96 mo (n = 29; 2 missing)

performing SP in combination with a CI would be to get better access and visibility during surgery.

In this study, we chose to call this procedure, using the formulation of Fisch and Mattox (9) as described in his skull base book, a subtotal petrosectomy with blind sac closure of the EAC and abdominal fat obliteration; however, in literature also, "middle ear obliteration" or "canal wall down mastoidectomy" with blind closure of the EAC are being used. In essence, there is no difference between the procedures performed under these terms.

MATERIALS AND METHODS

The database of CIs performed at the Gruppo Otologico from 2004 to 2010 contained 31 patients treated by means of 32 SPs. There was 1 bilateral case: a simultaneous implantation in bilateral temporal bone fractures. This group included 22 men and 9 women; their age ranged from 2 to 72 years. There were 4 children present in this group, aged 2, 3, 3, and 9 years. All procedures were single-stage procedures. The surgery was performed by 5 different surgeons, following the same surgical principles. Table 1 shows the included procedures.

SURGICAL TECHNIQUE

The surgery starts with a retroauricular incision, extended posterior-superiorly as in all our cochlear implant cases (4,8,9). The EAC is completely transected, and the skin is everted to perform a blind sac closure. It is medially reinforced with a second layer obtained by the subcutaneous tissue and cartilage of the tragus. Mastoidectomy is performed followed by removal of the posterior wall of the bony EAC. Anterior, inferior, and superior walls of the EAC are drilled to completely expose the annulus. The remnants of the EAC skin are removed en bloc with the tympanic membrane, the incus, and the malleus, if present. Drilling is then extended to as many pneumatized cells as possible (Fig. 1B). Residual mucosa is removed from the promontory and the tubal orifice. In case of chronic suppurative otitis media with/without cholesteatoma, all epithelial and inflammatory tissue is meticulously removed from the cavity. The Eustachian tube is packed with muscle, cartilage, or bone wax. This is performed before insertion of the array. Implant insertion is performed through the round window membrane (when present); in ossification cases, drill-out is necessary (5 cases in this study). The cavity is then packed with abdominal fat impregnated in rifampicin (2 ampullae: 500 mg in 6 ml), and the wound is sutured in 2 layers, the musculo-periosteal layer covering the fat.

In presence of a previous meatoplasty, closure of the EAC may be difficult. A possible solution for this is to create a long anterior-based skin flap from the skin covering the tragus and suture it to the skin of the posterior aspect of the external meatus. This technique was not necessary in this population.

In presence of a radical cavity, progressive elevation of the skin layer covering the cavity should be meticulously achieved to avoid leaving skin debris with risk of inclusion cholesteatoma in the obliterated cavity. Also in cases presenting with cholesteatoma, all matrix should be removed to keep the risk of residual cholesteatoma as small as possible.

In presence of a previous SP, the wound can simply be reopened using the same incision, and the fat can be removed. Then, the cochlea is opened via the round window, and the cochlear implantation is performed. The cavity is filled with freshly harvested abdominal fat.

Insertion of the CI is usually performed during the same stage of the SP; it can however be delayed to a second-stage surgery in cases with presence of active purulent

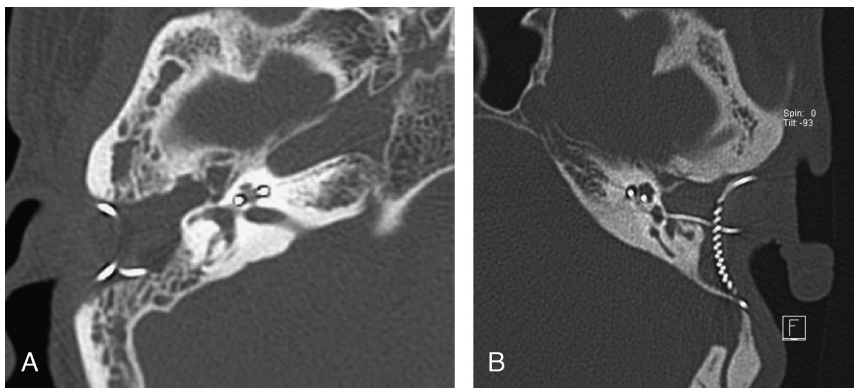

FIG. 1. *A*, Postoperative CT scan after subtotal petrosectomy with cochlear implantation in a patient affected by a temporal bone fracture on the left side. Note the fracture line through the labyrinth. Also note the amount of residual air cells within the mastoid. In the SP+CI technique, all residual cells within the mastoid should be removed: (*B*) A better example of a postoperative CT scan after subtotal petrosectomy with cochlear implantation in a left ear. All air cells within the mastoid are rightfully removed.

TABLE 2. *Indications for 32 subtotal petrosectomies with cochlear implantation in 31 patients with number of revisions, complications, and outcome*

Indication	No.	Notes	Complication	Outcome
Chronic otitis	4	0	—	
No cholesteatoma	4			
Cholesteatoma	0			
Previous canal wall down surgery	13	0	1 Extrusion of electrode array with polipous tissue and skin defect	Reoperation with repositioning of array
Previous subtotal petrosectomy	4	1 Previous explantation of cochlear implant, presenting with ossification (not included in ossification group)	—	—
Cochlear ossification	5	1 Case underwent 2 previous attempts elsewhere through a facial recess approach	—	—
Otosclerosis	3			
Meningitis	2			
Inner ear malformation	2	0	1 Subcutaneous cerebrospinal fluid leakage	Sterile puncture and head bandage; no residual effects
Temporal bone fracture	4[a]	0	—	—
Total	32		2 Complications (6%)	1 Reoperation (3%); 1 conservative treatment

[a]One patient with bilateral implantation.

discharge judged as too high a risk for the development of meningitis or when the risk of a residual cholesteatoma is considered too high; that is, when there is uncertainty of complete removal. In cases with risk of ossification of the cochlea, it is mandatory to perform CI insertion in a single-stage procedure, being the best and possibly only opportunity for introduction.

Perioperatively, antibiotics were administered: piperacilline 2 g twice daily during 7 days. After surgery, a head bandage was carried for 48 hours; then, the head wound was checked, and additionally 48 hours of headbandage followed. Time of stay in the hospital was 2 nights postoperatively. Facial nerve monitoring was used during all procedures. All patients enrolled in the vaccination program against *Streptococcus pneumoniae*.

RESULTS

Thirty-one patients were operated by means of 32 SPs combined with cochlear implantation. One patient was operated and implanted bilaterally. The indications for the procedure were variable (Tables 1 and 2).

Four cases consisted of chronic otitis without presence of cholesteatoma. In all these cases, cochlear implantation followed during the same procedure. No complications were registered in these patients.

Thirteen patients had had previous surgery resulting in a canal wall down procedure. One of these 13 needed revision surgery because of extrusion of the middle part of the array through the retroauricular skin (while the cochlear electrode was still in original and functioning position in the cochlea). This extruding part of the array was partially mobilized, reaccomodated in the cavity, and protected with an inferiorly pedicled muscle flap from the sternocleidomastoid muscle. The skin defect was surgically closed after circumferential excision and healed without further intervention.

Four patients were previously treated with a SP for chronic otitis/cholesteatoma before progression of the hearing loss requiring cochlear implantation. In these patients, the cavity was reopened and prepared for cochlear implantation. One case was revision surgery from a CI operation performed elsewhere: in this patient, the cochlea was ossified after removal of the previous cochlear array and needed a drill-out procedure for getting access to the intracochlear lumen. A full insertion of the cochlear electrode was subsequently performed.

In 5 patients, ossification of the cochlea was present because of otosclerosis (3) and meningitis (2). Four cases required a drill-out of the basal turn of the cochlea, whereas in 1 patient with meningitis, a full insertion in the scala vestibuli was performed. The second meningitis

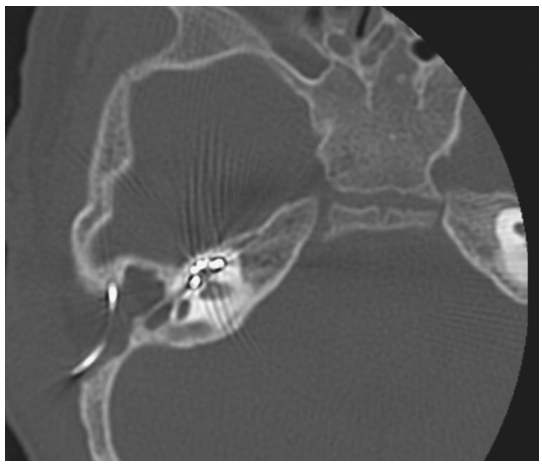

FIG. 2. Postoperative CT scan in the patient with CHARGE syndrome after cochlear implantation. Note the absence of the lateral semicircular canal (pathognomic for CHARGE) and the small size of the vestibulum. Also, a different angulation of the vestibular aquaduct is often present in CHARGE (not visible on this CT).

case was already operated twice in another center using the standard CI approach without successful CI introduction. Also in the previous SP group (n = 4), 1 patient had ossification of the cochlea as a result of explantation during revision surgery; this patient was not counted in this ossification group. In 2 additional cases of complete cochlear ossification (not included in this study) despite the use of SP, it was not possible to insert the cochlear array, and the surgery was converted to auditory brainstem implantation.

Two patients both children were diagnosed with an inner ear malformation: CHARGE syndrome and incomplete partition type I. In the last case, the procedure was complicated by a subcutaneous collection of CSF postoperatively. This was treated by sterile puncture and additional headbandage for 7 days. The patient recovered with no residual effects (Fig. 2).

Three patients had a bilateral temporal bone fracture with loss of hearing. One of these patients was operated on bilaterally simultaneously.

Of these 32 procedures, there were 2 revision cases of previous surgery performed elsewhere. No staged procedures were performed for any of the indications in this cohort of patients.

In these 32 procedures, 2 complications (1 extrusion and 1 subcutaneous CSF collection) were registered (6%). The first case needed reoperation (3%). Neither needed explantation.

Two patients were lost for follow-up. The remaining patients had a follow-up of at least 18 months (range, 18–96 mo). All patients are scheduled for a control CT scan at 1, 3, 5, and 10 years to monitor the development of residual cholesteatoma in the obliterated cavity. No cholesteatoma has been found in this population until now.

DISCUSSION

In this paper, 31 patients are presented with 32 subtotal petrosectomies with cochlear implantation. The indications for performing SP + CI were divers and will be discussed in separate paragraphs. The overall rationale for performing SP + CI is either to create a cavity that is secluded from the outside environment to lower the risks of repeated infections, CSF leakage, and the subsequent risk of developing meningitis or to have a better and safer access to the cochlea, especially in difficult anatomic conditions.

Indications

The indications for performing SP + CI in our clinics are now the following: chronic otitis media/cholesteatoma, presence of a radical cavity/canal wall down technique, cochlear ossification/obliteration, inner ear malformations, fracture of the temporal bone with inner ear involvement, and unfavorable anatomic conditions.

For these indications, the patient followed the same route and inclusion criteria for cochlear implantation as used in patients without the need for SP.

Specific advantages for every group:

Chronic Otitis Media

SP allows an exclusion of the CI from the external environment. In patients with chronic otitis media, in whom a stable, aerated middle ear cleft cannot be achieved, the most important risks of cochlear implantation are represented by returning infection leading to either labyrinthitis or meningitis or leading to extrusion of the implant. This can be extrusion of the electrode array out of the cochlea or through the tympanic membrane or breakdown of the retroauricular skin covering the implant (7,10,11). Also, the fact that the cochlear implant might be introduced through a contaminated field during a 1-stage procedure has to be considered. In chronic suppurative otitis media, tympanoplasty or tympanomastoidectomy in the same procedure or in a staged procedure is the alternative option, however, with the remaining risk of recurrence of disease and also the need for 2 surgical procedures (7,10–14). Revision surgery (myringoplasty and tympanoplasty) in presence of a CI, however, is always a challenge with a serious risk of having to sacrifice the CI during the procedure. Also, a staged procedure means postponing the cochlear implantation, which is not in all cases favorable. The same considerations apply to cases with cholesteatoma; the patient has to wait for 6 to 12 months for the cochlear implantation during the second-look procedure, although there is never an absolute secure moment after cholesteatoma surgery. Residual cholesteatoma may appear later than after these 6 to 12 months and recurrent cholesteatoma even much later.

SP allows a safer situation in both types of pathology (simple chronic otitis and cholesteatoma) in those patients in whom no stable situation can be reached, with more security on total removal of all disease also because, due to absence of sensorineural hearing, removal of the disease and drilling may be performed more aggressively (4,8,15). However, radiologic follow-up remains necessary because of the risk of residual cholesteatoma in the obliterated cavity.

In addition, packing of the Eustachian tube during SP avoids also any connection with the nasopharynx, excluding infections from contact with the middle ear and CI. Because an atelectatic middle ear is common in chronic otitis media and may in the long-term lead to development of cholesteatoma, one should consider performing a SP in these cases (12). Additionally, also in patients with a cleft palate and thus impaired Eustachian tube function, one could consider SP, in anticipation of a future atelectatic middle ear with higher risk of development of cholesteatoma (10).

Presence of a Radical Cavity/Canal Wall Down Technique

In this situation, initial attempts to insert the CI in a radical cavity/canal wall down procedure resulted in complications, mainly extrusion of the array through the very thin epithelial lining of the cavity and infection (5–7,14). Also, cavities are in direct contact with the external environment and can repeatedly become infected, thus posing a threat for the cochlear implant. Although

there are different techniques of covering the array described (using muscle or cartilage) (16), we think that SP with abdominal fat is the safest and most permanent solution. Presently, the knowledge and agreement of adopting this technique in previous canal wall down procedures is growing.

Cochlear Ossification/Obliteration

Partially or totally obliterated cochlea can present as a result of postmeningitis deafness, in autoimmune inner ear diseases, after fracture of the labyrinth, as a result of chronic middle ear or cavity infection and in retrofenestral otosclerosis (17–21). In the presence of such pathology, a limited or more extensive drill-out procedure of the cochlea would be the first step in hearing revalidation.

A dangerous complication especially in a more extensive drill-out procedure could be damage of the carotid artery, situated in close relation to the most anterior part of the basal turn (22–25). In these cases requiring drilling of the total basal turn, identification of the carotid artery may be advisable. CT and MR imaging helps in the decision-making process and show the middle and basal turn with its patency; however, the clinical findings might be different because of limitations in imaging.

Both the limited and the extensive drill-out procedures are usually performed through a facial recess approach (sometimes with additional removal of the incus). However, this may result in a demanding and dangerous situation because the narrow approach does not permit to control all landmarks and is also uncomfortable to perform the surgical maneuvers. SP offers an unobstructed view of all the middle ear anatomy and, if required, offers the possibility to identify also additional structures as the carotid artery and the jugular bulb. The larger approach offers the possibility to perform safer maneuvers with better access.

Unfortunately, not all attempts for a drill-out procedure lead to successful implantation. In this center, 2 cases had to be converted to ABI procedures because no cochlear lumen could be detected. It is advisable to perform these difficult CI cases in a center where conversion to an ABI can be done during the same procedure (26).

Inner Ear Malformations

For this group of indications, there are 3 reasons to perform cochlear implantation using the SP technique. First, comparable with the situation in cochlear ossification, there is the need to identify the available landmarks, if possible. Because of possible aberrances of middle ear structures like the round window niche and facial nerve, this is even more important in this indication. Second, the possibility of an intraoperative CSF leak/gusher is higher in inner ear malformations (27–32). Sennaroglu (33) even showed 9 (45%) of 20 ears with various kinds of malformations to result in CSK leakage. We think the CSK leak/gusher is better controlled through the obliteration of the Eustachian tube orifice and cavity. Third, in inner ear malformations, the risk of developing meningitis during life span is higher than in the normal population, even without CI surgery (34). In some inner ear malformations (especially in incomplete partition Types I and III) a cystic structure filled with perilymph/CSF may be present at the oval window niche, with the bony footplate being incomplete (29,33,35). To keep this lifelong risk minimal, we prefer SP, especially for the more severe malformations, although also this technique might not provide complete safety.

Fracture of Temporal Bone With Inner Ear Involvement

In severe trauma leading to a fracture through cochlea or labyrinth with loss of sensorineural hearing, a cochlear implantation is a possible solution for hearing revalidation when the cochlear nerve is still intact (34–39). As fractures of the otic capsule do not heal with formation of new bone but just by a fibrous bonding (Fig. 1a), a lifelong risk of developing meningitis remains in a standard CI approach, but also without cochlear implant surgery, this risk is present (40). In these cases in our opinion, SP in combination with cochlear implantation is mandatory. Additionally, this procedure will also give better access and visibility in a fractured temporal bone with distorted anatomy (Fig. 3).

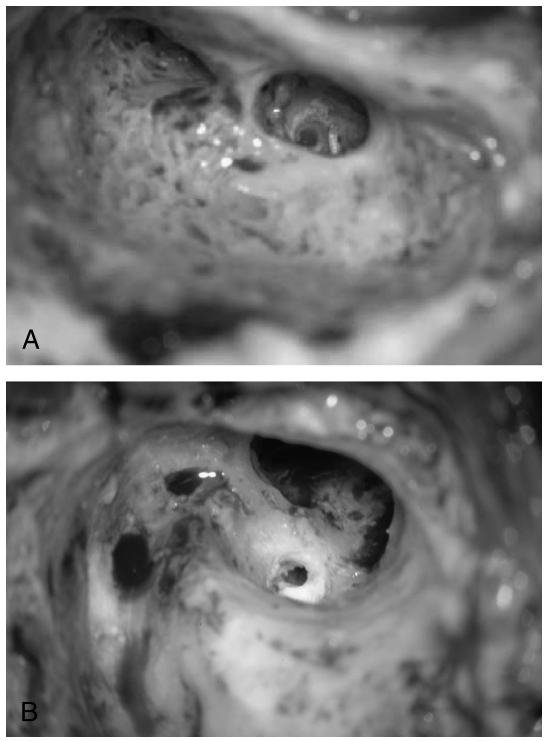

FIG. 3. Comparison of standard posterior tympanotomy technique (*A*) versus subtotal petrosectomy technique for cochlear implantation in a patient with ossification of the cochlea on the right side (*B*). Note the improvement in visibility and access to the cochlea and round window niche. Figure 3 shows the ossification in the basal turn, which is drilled out, giving access for insertion.

Unfavorable Anatomic Conditions for Posterior Tympanotomy

In cases with a very anteriorly positioned sigmoid sinus or other unfavorable anatomic conditions, a posterior tympanotomy will not be easy to perform; converting to SP will give much easier access. Also, the presence of a preexistent CSF leakage or meningocele will make SP favorable (41).

Contraindications for Subtotal Petrosectomy

There are also some reasons not to choose for SP with cochlear implantation. These can be divided in absolute contraindications and relative contraindications.

There is only one absolute contraindication: the presence of residual hearing to be spared and used by means of electroacoustic stimulation (42). For this technique, the speech processor is augmented with an intrameatal (acoustic) hearing aid. An open EAC is mandatory for the acoustic part of this stimulation.

Relative contraindications arise in presence of active infection of middle ear or cavity, especially in otomastoiditis caused by tuberculosis or a multiresistant microorganism. Reports on biofilm formation on cochlear implants have been described, making clear that once infected, it is difficult to save a CI by long-term antibiotic treatment (42–46).

In presence of active purulent discharge, the procedure can be staged when the risk of developing meningitis is considered too high. In these cases, SP with total eradication of the infection under antibiotic coverage has to be performed. After 3 to 6 months, when there is no sign of infection, the obliterated cavity can be reopened, and the cochlear implantation can be pursued. The use of fat to obliterate the cavity instead of muscle facilitates landmark identification during second-stage surgery, because of the fact that there are less adhesions. Although a vascularized, rotated temporalis muscle flap could also be used to obliterate the cavity, protecting the cavity and fat better against infection, we prefer to keep this structure in position to cover and protect the cochlear implant in the receiver niche. Until now, staging has not been required in our series.

Risks of Subtotal Petrosectomy

The risks ascribed to the SP approach are fat infection, breakdown of blind sac closure, and entrapped cholesteatoma. Additional risks are related to the abdominal wound; infection or subcutaneous hematoma can arise even if only a small amount of fat is required.

Infected fat in an existing SP is difficult to treat adequately with antibiotic therapy and might make revision surgery necessary. In our centers, abdominal fat is harvested shortly before use and is marinated in rifamipicin solution for 30 minutes secluded from air-born infections before application to keep the risk of infection as low as possible.

The blind sac closure of the EAC in SP can be considered the most vulnerable part of the skin suturing. Breakdown of the blind sac closure will give open access to the cavity with risk of infection and ingrowth of skin leading to cholesteatoma. Therefore, this closure needs to be performed with care. The second layer of the blind sac closure increases the stability of the closure and the safety of the procedure. No breakdown of the blind sac closure was found in this series.

The risk of entrapped cholesteatoma in the obliterated cavity should always be considered; however, meticulous surgical technique may reduce this risk to almost zero. In situations considered at high risk for a residual lesion, a staged procedure may be performed. However, all patients with SP + CI need prolonged postoperative follow-up. At our centers, CT follow-up is performed at 1, 3, 5, and 10 years after surgery. The presence of the CI impedes the routine use of MRI, even if MRI up to 1.5 Tesla can be performed using a bandage to fixate the cochlear implant. The visibility of possible cholesteatoma with MRI, however, will be impaired because of the presence of major artifacts on imaging. We prefer CT imaging in bone window for radiologic follow-up (Fig. 1). Although not the golden standard to detect residual cholesteatoma, the capacity of the CT in this particular situation is improved by the presence of the fat that creates an ideal interface for differentiation (Fig. 4). Additionally, repetition of CT examination could proof a lesion to grow and thus be more suspect for cholesteatoma.

Complication Rate in the Studied Population

In the 32 SPs + CI in this study, a complication rate of 6% was found. Another study showed 14 patients treated with SP and CI for chronic otitis with 3 complications: a temporary facial palsy, a retroauricular fistula, and an inflammation, making explantation necessary. This gives a complication rate as high as 21% in this population (5).

Comparison with the complication rate in normal CI surgery using posterior tympanotomy is interesting; we find 15.7% complications, of which, 4.5% major, in a Danish study with 148 pediatric and adult patients combined (1),

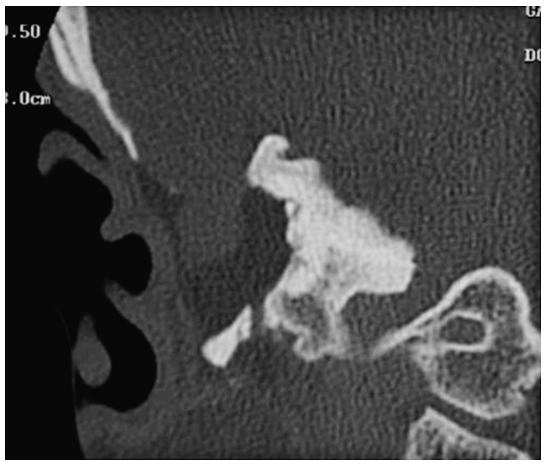

FIG. 4. Example of CT imaging of a residual cholesteatoma after removal of a petrous bone cholesteatoma. Note the difference in the density of the cholesteatoma compared with the abdominal fat.

7.3% in a German study with 697 pediatric and adult patients combined (2), and 6.3% major complications with 1.3 % permanent explantations in a population of 240 adult cochlear implantees in a British study (3).

Taking the complication rates of these studies into account, the rate of 6% in our population is small, also giving the fact that it comprises a special population. Additionally, none of the encountered complications in our study were related to the SP. Also, there were no cases of wrong insertion of the cochlear electrode in our population.

A drawback in our complication rate could be the follow-up time with a minimum of only 18 months (range, 18–96 months), which gives residual cholesteatoma ample time for developing. An additional study in future with a longer follow-up time will provide more information on this possible complication.

CONCLUSION

Subtotal petrosectomy with obliteration with abdominal fat and blind sac closure of the external ear canal combined with cochlear implantation is a procedure required in specific situations and lowers the risk of repetitive ear infections, CSF leakage, and meningitis by closing off all connection with the external environment. Additionally, it gives excellent visibility and access in difficult anatomy or drill-out procedures. Preservation of residual hearing can be considered the absolute contraindication, as an open external meatus is necessary for use of electroacoustic stimulation. Risks of the SP + CI procedure are infection of the abdominal fat, breakdown of the blind sac closure, and entrapped cholesteatoma. Follow-up with imaging is therefore mandatory. Given the fact that the complication rate found in the present study of SP with CI is comparable with the rates found in standard cochlear implantation, we think that CI surgeons should not be hesitant in using SP + CI for their patients presenting with the above-mentioned indications.

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