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Subtotal Petrosectomy: Surgical Technique, Indications, Outcomes, and Comprehensive Review of Literature

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Objectives/Hypothesis: To describe the technique of subtotal petrosectomy (STP), to analyze the outcomes, and to review the literature

Study Design: A retrospective review.

Methods: Four hundred sixty cases of STP performed for various indications were included in the study, which was conducted at a quaternary referral center for otology and skull base surgery. Surgical and audiological parameters, and complications were evaluated. Our results were compared with the existing literature on the subject.

Results: Two hundred ninety-seven (64.6%) patients had been subjected to multiple surgeries before an STP was performed. The most common indication for STP was recurrent chronic otitis with or without cholesteatoma, with 165 (35.9%) patients. Difficult cases of cochlear implantation, temporal bone fractures, and class B3 tympanomastoid paragangliomas were the next most common indications, with 91 (19.8%), 43 (9.4%), and 38 (8.3%) cases, respectively. The median follow-up of the patient pool was 36 ± 19 months. Recidivism and postauricular wound fistula were the most common complications, seen in five (1.1%) patients each. This series of STP is the largest reported in the literature

Conclusions: STP is a very useful and safe surgical tool in the management of a variety of problematic situations in otology, as it offers the possibility of a definitive cure by offering radical clearance. This procedure can be combined safely with hearing implantation procedures.

Key Words: Subtotal petrosectomy, blind sac closure, middle ear obliteration, chronic ear disease, cochlear implantation.

Level of Evidence: 4.

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INTRODUCTION

Subtotal petrosectomy (STP), with obliteration of the middle ear and mastoid and closure of the external auditory canal (EAC), is an effective solution in mastoid and middle ear diseases that are chronic and recurrent, leave behind a large surgical cavity, exposing vital structures like the dura, carotid, inner ear fluids, or cerebrospinal fluid (CSF), with no realistic chance of reconstruction of the conductive apparatus. Although this technique was introduced in the late 1950s and 1960s, Ugo Fisch introduced the term "subtotal petrosectomy" in 1965.[1,2] He described STP as the complete exenteration of all pneumatic tracts in the temporal bone, including retrofacial, retrosigmoid, antral, retrolabyrinthine, supralabyrinthine, infralabyrinthine, peritubal, and pericarotid cell tracts (Fig. 1). Although the initial description involved preservation of the otic capsule, it allowed expanding the procedure, when necessary, to exenterate the cochlea, the labyrinth, or the internal auditory canal. Blind sac closure of the EAC was recommended but was not mandatory.

Over the past couple of decades, there has been a growing interest in STP, and the indications for the same has also increased. However, due to the ambiguity of the initial description and also because this procedure is a preliminary step in many lateral skull base procedures, there is persisting confusion regarding the terminology and extent of bony resection in STP. A review of literature shows that authors have referred to any middle ear occlusion procedure with a blind sac closure, including expanded skull base procedures such as transotic, transcochlear, and infratemporal fossa approaches, temporal bone resections,[3,4] other skull base procedures for middle and posterior fossa tumors, and parotid surgeries,[5,6] as STP. Owing to the misrepresentation in the terminology of STP, the indications for the same in literature have also been diverse and often confusing. In this series, which is the largest reported series in the literature, we discuss the nomenclature, surgical technique, indications, and results of STP.

MATERIALS AND METHODS

This is a retrospective study conducted at a quaternary referral center for middle ear and lateral skull base pathology. The charts of all patients treated with STP from 1983 to December 2015 were analyzed. At our center, STP is a procedure that is defined by the following four important steps: 1) blind sac closure of the EAC; 2) canal wall down mastoidectomy

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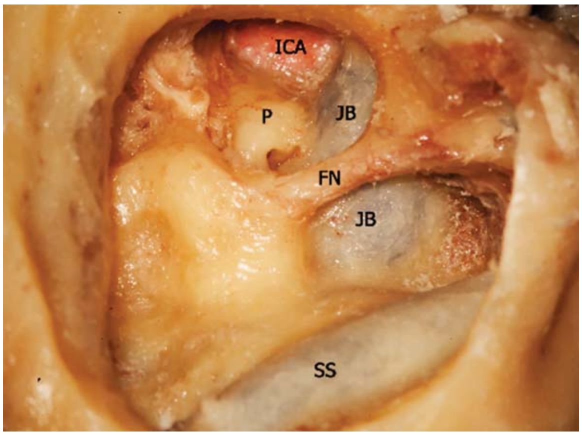

Fig. 1. The classical description of subtotal petrosectomy includes complete exenteration of all pneumatic tracts in the temporal bone including retrofacial, retrosigmoid, antral, retrolabyrinthine, supralabyrinthine, infralabyrinthine, peritubal, and pericarotid cell tracts. FN = facial nerve; ICA = internal carotid artery; JB = jugular bulb; P = promontory; SS = sigmoid sinus.

with complete removal of middle ear disease and removal of all epithelium; 3) exenteration of the mastoid cells, perisigmoid cells, perilabyrinthine cells, perifacial cells, and hypotympanic bone, with retention of the otic capsule, fallopian canal, middle fossa, and posterior fossa plates; and 4) obliteration of the surgical cavity with abdominal fat.

The inclusion criteria in the series included: 1) all procedures strictly fell under the definition of STP as defined above; 2) procedures with minor extensions of STP like partial drilling out of one or more of the semicircular canals, portions of the fallopian canal, or middle fossa plate necessitated by the extent of the disease were included; 3) STPs with simultaneous cochlear implantation (CI) were included. The exclusion criteria included: 1) when the procedure described above was expanded into a traditionally described skull base procedure like transotic approach, transcochlear approach, translabyrinthine approach, infratemporal fossa approach, subtotal temporal bone resections, or any other transtemporal skull base procedure; 2) when a blind sac closure of the EAC was not performed; and 3) when patients had incomplete records, <1 year of follow-up, or were lost to follow-up.

The charts of all patients were analyzed for past history, and otoscopic and general otolaryngological findings. The preoperative audiological records, including pure tone average (PTA; average of 0.5-1-2-4 kHz) of bone conduction (BC), air conduction (AC), and air–bone gap (ABG), and speech discrimination score (SDS) according to the Sanna classification of hearing,[7] were noted and analyzed. The radiological data, surgical details, and postoperative complications were noted and analyzed. At our center, the radiological follow-up is done with non–echo planar diffusion-weighted imaging (DWI) magnetic resonance imaging (MRI). In the early years when DWI was unavailable, all patients were followed up with a computed tomography (CT) scan, and if necessary an MRI with fat suppression. Patients are followed up for 10 years: every year for the first 4 years and then once every 2 years for the next 6 years.

Surgical Procedure

A wide retroauricular skin incision is used. The musculoperiosteal flap is shaped with a posteriorly based pedicle and elevated in a T fashion. The skin of the EAC is exposed and separated from the bone in the superior, posterior, and inferior quadrants (Fig. 2A). The skin is then transected completely in all quadrants at the level of the junction between the bony and cartilaginous portions of the EAC (Fig. 2B). The skin is then carefully separated from the cartilage all around and is everted outward. The everted skin is then sutured tightly using 3-0 resorbable sutures (Fig. 2C). The anterior and posterior edges of the underlying cartilage are also sutured to form a second layer of closure (Fig. 2D). The medial part of the skin is elevated completely up to the level of the annulus, and the tympanomeatal flap is covered with

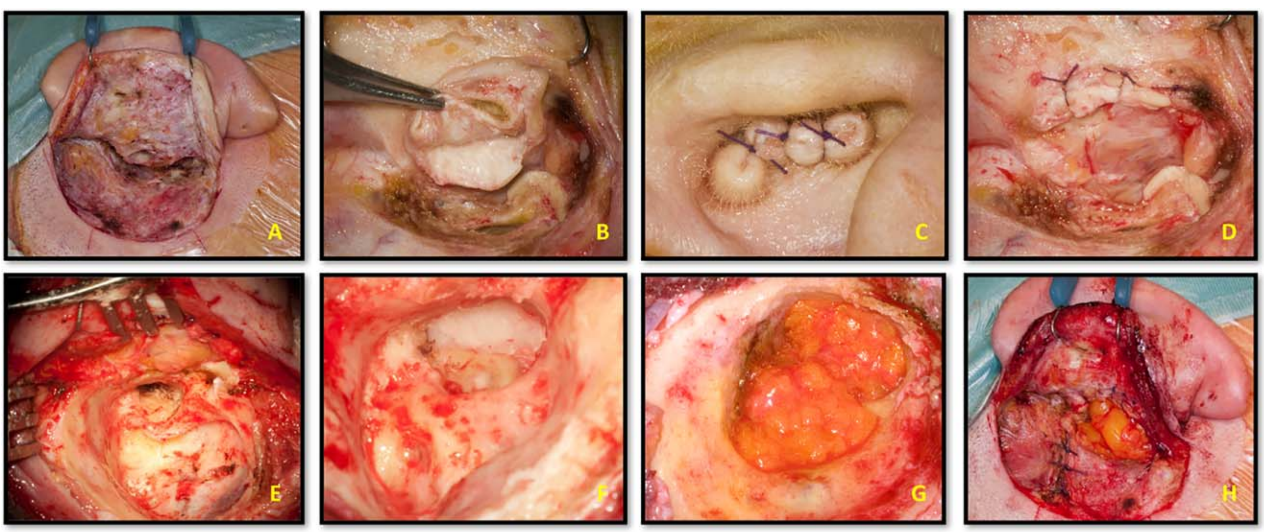

Fig. 2. (A) The external auditory canal is transected after the flaps are elevated. (B) The meatal skin and underlying subcutaneous tissue are separated into two layers. The meatal cartilage around the skin is dissected and removed. (C) The meatal skin is everted out through the canal and sutured with absorbable sutures. (D) A second layer of closure is achieved by approximating the cartilage of the tragus and the concha. (E) The canal wall down mastoidectomy involves exenteration of all visible cell tracts sparing the otic capsule, fallopian canal, and dural plates. The number of cells exenterated is determined by the extent of the disease and the indication for subtotal petrosectomy. (F) The eustachian tube is obliterated, with periosteum reinforced with muscle or cartilage and cemented in place by bone wax. (G) Autologous fat harvested from the abdomen is used to obliterate the cavity. (H) The skin is closed in layers.

aluminum foil. A canal wall down mastoidectomy is then performed, and varying amounts of bone is removed as indicated by the technique (Fig. 2E). The elevated tympanomeatal flap is then excised completely, making sure that there is no squamous epithelium left behind. The disease is excised completely. The ossicular chain, except for the stapes infrastructure, is removed. The extent of exenteration of the temporal cell tracts is determined by the extent of disease and the indication of STP. In the case of STP for an extensive cholesteatoma, the drilling of cells has to be extensive, whereas in the case of STP for a cochlear implant after a radical cavity, the extent of cellular exenteration may be limited. The eustachian tube (ET) is completely obliterated using periosteum, reinforced with muscle or small pieces of cartilage. This may be cemented in place with bone wax or fibrin glue (Fig. 2F). The resulting cavity is filled with fat harvested from the abdomen and treated with an antibiotic agent (Fig. 2G). The skin in closed in layers (Fig. 2H).

Review of Literature

A PubMed search was done using the terms "subtotal petrosectomy", "obliteration of the middle ear, mastoid, tympanomastoid compartment, and external auditory canal", and "middle ear obliteration". The search yielded a total of 106 relevant articles on STP, middle ear obliteration, and related terminology. Of them, 53 were excluded because the authors' description of STP or middle ear obliteration included more expansive skull base procedures. Twenty-four of them were case reports and hence excluded. One of the reports was eliminated because it had combined data from two centers including ours, and it was impossible to extract data from only the other center.[8] Finally, 28 case series were included in the analysis, for a total of 1,049 cases. The number of cases, pathology, surgical technique, and complications were tabulated and compared with the present study.

This study has been approved by the Ethical Committee for Research at the Casa Di Cura Hospital, Piacenza, Italy.

RESULTS

Of the 529 cases that were analyzed, 460 patients were included in the study based on the inclusion and exclusion criteria. The mean age of the study population was 51 years (range = 5–87 years); 251 patients were male (54.6%), and 209 were female (45.4%); 53% were right ears, and 47% were left ears. STP represented about 1.2% of the 34,520 otology and skull base surgeries performed at our center.

Pathology

Two hundred ninety-seven (64.6%) patients had been subjected to multiple surgeries before a STP was performed. The most common indication for STP was recurrent chronic otitis with or without cholesteatoma, with 165 (35.9%) patients. Eighty-seven (18.9%) of the 165 cases had erosion of the middle fossa plates and dural exposure. Difficult cases of CI, temporal bone fractures, and class B3 tympanomastoid paragangliomas were the other common indications, with 91 (19.8%), 43 (9.4%), and 38 (8.3%) cases, respectively (Table I).

TABLE I.
Pathologies for Which Subtotal Petrosectomy Was Performed in Our Series.

Pathology	Patients, No. (%)
Chronic otitis	165 (35.9)
Without cholesteatoma	21 (4.6)
With cholesteatoma	57 (12.4)
Cholesteatoma with dural exposure	87 (18.9)
Difficult cochlear implantation	91 (19.8)
Meningoencephalic herniation	64 (13.9)
Temporal bone fractures	43 (9.4)
Class B3 tympanomastoid paraganglioma	38 (8.3)
Petrous bone cholesteatoma	22 (4.8)
Facial nerve tumors	18 (3.9)
Iatrogenic CSF leak	4 (0.9)
Meningioma	4 (0.9)
Carcinoid	2 (0.4)
External auditory canal malignancies	2 (0.4)
Petrous apex cholesterol granuloma	1 (0.2)
Mastoid granuloma	1 (0.2)
Pleomorphic adenoma	1 (0.2)
Ewing sarcoma	1 (0.2)
Langerhans cell histiocytosis	1 (0.2)
Melanocytoma	1 (0.2)
Osteoradionecrosis	1 (0.2)
Total	460 (100)

CSF = cerebrospinal fluid.

CI With STP

The most common indications for CI with STP were previous surgeries and cochlear ossifications (48.3% and 18.7%, respectively). Seventy-six (83.5%) cases underwent a round window insertion, and 15 (16.5%) underwent a cochlear turn drilling out procedure. Full electrode insertion was possible in 81 (89%) cases. The most common complication was a CSF gusher, seen in two (2.2%) patients.

Audiological Analysis

Two hundred twelve (46.1%) of the patients presented with anacusis and were not included in the audiological analysis. The remaining 248 (53.9%) had the following audiological assessment. The average preoperative AC, BC, and ABG were 70.76 dB HL, 36.03 dB HL, and 37.99 dB HL, respectively. The average preoperative SDS was 90.57. The average postoperative AC and BC were 114.39 dB HL and 45.42 dB HL, respectively. In 34 (13.7%) cases, there was an average improvement in PTA BC between 0 and 15, 15 and 30, and 30 and 45 dB HL in 26, seven, and one patient respectively. In 117 (47.2%) patients, there was an average deterioration in PTA BC between 0 and 15, between 15 and 30, and >30 dB HL in 68, 34, and one patient, respectively. In patients with follow-up $\geq$ 5 years, the average PTA BC was found to deteriorate to 56.09 dbHL in 5 years.

Follow-up and Complications

The median follow-up of the patient pool was 36 $\pm$ 19 months. Five (1.1%) patients had a postauricular

TABLE II.
Details of Complications in Subtotal Petrosectomy.

Complication	Patients, No. (%)	Management	Outcome at Final Follow-up
Postaural wound fistula	5 (1.1)	Repair of fistula	Completely healed in all cases
Insufficient ET closure	4 (0.9)	Observation	Small pocket of air around the ET orifice seen in radiology; NED in all cases
Residual/recurrent cholesteatoma [recidivism]	5 (1.1)	Revision surgery	NED in both cases
Deterioration in FN function	2 (0.4)	No active intervention	1 recovered to HB grade I
Fistula of blind sac closure	4 (0.9)	Repair of fistula	Permanent closure in both cases
Retroauricular hematoma	4 (0.9)	Drainage	Completely healed in both cases
Mastoid abscess secondary to infected fat	1 (0.2)	Drainage + antibiotics	Completely healed
Electrode extrusion	1 (0.2)	Reimplantation	CI working successfully
Total	26 (5.6)		

CI = cochlear implantation; ET = eustachian tube; FN = facial nerve; NED = no evidence of disease.

wound fistula, all of whom were reoperated on. The wound was closed with a local musculoperiosteal flap. Five (1.1%) patients had recidivism. Four of them were cases of cholesteatoma, and one was a case of facial nerve (FN) tumor. All patients were reoperated on and have since remained disease free. Two (0.4%) patients had worsening of FN function, both of whom had normal FN function preoperatively. The first patient deteriorated to House-Brackmann (HB) grade II after surgery without recovery and the other to HB grade III with spontaneous recovery to HB grade I within 9 months (Table II).

DISCUSSION

Development of Technique

This procedure has its origins in a report by Rambo,[9] in which he described the musculoplasty technique for recalcitrant suppurative diseases, wherein he used the temporalis muscle pedicled flap to obliterate the cavity but left the EAC open. In another study,[10] he described his increased success in cases where he closed the EAC in a blind sac fashion using an endaural incision and without obliterating the ET. In the 1960s, Fritz & Crawford[11] and Tschopp published large series of over 100 cases using a similar technique. In 1976, Gacek developed this technique by using a postauricular incision, closure of the EAC and the ET, and cavity obliteration by harvesting abdominal fat. He used this in complicated cases of chronic otitis media with dural exposure and cerebrospinal fluid leak. Subsequently, the procedure became standardized after publication of large series by prominent centers that also expanded the indications for STP to other situations, including cochlear and other hearing implants.[1,12,14–16]

Nomenclature

Although the terms “middle ear obliteration” and “total obliteration of the mastoid, middle ear (cleft) and EAC” had been used in the past, the term “subtotal petrosectomy” was first used by Coker et al.[1] in 1986. However, in 1988 Ugo Fisch, in his classic textbook,[2] made a distinction between STP and other standard lateral skull base procedures. What essentially separates STP from other skull base procedures is that the approach itself is more conservative compared to other lateral skull base procedures. Whereas most of the air cell tracts in the mastoid and middle ear are completely exteriorized in STP, the cortical bony plates over the middle fossa, posterior fossa, and sigmoid, the otic capsule, and the fallopian canal are preserved. They are drilled out only when the disease demands it. Conversely, other definitive lateral skull base procedures such as the translabyrinthine and transotic approaches always involve drilling out the cortical bony plates over the middle and posterior fossa and destruction of the labyrinth, as part of the approach to remove the disease situated in the deeper parts of the temporal bone. Similarly, in the infratemporal fossa approach, the tympanic bone is drilled out and the FN is rerouted to reach the areas surrounding the jugular bulb or the infratemporal fossa anteriorly. There is particular confusion when it comes to malignancies of the EAC, where subtotal temporal bone resection is often confused with STP. It is important that the distinction be made clearly. Subtotal temporal bone resection follows drilling of the temporal bone following a lateral temporal bone resection wherein the entire tympanic bone is removed en bloc, including the anterior canal wall along with retroparotid soft tissue exposure and dissection. This procedure is often accompanied by varying degrees of parotid and lymph node dissection. STP, conversely, does not involve excision of the anterior canal wall and drilling out the entire tympanic bone, and certainly does not involve parotid or lymph node dissection. It is not sensible to include all transtemporal procedures that require a blind sac closure of the EAC as STP even if STP could be the first step in the procedures.

Indications

STP is indicated in any disease primarily in the middle ear and mastoid with limited extensions into deeper parts of the temporal bone that leaves behind a large cavity. Its indications can be described as in Table

TABLE III.
Indications for Subtotal Petrosectomy.

Indications	Pathology
To eliminate recurrent infection by drilling out multiple air cell tracts and to remove large cholesteatomas, which do not extend deeply into the petrous apex or the internal auditory canal	Chronic otitis media
	Middle ear cholesteatoma
	Limited petrous bone cholesteatoma (involving the labyrinth or perilabyrinthine cells tracts only)
	Osteoradionecrosis
To remove large tumors without intradural extensions	Tympanomastoid paragangliomas (B2/3)
	Facial nerve tumors of the tympanic and mastoid portions limited to the mastoid/middle ear cleft
	Other tumors
To obliterate the middle ear and mastoid cleft from the external environment to eliminate chances of intracranial spread of infection due to exposure of dura, inner ear fluids	Temporal bone fractures involving the otic capsule
	Meningoencephalic herniation
	Iatrogenic CSF leak
To allow CI and AMEI in difficult cases	Chronic otitis (in radical cavity)
	Cochlear obliteration and ossifications that require a partial drilling out
	Inner ear malformations
	Temporal bone fractures involving the otic capsule
	Revision cases

AMEI = active middle ear implantation; CI = cochlear implantation; CSF = cerebrospinal fluid.

III. STP offers an excellent solution in complicated and recurrent cases. There have been reports where unfortunate patients have undergone surgery up to 26 times before an STP offered a permanent solution.[17] In our own series, we have encountered cases with up to eight previous surgeries, and it is in such patients that STP offers the maximum benefit. This benefit is more pronounced in patients with good contralateral ear and it also allows underwater activity.

Surgical Technique

The procedure of STP has been described and discussed in detail elsewhere.[18–20] Our experience has shown that a few important techniques can be used to optimize the results of STP. The postauricular incision must be wide to avoid a fistula that can arise from the friable skin due to previous surgeries (Fig. 2A). The subcutaneous musculoperiosteal flap must be elevated with a posterior pedicle to avoid incising in the area of the previous scars. The underlying conchal and tragal cartilages can be approximated to create an additional layer (Fig. 2B). In pleuri-operated cases, the tragal cartilage can be brought back posteriorly and sutured to a soft tissue flap as a second layer. While performing the canal wall down mastoidectomy, it is better to remove as many cell tracts as possible to ensure that there is no residual disease. The perilabyrinthine, peritubal, and hypotympanic cell tracts are removed routinely except in cases of CI in noninfective cases. The peritubal cells must be removed as well, because they can form the route for CSF to the nasopharynx, bypassing the closed ET. The skin, annulus, and tympanic membrane with malleus and incus can be removed en bloc to lower the risk of leaving some skin behind. It is of paramount importance to ensure the removal of every bit of epithelium in the cavity to avoid a recurrent cholesteatoma. The stapes superstructure is removed, because leaving it behind could allow fat to exert a pistonlike pressure on the stapes or frank subluxation, leading to postoperative vertigo.[5,20] The closure of the ET is an important step, and it must be done meticulously to prevent an opening. The mucosal lining of the ET entrance is mobilized and folded back into the ET. The mucosa is cauterized with bipolar coagulation, after which the orifice is filled with muscle, cartilage, and bone wax to seal it off from the tympanic cavity. Removal of all the surrounding mucosa ensures better adherence of the wax to the bone. The wound is closed in two or three layers.

STP With Implants

The first series of STP with CI were reported in the mid-1990s, when the surgery was staged as a means to look for residuals and also to eliminate chances of infection during CI. However, we believe that a well-performed STP enables a simultaneous CI and the surgery must be staged only in case of doubt regarding disease clearance. This philosophy is finding acceptance with more authors.[21–23] Our low complication rates have demonstrated that performing simultaneous STP with CI is a feasible option and should be among the surgical options in CI surgery.[24]

Complications

In the early years, STP was considered hazardous due to increased incidences of recurrent disease and there was a general hesitancy among surgeons in adopting this procedure. A closed cavity meant that recurrences could not be detected and patients often

TABLE IV.
Comparison of Outcomes of Our Series With Other Important Series in Literature.

Author	Cases, No.	Age Group	Follow-up	Indication	Preoperative Severe to Profound Hearing Loss	Surgical Notes	Cavity Obliteration	Failures	Other Complications (%)
Rambo 1958[9]	4	Adult/pediatric	NA	Recurrent COM, cholesteatoma	75%	EA incision, RM, no obliteration of ET, single-layer EAC skin closure	Temporalis muscle	—	—
Fritz & Crawford 1960[11]	157	NA	NA	Recurrent COM, cholesteatoma	NA	EA incision, RM, no obliteration of ET, single-layer EAC skin closure	Temporalis muscle	Recurrent cholesteatoma (3.8%)	NA
Gacek 1976[13]	6	Adult	2–7.5 years	Recurrent COM, cholesteatoma	83.3%	PA incision, RM, ETO, single-layer EAC skin closure	Abdominal fat, soft tissue pedicle	—	—
Tschopp 1960[12]	100	NA	NA	Recurrent COM, cholesteatoma	NA	EA incision, RM, no obliteration of ET, single-layer EAC skin closure	Temporalis muscle	Recurrent cholesteatoma (7%)	NA
Bartels & Sheehy 1981[12]	27	Adult/pediatric	0.5–10 years	Recurrent COM, cholesteatoma, TB, prolapse of MC, fistula, FNP	96.3%	PA incision, RM, ETO, single-layer EAC skin closure, FN grafting in 1 case, drain in case of infected cavities, second stage in 1 case	Temporalis muscle, Palva flap, abdominal fat, bone pâté	Revision (22.2.4%), epithelial pearl (3.7%)	Delayed healing (7.4%), PAF (3.7%), malignancy (3.7%), abscess (3.7%)
Nadol & Schuknecht 1984[14]	7*	Adult	2 months to 5 years	TBM	NA	PA incision, RM/LTBR/STBR, ETO, single-layer EAC skin closure, drain in all cases	Free muscle, muscle pedicles, myocutaneous flap, abdominal fat	Death (28.6%; as against 47.3% in remaining 19 nonobliterated cases after ORN)	Delayed healing 14.3%),
Schuknecht & Chandler 1984[29]	44	Mean age 40.5 years	$<$1 year (39%), 1–5 years (18%), 5–9 years (20%), 9–20 years (23%)	Recurrent COM, cholesteatoma, mental retardation, MEH, CSF leak	89%	PA incision, RM, ETO, single-layer EAC skin closure, drain in all cases	Free muscle, muscle pedicles, myocutaneous flap, abdominal fat,	Revision surgery (11%) including recurrent cholesteatoma (6.8%; 1 case of total FNP)	Infection (15.9%, EAC fistula (2.3%)
Coker and Jenkins 1986[1]	109[†]	NA	NA	Recurrent COM, cholesteatoma, TBM, intratemporal carotid surgery, TBF	NA for selected subset	PA incision, RM + exenteration of additional cell tracts, ETO, 2-layer EAC skin closure	Temporalis muscle flap over abdominal fat	NA for selected subset	NA for selected subset
Ma & Fagan 1988[30]	3	Adult	NA	ORN	NA	Preauricular or PA incision, RM + exenteration of additional cell tracts, ETO	Temporalis muscle flap	—	Wound breakdown (33%)

TABLE IV.
(*Continued*)

Author	Cases, No.	Age Group	Follow-up	Indication	Preoperative Severe to Profound Hearing Loss	Surgical Notes	Cavity Obliteration	Failures	Other Complications (%)
Parikh & Brookes 1994[31]	10	Adult	—	COM, cholesteatoma	100%	PA incision, RM + exenteration of additional cell tracts, ETO, 2-layer EAC skin closure	Abdominal fat	—	—
Gray & Irving 1995[33]	4	Adult	<1 year	CI in COM	100%	PA incision, RM + exenteration of additional cell tracts, ETO, single-layer EAC skin closure; CI in 2nd stage	Abdominal fat, fascia graft	Recurrent cholesteatoma (25%)	—
Black 1998[32]	38	NA	Average 4 years & 6 months	COM, cholesteatoma	NA	PA incision, RM, ETO, no skin suturing, only approximation, 2-stage procedure	Fibrous tissue	15% residual discovered in 2nd stage	NA
Issing 1998[17]	14	Adult/pediatric	Average 28 months	CI in COM & Mondini dysplasia	100%	Preauricular incision, RM + ETO, 3-layer EAC closure; 1-stage CI (71.4%)	Abdominal fat	Infection and re-exploration (7.1%)	PA fistula (14.3%), FNP (7.1%), Infection (7.1%), seroma (7.1%)
El-Kashlan 2003[34]	27	Adult/pediatric	1–10 years	CI in COM & Mondini dysplasia	100%	EA incision, RM, ETO, 2-layer EAC skin closure	Abdominal fat & temporalis muscle flap	Recurrent cholesteatoma (7.4%)	EAC fistula (7.4%)
Kos 2006[35]	46	Adult/pediatric	Mean 8 years	COM, cholesteatoma	100%	EA or PA incision, STP	Abdominal fat	Recurrent cholesteatoma with abscess (2.2%)	—
Senn 2011[36]	21	Adult/pediatric	Average 7 years	PBC (67% supralabyrinthine)	81%	STP + drilling into petrous bone	Abdominal fat & transposed muscle flap	Recurrent cholesteatoma (19%), FNP (9.5%)	—
Magliulo 2012[37]	26	Adult	Mean 5.6 years	TBF	100%	STP, FN grafting (15.4%)	Abdominal fat	—	—
Verhaert 2013[38]	22	Adult	NA	AMEI in COM & cholesteatoma	100%	STP in 1st stage & AMEI in 2nd stage	Abdominal fat & periosteal flap	—	EAC fistula (1.4%), PA fistula (4.5%)
Baranano 2013[39]	36	Adult/pediatric	NA	CI in COM & cholesteatoma	100%	Simultaneous STP + CI (27.8%), staged (72.2%)	Abdominal fat, muscle or bone pâté	Explantation (8.3%), electrode extrusion (2.8%)	Abscesses (8.3%), subcutaneous emphysema (2.8%), EAC fistula (2.8%)
Henseler 2014[22]	10	Adult	3–6 years	AMEI in COM & cholesteatoma	100%	Simultaneous STP + AMEI (90%), staged (10%)	Abdominal fat & temporalis muscle flap	—	Skin necrosis over implant (10%)

TABLE IV.
(*Continued*)

Author	Cases, No.	Age Group	Follow-up	Indication	Preoperative Severe to Profound Hearing Loss	Surgical Notes	Cavity Obliteration	Failures	Other Complications (%)
Vincenti 2014[40]	19	Adult	NA	CI in COM & cholesteatoma	100%	Simultaneous STP + CI (60%), staged (40%)	Abdominal fat	Recurrent cholesteatoma (5.3%)	Scala vestibuli implantation (10.5%), EAC fistula (5.2%)
Magliulo 2015[41]	10	Adult/ pediatric	NA	COM & cholesteatoma, MEH	100%	STP	Abdominal fat	—	—
Kammeijer 2015[42]	22	Adult/ pediatric	Median 7 years	TBM, ORN	100%	STP	Abdominal fat + temporalis muscle, microvascular free flap, long pedicled flap	CSF leak (4.5%), infection & FNP (4.5%), free flap failure (4.5%)	PA fistula (13.6%), wound infection, fat infection & blind sac necrosis (4.5%)
Bernardeschi 2015[43]	26	Adult	Mean 21 ± 18 months	CI in COM & cholesteatoma, meningitis, LVA, aplasia, TBF	100%	STP	Abdominal fat	Electrode extrusion (11.5%), device failure (3.3%), recurrent cholesteatoma (3.8%)	—
Szymanski 2016[23]	19	Adult/ pediatric	8 months to 10 years	COM	100%	Simultaneous STP + CI (73.7%), staged (26.3%)	Abdominal fat + temporalis muscle	—	Failure of EAC closure (5.2%)
Schwab 2016[44]	4	Adult	6–17 months	AMEI in COM & cholesteatoma	100%	STP in 1st stage & AMEI in 2nd stage	Abdominal fat	—	—
Lyutenski 2016[45]	212	Adult/ pediatric	NA	CI/AMEI/direct acoustic cochlear stimulator in COM & cholesteatoma	100%	Simultaneous STP + implant (5.6%), staged (94.4%); 3-layer suture	Abdominal fat, temporalis muscle flap, polydioxanone foil/bovine pericardium, allogenic fascia	Recurrent cholesteatoma (2.3%), device explantation (0.5%)	PA/EAC fistula (16%), infected fat (0.5%)
Yung 2016[46]	26	Adult	Average 22–39 months	COM, OM, ORN	NA	STP	Abdominal fat, temporoparietal fascial flap	—	PA fistula (3.8%), EAC fistula (7.7%), fat necrosis (3.8%)
Our series	411	Adult/pediatric	Median 36 ± 19 months	COM, CI, MEH, TBF, TMP, FNP, CSF leak	212 (46.1%)	STP, simultaneous STP + CI (%), staged (%)	Abdominal fat	Recidivism (1.1%), electrode extrusion (0.2%)	PA fistula (1.1%), insufficient ET closure (0.9%), FN deterioration (0.4%), Blind sac closure fistula (0.9%), fat infection (0.2%)

*Only seven of the 27 cases underwent total obliteration.

†Remaining 263 cases were translabyrinthine, transotic, or infratemporal fossa approaches.

AMEI = active middle ear implant; CI = cochlear implantation; COM = chronic otitis media; CSF = cerebrospinal fluid; EA = endaural; EAC = external auditory canal; ET = eustachian tube; ETO = eustachian tube obliteration; FN = facial nerve; FNP = facial nerve paralysis; LTBR = lateral temporal bone resection; LVA = large vestibular aqueduct; MC = mandibular condyle; MEH = meningoencephalic herniation; NA = not available; OM = osteomyelitis; ORN = osteoradionecrosis; PA = postaural; PAF = postauricular fistula; PBC = petrous bone cholesteatoma; RM = radical mastoidectomy; STBR = subtotal temporal bone resection; STP = subtotal petrosectomy (as described in this report); TB = tuberculosis; TBF = temporal bone fracture; TBM = temporal bone malignancies; TMP = tympanomastoid paraganglioma.

presented with an FN palsy due to recurrences. However, with the development of MRI and DWI MRI in particular, recurrences as small as 2 mm can now be detected.[25] Refinements in the surgical techniques and better microscopes have also ensured reduction of residuals and recurrences. Our recidivism rates of 1.1% is less than the reported rates of recidivism in canal wall down procedures (with long term follow-ups), which range from 1.5% to 17%.[25–27]

Follow-up

It is mandatory to follow up all patients after an STP with radiology. In the past, a combination of CT and MRI was used at our center to detect recurrences, but the DWI sequences in MRI are a standard tool to detect recurrences. We recommend a DWI MRI after 6 months, after 1 year, and once every 2 years thereafter for at least 10 years. In cases of STP with CI, a high-resolution CT (HRCT) scan is used to follow up the patient. The radiological interface created by the fat in the cavity increases the diagnostic efficacy of HRCT for residual and entrapped cholesteatoma. If HRCT shows a doubtful lesion, an MRI can be done safely using a 1.5T MRI without much distortion. However, if the distortions are obvious and hamper visualization, the magnet must be removed and replaced after the MRI is done. Recent development of implants with a self-aligning magnet implant that is MRI safe has mitigated this problem.

Review of Literature

The review of literature in Table IV shows the evolution of the procedure through the past 6 decades. Only four studies have a study population of >100 patients, and among them, the present study is the largest. It can be seen that the indications of STP have increased over the years and apart from middle ear pathology, many centers combine it with hearing implantation procedures. The techniques of STP as described in this series have been routinely applied at most centers. Complication rates have been reduced significantly over the years, and one of the lowest rates of complications compared to the literature was observed in our series.

CONCLUSION

STP is a very useful and effective surgical tool in the management of a variety of problematic situations in otology, as it offers the possibility of a definitive cure by offering radical clearance. This procedure offers excellent exposure, provides middle ear exclusion, and can be combined safely with hearing implantation procedures. Complications are minimal if the technique is followed correctly.

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