European Archives of Oto-Rhino-Laryngology (2023) 280:4869–4878
https://doi.org/10.1007/s00405-023-08005-w

OTOLOGY

Exclusive endoscopic ossiculoplasty with autologous material: step-by-step procedure and functional results

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Received: 26 December 2022 / Accepted: 2 May 2023 / Published online: 9 May 2023

Abstract

Purpose To describe the surgical procedure of exclusive endoscopic ossiculoplasty (EEO) with autologous grafts and evaluate audiological results, focusing on the advantages or drawbacks compared to the corresponding microscopic technique.

Methods A retrospective review of consecutive adult and pediatric patients affected by chronic otitis media (COM) with or without cholesteatoma who underwent EEO was conducted. Only autologous ossiculoplasty was included in the study. The procedure was performed by experienced surgeons of our institution between November 2014 and September 2019. Hearing outcomes were evaluated using postoperative air–bone gap (ABG) and success rates in different subgroups of patients and different types of ossiculoplasty (OPL) were analyzed. Our results were finally compared with the existing literature regarding both microscopic and endoscopic ossicular chain reconstruction.

Results In total, 74 endoscopic ossicular chain repair procedures performed within the study period met the inclusion criteria. Of these, 21 were pediatric patients (28%) and 53 were adults (72%). Surgical reconstruction procedures included 43 partial ossicular reconstructions (POR) and 31 total ossicular reconstructions (TOR). The postoperative ABG improved significantly compared to preoperative measurements, and the mean ABG closure was 7.85 dB HL ($p = 0.00064$). No statistically significant differences in audiological outcomes between TOR/POR techniques and pediatric/adult groups were found in our study cohort, with p values of 0.10 and 0.88, respectively.

Conclusions At present, EEO can be considered a valid surgical option for re-establishing a functioning ossicular chain with acceptable hearing restoration in children and adults. Further reports in wider case series are required to confirm these results.

Keywords Ossiculoplasty · Endoscopic ear surgery · Endoscopic ossicular chain reconstruction · Total ossicular replacement · Partial ossicular replacement · Incus interposition · Autologous reshaped incus

Introduction

Ossiculoplasty (OPL) is a surgical procedure that restores sound transmission of the middle ear system when an ossicular chain discontinuity occurs due to malformations, trauma, neoplasms, or COM, with or without cholesteatoma [1, 2]. Thus, the principle of OPL is to restore the mechanical connection between the tympanic membrane (or residual malleus) and the stapes superstructure (or stapes footplate). In general, the types of prosthesis used for ossicular chain reconstruction are divided into two categories: partial ossicular replacement prosthesis (PORP) and total ossicular replacement prosthesis (TORP) depending on the presence or absence of the stapes superstructure, respectively [2, 3]. Over the years, a wide range of autografts, allografts, and synthetic materials have been used for reconstruction [2–4].

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Since the 1990s, many surgeons have used bioinert materials such as titanium, which is at present one of the main reconstructive options because of its light weight, rigidity, and good visualization of its distal end during insertion [1]. Nevertheless, these prostheses are quite expensive and the rate of extrusion is not negligible, although generally low (1–5%) [1, 5]. On the other hand, autologous materials (especially remodeled incus) have shown to be at least as effective as synthetic prostheses, but they also carry some disadvantages such as prolonged operative times for reshaping, the possibility of harboring microscopic residual cholesteatoma, and limited availability depending on the ossicular chain status [2, 6, 7].

In addition, there are still some controversial aspects regarding the timing of ossicular chain reconstruction after cholesteatoma removal (single-stage vs second-stage OPL) and, more recently, the use of a microscopic or endoscopic approach [8–10].

In fact, during the last 2 decades, endoscopic ear surgery has gained popularity in otological practice in a wide range of otological procedures including endoscopic myringoplasty, tympanoplasty for cholesteatoma and COM, and even stapedoplasty [11, 12].

The advantages of the endoscopic tool include the possibility of using a minimally invasive approach allowing enhanced visualization of the middle ear anatomy, and better cosmetic outcomes with a low rate of postoperative complications [13]. The main potential advantage of the endoscopic tool in OPL procedures is precise prosthesis placement, even in patients with challenging middle ear anatomy, although there is still a paucity of studies investigating the audiological results of endoscopic ossicular chain reconstruction [10, 14].

Therefore, this study aimed to evaluate the hearing outcomes of a large series of EEO procedures performed in a tertiary referral center using various autologous materials.

Materials and methods

Patient selection

A retrospective review was conducted on 182 consecutive adult and pediatric patients (age range 4–79 years) who underwent EEO between November 2014 and September 2019 at the Otolaryngology Department of the University Hospital of Verona.

The inclusion criteria were as follows:

- Patients with COM with or without cholesteatoma
- Ossicular chain defects caused by:
  - direct ossicular erosion in cholesteatoma patients
  - incus or malleus removal during cholesteatoma surgery if involved in epidermization to achieve radicality
  - incus removal to access the flogistic tissue and/or cholesteatoma located medially to the ossicular chain
- Single-stage or second-look fully endoscopic OPL
- Use of autologous materials for ossicular chain reconstruction: autologous reshaped incus (ARI), tragal/conchal cartilage, or sculpted mastoid bone
- At least 6 months of postoperative follow-up.

The exclusion criteria were as follows:

- Diagnosis different from COM or cholesteatoma (i.e., traumatic ossicular chain dislocation, middle ear neoplasm).
- OPL performed under microscopic view.
- Reconstruction using synthetic prostheses.
- Postoperative follow-up of < 6 months.

Preoperative assessments included otoendoscopy, audiometric tests, and computed tomography (CT) scans of the temporal bones to evaluate the extent of the disease and the status of the ossicular chain.

Audiometric evaluation was performed in every patient according to the guidelines published by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology-Head and Neck Surgery [15]. Pure-tone thresholds for bone and air conduction were obtained at 500, 1000, 2000, and 3000 Hz. The pure-tone average (PTA) was calculated for bone and air conduction, and the ABG was defined as the difference between the PTA of bone conduction and PTA of air conduction.

Surgical procedure

All patients included in this study underwent endoscopic ear surgery under general anesthesia using a 0° endoscope (or a 45° endoscope if exploration of hidden areas, such as the retrotympanic region, was required). The main surgical steps are presented in Fig. 1.

Cholesteatoma removal

After infiltration of the skin of the external auditory canal (EAC) with local anesthetic and epinephrine solution, an incision is made with a round knife approximately 0.5–1 cm lateral to the tympanic membrane, and a tympanomeatal flap is elevated. The flap is gently detached from the handle of

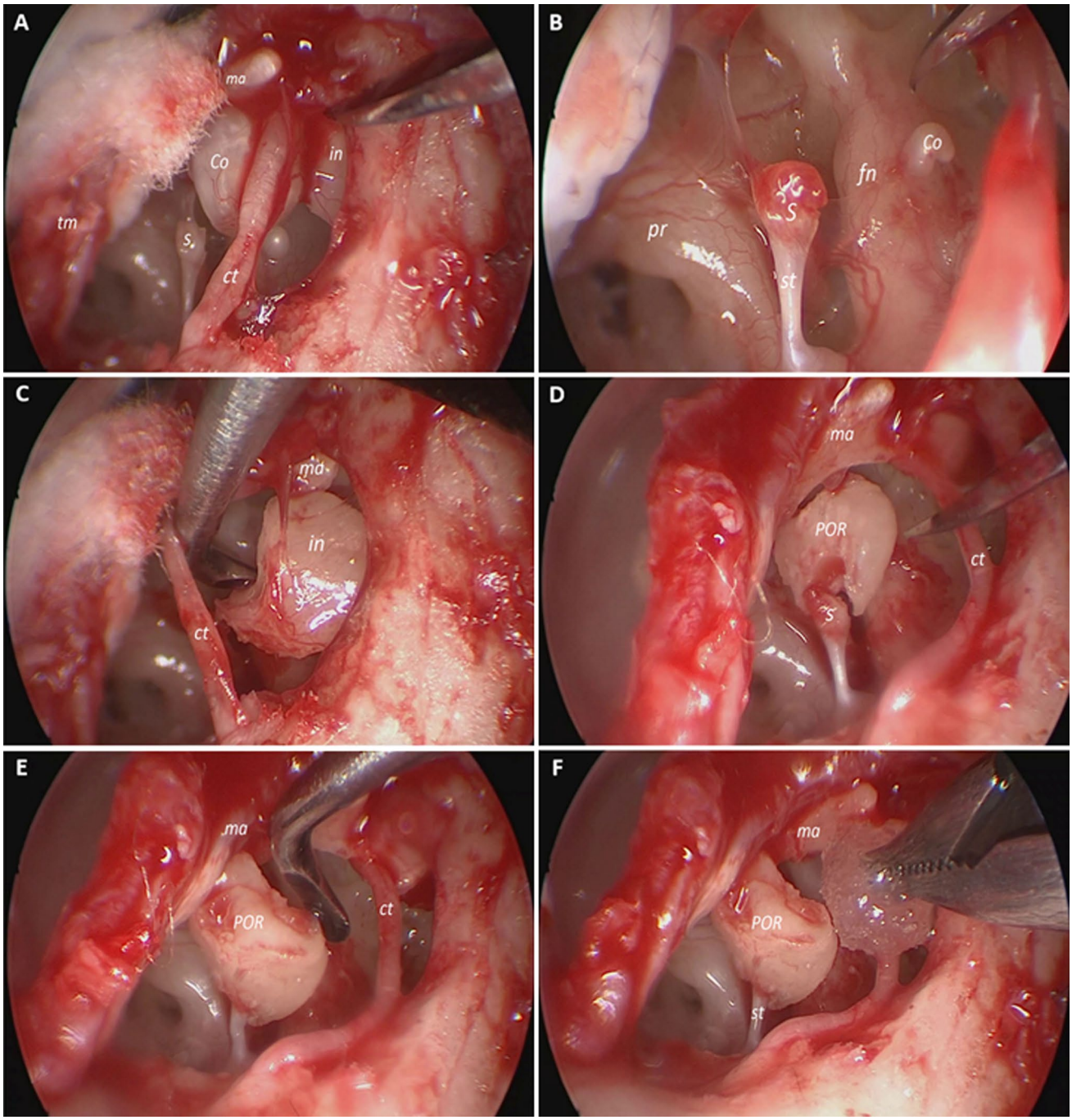

Fig. 1 Left ear, 0° endoscopic view. **A** After elevation of the tympanomeatal flap, a cholesteatoma pearl (*Co*) was encountered in the mesotympanum and between the malleus (*ma*) and incus (*in*). The long process of the incus was eroded. **B** After pearl removal, endoscopic examination of the retrotympanic cavity revealed minor residual disease just above the facial nerve canal (*fn*). The stapes (s) superstructure was intact. **C** The chorda tympani (*ct*) was mobilized and erosion of the long process of the incus is now clearly identifiable. The incus was then disarticulated from the head of the malleus and removed. **D** Partial ossiculoplasty reconstruction (*POR*) was performed with a reshaped incus placed between the malleus and the stapes superstructure. The groove for the stapes superstructure is highlighted (*dotted line*). **E** POR was correctly placed with the help of a magnifying endoscopic view. **F** Adsorbable sponges were inserted into the middle ear cavity to support the reconstruction. *pr* promontory, *st* stapedial tendon

the malleus and the middle ear cavity is carefully inspected, paying special attention to the status of the ossicular chain. Atticotomy is performed to expose the incudomalleolar joint and improve the surgical view of the incudostapedial joint. If cholesteatoma caused bony erosion, the damaged ossicles are removed. Moreover, in case of extension of pathology

medially to the incus and malleus head (e.g., in the supragenicular fossa or medial epitympanum), these structures are removed to create a surgical corridor to gain control of the entire epitympanic compartment [16, 17].

Ossiculoplasty

In single-stage OPL, endoscopic ossicular chain reconstruction is performed concurrently with COM surgery. If there is concern about residual disease, ossicular reconstruction is postponed to a second-look procedure after 12–18 months (second-stage OPL).

Whenever available, ARI is the first choice for reconstruction. The long process of the incus is disarticulated from the stapes superstructure and then gently pushed upward to detach the body of the incus from the head of the malleus. Thus, the incus is completely freed and can be removed. The ossicle is held using Klemmer or mosquito forceps, and remodeling is performed under loupes magnification with a small cutting burr. The body of incus is gently grabbed with Klemmer and the lateral side of its short process is drilled. Then, the long process is shortened, obtaining a 'shoe-shaped' neo-incus. The upper surface of the incus is drilled, creating a caved surface for articulation with the malleus handle. On the contralateral side, a small hole is drilled for articulation with the head of stapes. Figure 2 shows our technique for incus reshaping. If the incus is eroded to a point that prevented its use, other autologous materials are harvested: conchal or tragal cartilage, and sculpted mastoid cortical bone via a postauricular approach. A POR is placed when a mobile stapes superstructure is present (Fig. 3A), whereas a TOR is used when only the stapes footplate is preserved (Fig. 3B). When a POR or TOR procedure was performed with other autologous materials, the latters were redesigned with the same rationale experienced for the incus. A square-shaped bloc is remodeled with stapes' and malleus' joint grooves in case of POR, while a triangular shaped piece is placed onto a small hole within stapes' platina and anchored to malleus or a tympanic graft in case of TOR [18].

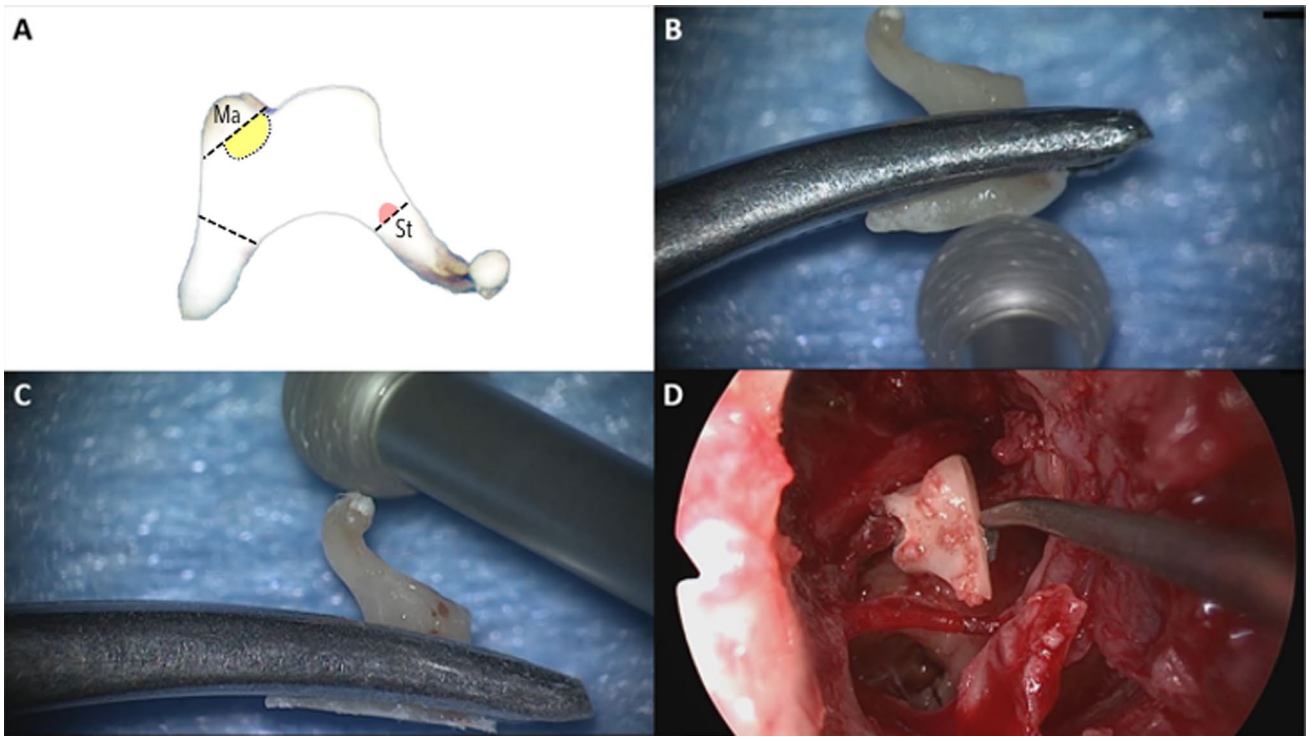

Fig. 2 Technique of incus remodeling for POR. **A** Scheme of a normal incus with drilling lines and articular facets for malleus (Ma) and stapes (St) drawn on its surface (black dotted lines, yellow and pink areas, respectively). **B** The body of incus is gently grabbed with a Klemmer and the lateral side of its short process is drilled with a small cutting burr, creating a straight surface for articulation with the malleus handle. **C** The long process of incus is also shortened, and then, a small hole is harvested to articulate it with stapes head. **D** Final intraoperative endoscopic view of 'shoe-shaped' remodeled incus; the neo-incus is placed between ossicular remnants with the aid of a hook

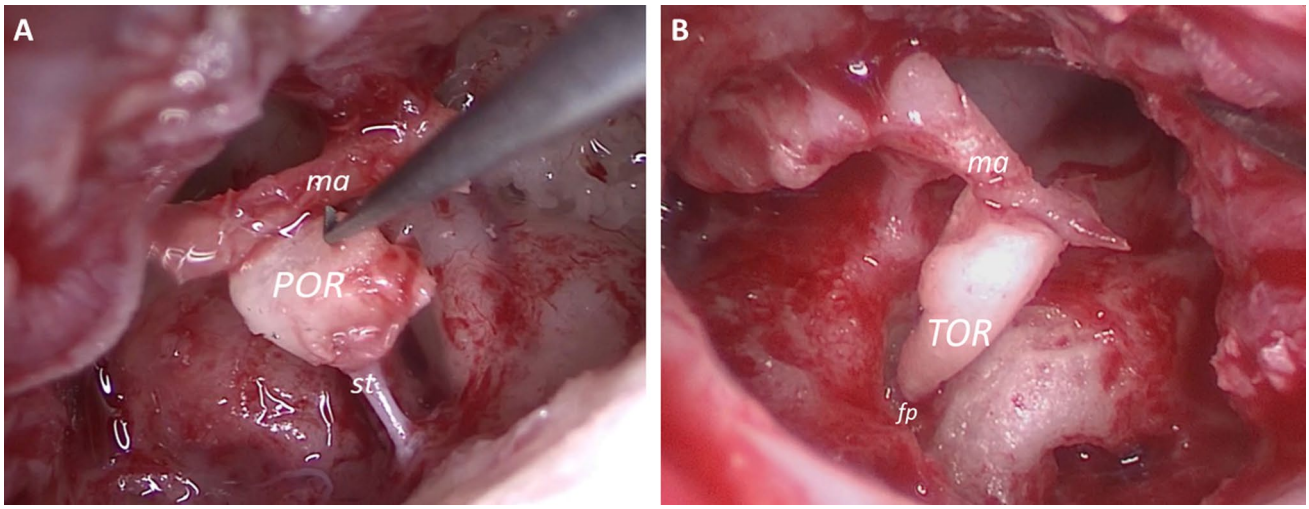

Fig. 3 **A** Left ear, 0° endoscopic view. Example of endoscopic POR placement with reshaped incus between the handle of the malleus (*ma*) and the stapes superstructure. A hook was used to help attain the correct position. **B** Right ear, 0° endoscopic view. Example of endoscopic TOR placement using a reshaped incus between the handle of the malleus and the stapes footplate (*fp*). *st* stapedial tendon

After correct prosthesis positioning, adsorbable sponges are inserted into the middle ear cavity to support the reconstruction. Finally, the tympanomeatal flap is repositioned and the EAC is packed with adsorbable sponges.

No strut was ever made to the malleus handle in our case series. The reconstruction of the pars tensa with cartilage was performed in the cases of a wide tympanic membrane defect or if the malleus handle was removed or absent.

Compliance with ethical standards

All of the procedures performed in studies involving human participants were in accordance with the ethics standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethics standards. Due to the retrospective and observational nature of the study, the Ethics Committee "Comitato Etico delle province di Verona e Rovigo" has given the approval to the study without the need of formal discussion.

Informed consent was obtained from all individual participants included in the study.

Statistical analysis

This was performed using R version 3.5.2 (R Foundation for Statistical Computing, Vienna, Austria). Univariate analysis of the data was conducted using the *t* test for normally distributed continuous variables, Mann–Whitney *U* test for non-normally distributed continuous variables, and chi-squared test or Fisher's exact test for categorical variables. Statistical significance was set at $p < 0.05$.

Results

A total of 182 OPL procedures were retrospectively reviewed for both primary tympanoplasty with concomitant OPL and a second-look procedure for COM with or without cholesteatoma. All surgical procedures were performed between November 2014 and September 2019 in the Otolaryngology-Head and Neck Surgery Department of Verona University Hospital.

Of the 182 patients selected, 108 did not meet the inclusion criteria and were excluded from this study. Seventy-four patients who underwent exclusive endoscopic OPL were enrolled in this study. The male/female ratio was 1.06 (38 M, 36 F), while the mean age at surgery was 37.8 years (range 4–79 years). The cases were divided into two groups according to their age: the cut-off was set at an age of 18 years, giving 21 patients (mean age 10.05 ± 3.84) in the pediatric group and 53 (mean age 48.79 ± 16.77) in the adult group. POR was performed in 43 patients (54%) and TOR in 31 patients (42%). A total of 45 patients (60%) underwent OPL during the first-time surgery (primary OPL) at the same time as endoscopic tympanoplasty for cholesteatoma removal: 10 TOR and 35 POR. In 31 cases (40%), the OPL was performed during revision tympanoplasty or a second-look procedure (secondary OPL), with a higher prevalence of TOR ossiculoplasty (20 vs 9). Regarding the preoperative status of the ossicular chain in terms of erosion grading, the stapes was completely intact in half of the cases ($n = 37$), while in the others, it had various degrees of epidermization/erosion or there was a complete absence of the superstructure. The materials used to perform the OPL were ARI in 45 procedures (61%), mastoid cortical bone in 15 cases (20%), tragal

or conchal cartilage in 11 cases (15%), and remodeled malleus head in three cases ($n=3$, 4%). No cases of sensorineural hearing loss were observed in our patients.

In none of the patient, the removal of the malleus was needed to facilitate the reconstruction, because the magnification of the endoscopic view enabled a safe and easy OPL positioning. Moreover, no revision surgeries were performed in the present series for ossicular chain dislocation or OPL extrusion.

Hearing outcomes

Preoperative audiometric evaluation of the hearing threshold (dB HL) at frequencies of 0.5, 1, 2, and 3 kHz showed a bone conduction (mean ± standard deviation, SD) of 21.60 dB HL ± 14.04 (range 5.00–58.75 dB HL), while air conduction was 49.65 dB HL ± 21.36 (range 12.50–110.00 dB HL); therefore, the overall preoperative ABG was 28.05 ± 10.83 dB HL (range 7.50–57.50 dB HL).

Regarding surgical outcomes in the postoperative audiometric evaluation, air conduction was 40.55 ± 20.55 dB HL and bone conduction was 20.36 ± 12.25 dB HL. The corresponding ABG was 20.20 ± 11.93 dB HL. Moreover, there was a statistically significant improvement in ABG closure of 7.85 ± 10.81 dB HL between the preoperative and postoperative ABG (Mann–Whitney *U* test, $p<0.00064$).

Comparative analysis

TOR vs. POR

The audiological results for TOR and POR are summarized in Table 1. The two groups were homogeneous with regard to age (39.83 vs. 36.40 years, respectively), sex (16 females and 14 males vs. 20 females and 23 males, respectively), side of surgery (16 right and 14 left ears vs. 14 and 29, respectively) ($p>0.05$), and preoperative air and bone conduction ($p=0.06057$ and $p=0.0968$, respectively).

Regarding postoperative audiological results, air conduction was significantly better in the POR group ($p=0.00964$), and postoperative ABG in the POR group was significantly lower than that in the TOR group ($p=0.00508$). Nevertheless, there was no statistically significant difference in ΔABG between pre- and postoperative outcomes in patients who underwent POR or TOR ($p=0.10027$).

Pediatric vs adult patients

Audiological outcomes were analyzed in both the pediatric and adult populations. No statistically significant differences were found between these two groups in terms of pre- and postoperative ABG ($p=0.93624$ and $p=0.77948$, respectively), as well as ΔABG ($p=0.88076$).

Primary vs secondary ossiculoplasty

There was no statistically significant difference in the audiological outcomes between primary and secondary OPL. ABG closure was similar in these two populations (8.96 vs 5.69 dB HL, respectively) with a chi-squared test *p* value of 0.8493. Furthermore, the PTA-ABGs did not show a significant difference in hearing gain between the two groups ($p=0.08012$).

Discussion

Over the years, different materials and surgical techniques for OPL have been reported in the literature. The first record of surgical ossicular chain reconstruction dates back to the 1950s, when Hall and Ryztner restored transmissive continuity with an autologous prosthesis [19]. Since then, several studies have reported various homologous or biocompatible materials that would provide overlapping functional results and a few side effects [20].

The advent of endoscopic surgery applied to the middle ear and its increasing global diffusion have brought attention to this minimally invasive and safe procedure [13, 21,

Table 1 Hearing data and postoperative outcomes (pure-tone average ± standard deviation) by categorization in partial ossicular reconstruction (POR) vs total ossicular reconstruction (TOR) populations and in pediatric vs adult groups

Study group	Preoperative values (PTA ± SD, dB HL)			Postoperative values (PTA ± SD, dB HL)			Difference	*P* value
	Bone conduction	Air conduction	ABG	Bone conduction	Air conduction	ABG	ΔABG	
TOR	25.75 ± 15.85	56.94 ± 23.40	31.19 ± 11.24	23.17 ± 13.40	49.74 ± 23.99	26.57 ± 14.38	***4.62 ± 12.02***	*p = 0.10*
POR	18.79 ± 12.23	44.69 ± 18.80	25.90 ± 10.25	18.44 ± 11.31	34.29 ± 15.47	15.85 ± 7.61	***10.01 ± 9.56***	
Adult	25.71 ± 14.32	56.18 ± 20.97	30.47 ± 10.61	24.34 ± 12.22	45.87 ± 21.20	21.52 ± 12.85	***8.95 ± 11.60***	*p = 0.88*
Pediatric	11.25 ± 6.21	33.19 ± 12.16	21.94 ± 9.30	10.30 ± 4.29	27.14 ± 11.36	16.84 ± 8.99	***5.09 ± 8.45***	

PTA pure-tone average, *ABG* air–bone gap

22]. The main advantage of the endoscope is that it confers an excellent view, even of hidden areas in the middle ear, particularly when attempting to achieve radicality in cholesteatoma surgery [23, 24]. Furthermore, an excellent view of the anatomic structures of the middle ear is crucial in many different conditions, such as ossicular chain malformation or challenging middle ear anatomy [11, 25, 26].

Therefore, the endoscope could also be a useful tool in OPL, providing an optimal view of the oval window and stapes superstructure to position the graft with great precision, even in unfavorable anatomic conditions. These considerations explain our choice of the endoscope whenever possible, especially in pediatric cases where ossicular reconstruction can be completed during the first surgical procedure. In fact, since the use of the endoscope allows to achieve a slightly higher rate of surgical radicality by exploring the hidden areas of residual disease (e.g., the sinus tympani) during the tympanoplasty [27], we performed EEO as a single-stage procedure in most pediatric patients of our cohort. In our opinion, this approach could be encouraged in these patients because of the early hearing recover. On the other hand, the potential disadvantages of endoscopic OPL are the same as those of other endoscopic surgical procedures on the ear: single-handed work and lack of stereoscopic vision [28, 29].

In a recent randomized-controlled trial, Das et al. examined two uniform populations that underwent endoscopic or microscopic OPL procedures using Teflon prostheses. Endoscopic ossicular restoration appears to provide superior visualization and significantly improves early hearing outcomes. However, the long-term benefits overlap [14]. The audiological results in our study are consistent with those of other studies, with a mean ΔABG reduction of 7.85 dB HL ($p = 0.00064$).

Regarding OPL, a broad set of materials has been investigated for re-establishing ossicular chain continuity including autologous or homologous ossicles, cartilage or bone grafts, hydroxyapatite, polyethylene (Teflon), or titanium alloplastic prostheses. The main advantages of autologous grafts are their very low extrusion rate, biocompatibility, and low cost. On the other hand, allograft prostheses are easy to source, reducing the operation time and eliminating the need to remodel the OPL procedure; however, they are more expensive and have a higher extrusion rate [30–33]. In the present work, our choice to use autologous grafts for reconstruction was dictated by the more versatility of these materials, especially ARI, which can be remodeled in a personalized fashion. Moreover, we observed no cases of extrusion with the use of autologous materials: a clear advantage over prosthetic allografts, which carry a low risk of extrusion as reported in a recent meta-analysis [34]. Several studies have already analyzed different OPL materials, but a consensus has not been reached. Some authors have reported the superiority of allogenic prostheses, especially titanium prostheses, in terms of audiological results and displacement rates, whereas others have showed better results in the incus interposition group, even in a prospective setting [35]; however, the topic remains controversial [36–40].

Although, at present, titanium prostheses appear to be the preferred option in OPL compared with non-titanium versions, a recent meta-analysis has shown that the former are not superior to the latter. This is true even when considering the type of prosthesis (that is PORP or TORP) [41].

Similarly, one of the most interesting recent studies by Órfão et al. confirmed the absence of a statistically significant association between ABG gain and independent variables among the materials used for OPL, although in their first unadjusted analysis, titanium implants may be associated with better results [5].

Among autograft materials, Malafronte et al. first reported the acoustic and surgical qualities of the homonymous double tragal cartilage block (DCB) and compared it with the incus graft in partial OPL. This remodeling seemed to provide better results in terms of the 6-month postoperative ABG (87.9% < 20 dB HL vs 54.5%, $p = 0.0002$), perhaps because of problems associated with erosion/lack of malleus. Moreover, DCB has been reported to have lower rates of prosthesis displacement and fixation (0% vs 34% and 11.3%, respectively) [42].

In our study, an autologous incus interposition graft was the first choice for reconstruction. When it was not possible to harvest the incus due to erosion or epidermization, other materials, such as mastoid cortical bone, or tragal or conchal cartilage, were used successfully. We found a superior audiological result for POR in both mean postoperative air conduction and postoperative ABG than in TOR. This confirms the central role of an intact stapes superstructure in achieving optimal hearing results. The mean ABG closure was also better in the POR group (10.00 and 4.88 dB HL, respectively), although a statistically significant difference was not found because of the limited size of the study population [5, 14, 43, 44].

An interesting result that was found in this study was the similarity of audiological results between primary and secondary OPL. The ABG closures were higher in the primary OPL group than in the secondary OPL group (8.96 vs 5.69 dB HL, respectively), probably due to the higher rate of TOR in the latter group, but this difference was not statistically significant. Therefore, we believe that the decision to perform a primary OPL or second-stage procedure can only be based on the risk of cholesteatoma recurrence. In low-risk cases, an OPL procedure can be performed at the time of the primary surgery for cholesteatoma, with the advantage of immediate hearing restoration and avoidance of a second procedure, with the same functional results as a

Table 2 Summary of population sizes, demographic data (pediatric or adult population), surgical approach (endoscopic or microscopic surgery), materials used for ossicular chain reconstruction, type of prosthesis (TORP or PORP), and audiological outcomes in the most relevant studies on ossiculoplasty

Literature study	Population (n)	Age group	Surgical approach	Material	OPL type	ΔABG
Marchioni et al. [29]	14	Pediatric	EES	Autologous	POR	4
					TOR	30.3
Caloway et al. [49]	91	Pediatric	EES	Autologous, Alloprosthesis	POR/TOR	10.0
	91		MES		PORP/TORP	14.2
Zakzouk et al. [51]	9	Pediatric/adult	MES	Autologous	TOR	3
	40	Pediatric/adult		Titanium	TORP	12
Órfão et al. [5]	48	Pediatric/adult	MES	Autologous	POR/TOR	4.0
	26			Titanium	PORP	10.8
	17				TORP	11.3
Yawn et al. [52]	23	Adult	EES	Alloprosthesis	PORP	10.1
	8				TORP	17.5
	19		MES		PORP	11.4
	12				TORP	12.8
Potsangbam and Akoijam [22]	12	Pediatric/adult	EES	Autologous	POR	19.2
	2				TOR	8.7
	14			Titanium	PORP	18.1
	6				TORP	20.3
O'Reilly et al. [30]	137	Pediatric/adult	MES	Incus	POR	8.7
Özdamar and Sen [50]	30	Pediatric	MES	Autologous, Alloprosthesis	POR/TOR	24.4
	30	Adult			POR/TOR	20.8

Abbreviations: *AGB* air bone gap, *OPL* ossiculoplasty, *EES* endoscopic ear surgery, *MES* microscopic ear surgery, *PORP* partial ossicular replacement prosthesis, *TORP* total ossicular replacement prosthesis, *POR* partial ossicular replacement, *TOR* total ossicular replacement

delayed procedure. In high-risk cases, it is recommended to perform OPL during a second-look procedure within 2 years of the initial surgery to check for the presence of cholesteatoma recurrence or residuals, and reconstruct the ossicular chain in a dry and well-healed tympanic cavity.

Regarding the comparison between pediatric and adult populations in this study, audiological results in these two groups were comparable in terms of preoperative ABG ($p=0.93624$), postoperative ABG ($p=0.77948$), and ΔABG ($p=0.88076$). Pediatric cases of tympanoplasty and ossicular chain reconstruction are thought to be challenging due to the smaller external auditory canal and middle ear cavity [45–47]. The present data demonstrate that endoscopic OPL can be performed safely, even in young children, obtaining good audiological outcomes [48]. Our data are consistent with those in the study by Caloway et al., who reported a pediatric series of 100 patients implanted largely with titanium prostheses ($n=91$) and obtained a ΔABG of 10.5 dB HL [49], and also with data obtained by Özdamar et al. who achieved even better audiological results in the pediatric group compared with the adults [50]. A comparison between the principal studies in the literature along with their main characteristics is presented in Table 2.

A limitation of the present study is that a long-term audiometric follow-up longer than 1 year was not possible in all the patients for logistic reasons, and therefore, data about long-term complications and failure (e.g., due to ossiculoplasty ankylosis) were not provided by the present article. In conclusion, further studies are needed to compare the results of EEO with autologous materials and EEO with artificial prothesis.

Conclusions

This study demonstrates that endoscopic OPL with autologous material is a safe and minimally invasive procedure, and it can be a valid alternative to the microscopic technique. Moreover, this study shows that OPL can be performed at the time of the first surgery or as a secondary procedure with achievement of similar functional results. In addition, in the pediatric population, this technique could be a feasible and safe alternative to the traditional microscopic procedure, even in young children.

Author contributions All of the authors have read and approved the manuscript.

Funding This study was not funded.

Data availability The data supporting the findings of this paper are available and can be provided if requested.

Declarations

Conflict of interest The present authors have no financial relationship to disclose.

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