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# Endoscopic Ear Surgery in Children

*Luca Oscar Redaelli de Zinis and Nader Nassif*

## Abstract

Endoscopic assistance is gradually gaining recognition in otology not only for office examinations but also during surgery. The first endoscopic surgical procedure that was started in our institution was endoscopic ventilation tube placement to manage children with stenotic and curved canals. Following this, endoscopy was used in all type I tympanoplasty and stage I cholesteatoma removals with the advantage of avoiding a postauricular or endaural approach. The last application of endoscopic assistance was to better visualize round window and scala tympani via posterior tympanotomy during cochlear implantation. There are several advantages in using endoscopes: the wide view obtained and the possibility to observe areas behind the angle with less invasiveness and its excellent resolution, in addition to its intense light and higher magnification that facilitates teaching and tutoring. The limits of endoscopic surgery are that one hand is always needed to hold the endoscope and the lack of a third dimension. Until miniaturization of 3D systems allow the possibility to work in the narrow external ear canal, in order to overcome the limitation that one hand is dedicated to the endoscope, we will describe the use of an endoscope holder in otologic procedures.

**Keywords:** endoscopy, ear surgery, pediatric otology, chronic otitis media, cholesteatoma, otitis media with effusion, cochlear implantation, myringoplasty, tympanic membrane perforation

## 1. Introduction

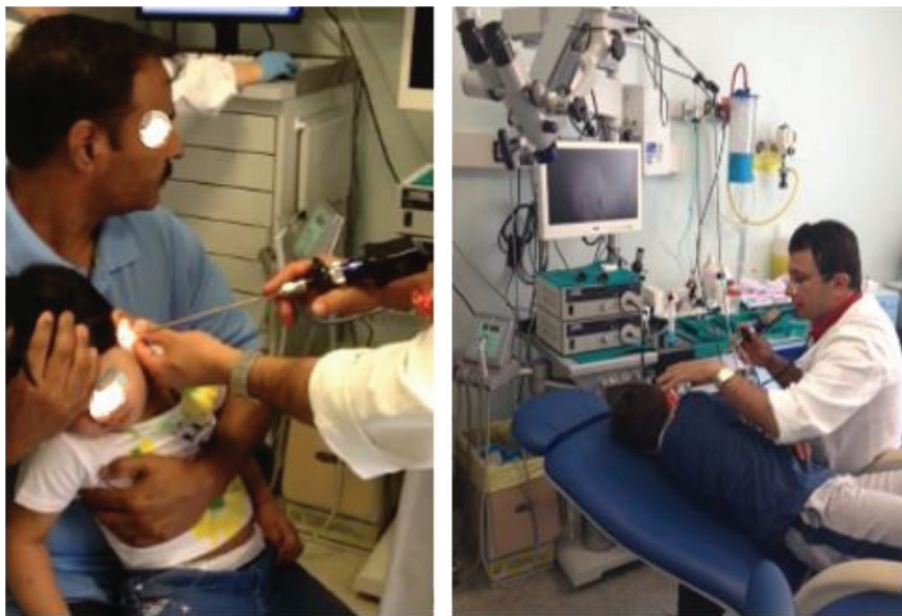
The impressive technological evolution of the last decades and the miniaturization of instruments have allowed to intervene with less invasiveness and better functional results in the field of surgical otology. The introduction of endoscopy with rigid endoscopes, coupled with video processors and high definition monitors, has opened new alternatives to conventional and validated otomicroscopic surgical approaches to the middle ear and avoid external access to various pathologies. Otoendoscopy is gradually taking hold on otology not only in diagnostic approaches but also in surgical aspects. It is well known that the endoscope has the advantage of offering a wider view compared to microscopes.

One of the first endoscopic surgical approaches to the middle ear was described by Thomassin [1]. Thereafter, many articles were published on otoendoscopic surgical procedures. Its limits are related to the lack of a third dimension, and in case of bloody fields, surgery becomes demanding and troublesome. In this chapter, we will discuss our experience developed over the years in endoscopic otology in children starting in 2004 as a diagnostic tool and then gradually as a surgical instrument

starting from ventilation tube placement, myringoplasty, cholesteatoma removal, ossiculoplasty, cochlear implantation, and, finally, the application of a holder for two-handed endoscopic surgery.

## **2. Endoscopy as a diagnostic tool**

Endoscopy provides an easy and comfortable means of examining the external auditory canal (EAC) and tympanic membrane in children for diagnostic purposes and follow-up as data is recorded and archived on a hard disk. Most children are uncooperative during office sessions for pre- and post-operative evaluations when they are laid on a bed under the microscope. With endoscopy, the child can sit on the lap of his/her parent, feeling safe and being more compliant, but otherwise by him/herself (**Figure 1**).



**Figure 1.**  
*On the left, a child sitting on the lap of his father during endoscopy; on the right, a boy lying on the examination bed by himself.*

## **3. Ventilation tube placement**

Myringotomy with placement of ventilation tubes (VT) is considered to be basic treatment for the ENT surgeon in certain pathologies of the middle ear such as otitis media with effusion (OME). The alternative to the use of a microscope in carrying out such a procedure is a rigid endoscope.

Endoscopic VT placement was started at our ENT Pediatric Department in 2008 by one colleague and was gradually followed by colleagues who shifted from a microscope to an endoscope until 2012, when all grommets were placed endoscopically. Nowadays, it is considered as standard technique, owing to the easy and straightforward nature of the procedure.

No special prior preparation is needed for endoscopic VT placement. In pediatric patients, the procedure is always performed under general anesthesia. The patient is placed in an otosurgical position, and cleansing of the surgical field is performed using an antiseptic product prior to removal of wax or debris when present. Wax is not a limitation in our hands, in contrast to what noted by other authors [2]; it is easily

handled and cleaned endoscopically. Hair trimming was not needed in any patient. Antifogging liquid is needed to avoid blurred vision noted in another study [3].

The endoscopic procedure is stepwise starting with myringotomy in the anterior quadrants (**Figure 2A**) using a sickle knife; suctioning of secretions from the middle ear; positioning the rim of the grommet by forceps on the site of the incision (**Figure 2B**); and gentle slipping of the grommet inside the myringotomy with a needle or a pick (**Figure 2C**). We usually use two types of VTs: a Shepard grommet made of fluoroplastic and silicone Goode T-Tubes.

No age-related limitations were encountered in endoscopic VT placement and, in fact, the age of our patients at surgery ranged from 1 month to 15 years.

The **endoscope** to use in such procedures is 0° angled. At the beginning of our experience, surgical treatment was also performed with a 30° angled scope, but no significant benefit over the 0° endoscope was observed. Moreover, as described in other studies, different lengths of endoscopes, such as 6, 11, 14, 16, and 18 cm, can be used to carry out endoscopic management [2, 4]. In our hands, the use of 11 cm or longer scopes offers greater maneuvering space for other tools without limiting the excursion of the operative hand by touching the camera.

**Endoscopes** with different **diameters** (1.9, 2.7, 3, and 4 mm) are also available. Some authors have suggested the use of a small (2.7 mm) scope in pediatric patients [2]. In our experience, 3 or a 4 mm scopes can be used interchangeably except for stenotic, bending EAC or syndromic patients (i.e., Down S., Goldenhar S., Pallister-Killian S., etc.), and in that case, a 3.0 mm endoscope is recommended. A 2.7 mm, 18 cm long endoscope is avoided because in comparison with the 3.0 endoscope, it has less luminosity should slight pressure be exerted on the shaft and a black crescent appears laterally, reducing the operating field. As we all know, in narrow or oblique EACs, positioning of VTs with an operating microscope can be a troublesome task. The ear speculum itself occupies space in the membranous ear canal, further reducing its diameter. Secondly, in a curved EAC, it is often not possible to view the inferior quadrants of the eardrum where the tube should be placed. On the contrary, the use of an adequate endoscope in a narrow and curved canal offers a larger visual field. According to our experience, it is preferable to use an endoscope with a larger diameter that is compatible with the size of the EAC. There is no need for special **tools** for endoscopic placement of grommets. The same instrument set used in a standard microscopic approach is required. In our experience, sickle knives with the smallest tips, both straight and slightly curved, are the best choice. Additionally, delicate ear forceps having a working length of 8 cm are usually well handled. Suction tubes that fit well in the pediatric age are those with diameters from 3 to 5 French.

The standard **endoscopic technique** for grommet insertion has been described above, whereas T-tube placement is more articulated, especially in the presence of atelectasis. However, in these cases, the degree of difficulty is not different from conventional otomicroscopy procedures. After myringotomy, the T-tube is grasped



**Figure 2.**  
(A) Myringotomy, (B) suction of secretions, and (C) positioning of the grommet.



either by both wings together or by one only and inserted inside the incision. The advantage of otoendoscopy compared to the operating microscope is that during placement of the T-tube, one can clearly evaluate the depth of insertion of the tube wings (**Figure 3**). The endoscope itself may be used to keep the T-tube in position while releasing and extracting the forceps.

Furthermore, an endoscopic surgical technique can be influenced by the size of EAC. Whenever the EAC diameter is stenotic, the surgical maneuver differs from standard cases. As performed in our patients, the tube is laid at the meatus and is then pushed medially and inserted in the myringotomy with a pick. The scope is not introduced deeply in the ear canal, but is stopped after its entrance. The impression of the endoscope on the membranous wall of the EAC can be noticed in **Figure 4A** and stenosis of the EAC with a diameter equal to that of the grommet is observed in **Figure 4B**.

In one of our patients, stenosis was not the only difficulty: the reduced space between the ear drum and the anterior wall of the EAC, that is, the acute anterior tympanomeatal angle, limited the surgical maneuvers was also problematic. Rotating the tube inside the incision was impossible due to the hindrance of the anterior wall. In this specific case, it was decided to switch to a T-tube to complete the procedure successfully (**Figure 5**). This was possible because in a very narrow space, holding the T-tube with a Hartmann forceps under endoscopic control allowed the flanges of the T to enter the myringotomy directly.

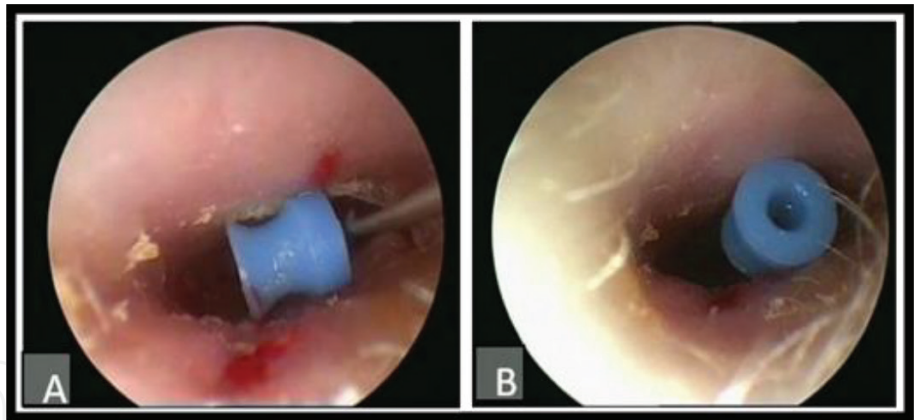
The type of **grommet** selected is another important issue in endoscopic myringotomies with VTs. Rigid materials such as fluoroplastic have some advantages over elastic ones (such as silicone or microgel). The reason lies in the need to push the grommet with a needle or a pick in smaller size EACs. The instruments would penetrate soft materials, thus not enabling correct insertion or getting stuck in it. In a couple of cases, the VT bounced back and we had to repeat the maneuver. Elastic materials might be preferred in wide EACs, where the grommet is applied directly by the ear forceps.

The **limitations** in handling instruments differ between left-handed and right-handed surgeons. For those right handed, tube placement in the right ear canal is more demanding, owing to the higher risk of excoriation of the inferior wall of the EAC and subsequent bleeding (**Figure 6**).

In left ears, the field of vision improves but there is a higher risk of skin lesions or hematoma of the anterior wall of the EAC. The opposite applies for those who are left handed; that is, excoriation of anterior canal wall in the right ear canal and inferior wall of the left ear canal (**Figure 6**).



**Figure 3.**  
*Positioning of T-tube grabbed by its wings.*



**Figure 4.**  
*Positioning of the grommet in stenotic EAC. (A) Notice the impression of the 2.7 mm endoscope greater in diameter w.r.t the EAC and (B) diameter of the grommet compared to that of the EAC.*

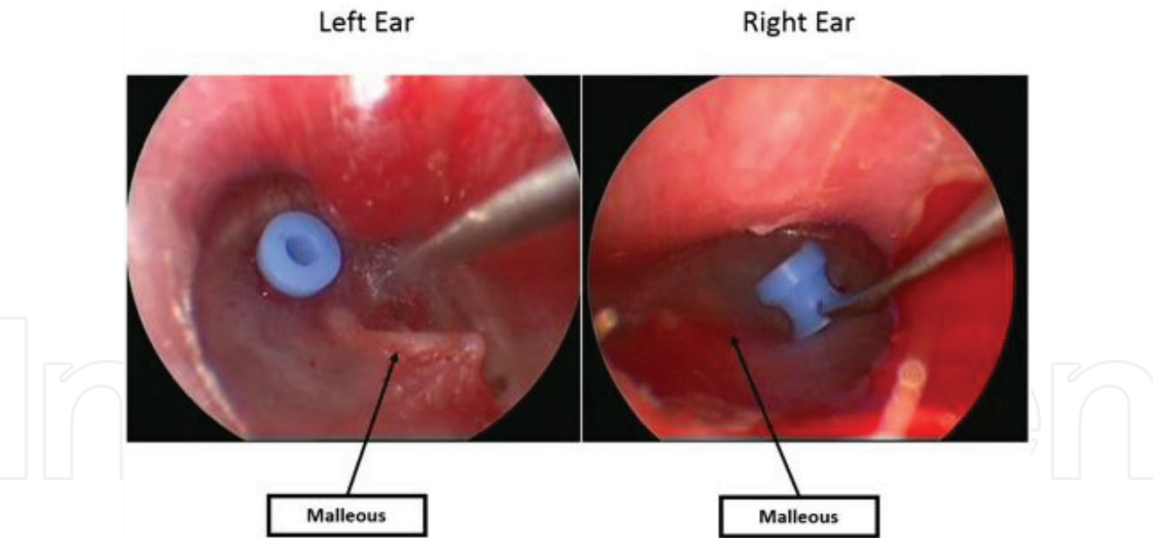
According to the literature, a major limit of endoscopic ear surgery is bleeding. When it occurs, the surgeon is sometimes forced to interrupt or convert the procedure to an otomicroscopic, bi-manual technique [12, 13, 15]. Senior surgeons are accustomed to use the left hand for suction (if right-handed) and the right hand to maneuver the instruments within the EAC, due to traditional otosurgical training. This allows maintaining the tiny operative field within the ear canal clear from blood. In our series, bleeding was never a relevant issue: in no instance did the procedure become so demanding and troublesome that there was the need to convert it to the microscope. In case of bloody field due to inadvertent tearing of the canal skin, the simple application of a sponge soaked with a vasoconstricting agent such as epinephrine 1/1000 for a few minutes allowed adequate hemostasis. Following this, rinsing the ear canal with warm water or saline also helps to clear the field. It is clear that the surgical skills of the operator and his/her experience with the use of endoscopes play an important role in minimizing surgical trauma.

Single **handedness** in endoscopy is considered by different otologists as a limitation in ear surgery, even for simple procedures such as VT placement [2, 3]. According to our experience, this is not the case as long as the skin of the ear canal is respected by taking into consideration the above advice.

Unlike other studies in the literature [3], based on our experience, no special **training** for endoscopic grommet positioning is required. Special training is definitely required for more complex procedures such as tympanoplasties,



**Figure 5.**  
*T-tube placed in stenotic EAC.*



**Figure 6.** *Iatrogenic hematoma of the left ear anterior wall and excoriation of the right ear inferior wall for a right-handed surgeon.*

ossiculoplasties, and stapedotomies. In fact, the learning curve for grommet insertion is very short, especially for colleagues who already perform endoscopic sinus surgery.

In conclusion, otoendoscopic VT placement is a valid and secure procedure. It is applicable in all patients independent of age, type of tube, Grommet tubes and T tubes, and anatomical conformation. The surgical approach is especially advantageous for grommet placement in narrow and curved EACs. In bloody fields, surgery may become more time consuming, but never compels the surgeon to abandon the technique. The learning curve is steep, especially for surgeons who are acquainted with endoscopic sinus surgery. Both cost-wise and in terms of logistic handling, the endoscope offers clear advantages. Nevertheless, the operating microscope must always be available in the operating room for rare cases of high jugular bulb or aberrant course of the internal carotid artery in the middle ear, which raises the hypothetical risk of bleeding that would not be controllable by an endoscopic approach alone. The endoscopic approach yields results that are comparable to traditional otomicroscopic techniques, but it is clearly superior in anatomically complex cases.

#### 4. Tympanoplasty (myringoplasty)

**Myringoplasty (MP)** in children is one of the most common otologic procedures and can offer a success rate as high as 95% [5, 6]. It is considered a challenging procedure in children compared to adults due to narrowness of the EAC and generally smaller size of the ear [7, 8]. In a pediatric age, access to the tympanic membrane and elevation of tympanomeatal flap (TMF) to perform MP generally necessitates perimeatal incision by employing an endaural or postauricular approach, especially in anterior and subtotal perforations, whereas a transmeatal approach is suitable only for small and posterior perforations [9–14]. In such cases, surgeons would not operate on children until the age of 10–14 years due to technical difficulties encountered in small anatomy, inability of the child to co-operate post-operatively, and increased risk of psychological trauma [10, 15–19]. In anterior perforation, surgery is more challenging as graft placement may be inaccurate [19], and the anterior aspect of the eardrum is more difficult to visualize, especially in children where the external ear canal dimensions are constraining [20, 21]. In our department, we have adopted an endoscopic technique since 2011 [22]. The

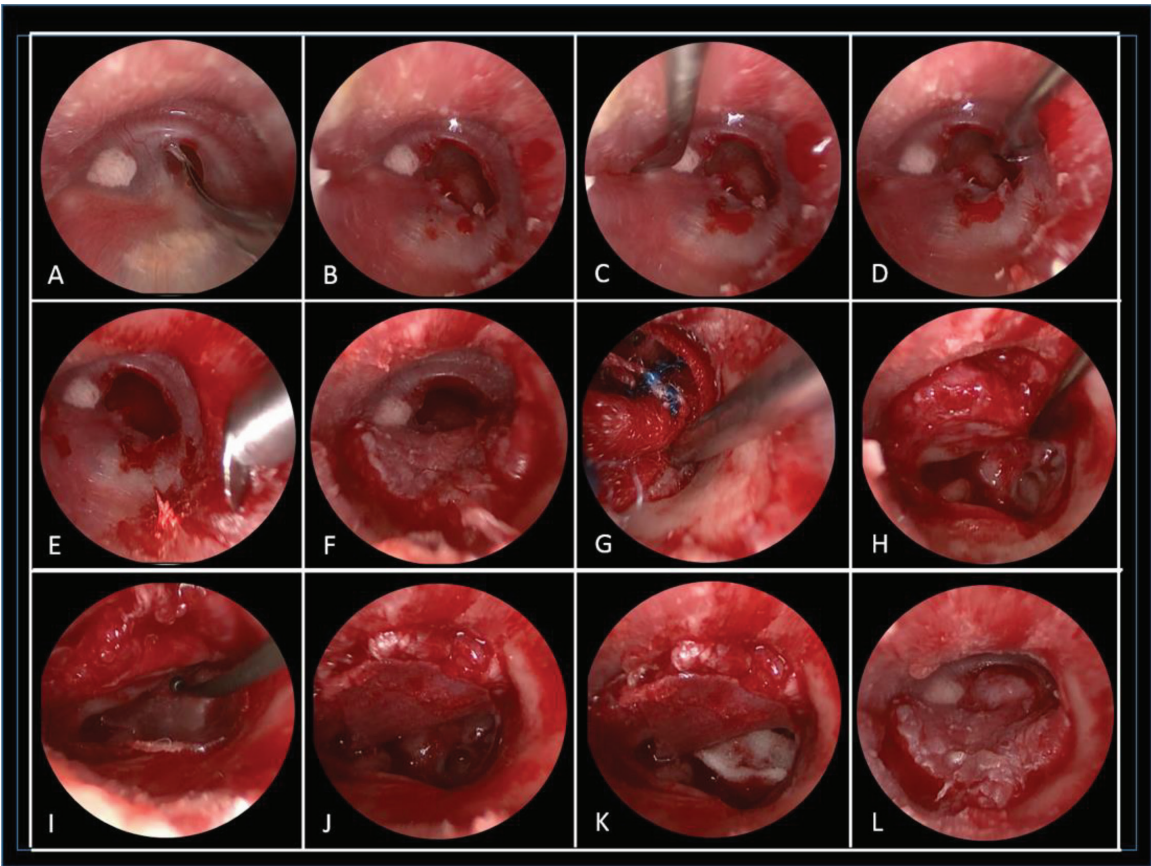


use of endoscopy to perform myringoplasty may obviate such limiting factors. In agreement with our experience and that of others reported in the literature [23], an endoscopic approach can offer many advantages over a microscope approach in children. It provides the possibility to decrease morbidity by avoiding postauricular or endaural incision and applying a transcanal approach.

The **technique** consists of refreshing the margins of the perforation using a sickle knife or Rosen needle and grasping forceps. Two vertical incisions are performed at 12 and 6 o'clock on the skin, and at a horizontal one at about 0.2 cm from the annulus and the medial TMF is elevated. The graft is inserted under the anterior margin of the perforation, underlay fashion, and under or above the handle of the malleus depending of the extension of the perforation (**Figure 7A–L**); in the case that the perforation involves the anterior quadrants, it is applied over the malleolus (**Figure 8A, B**). Gelfoam is applied adequately in the middle ear, and then both the free part of the flap and the graft are repositioned.

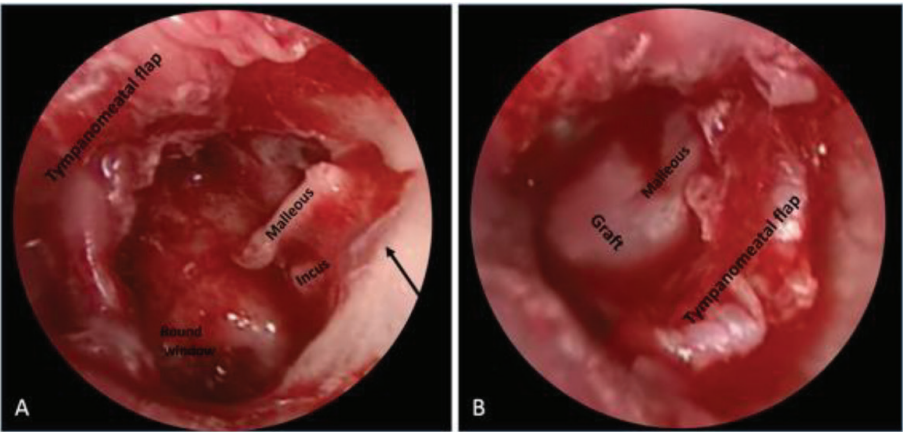
According to literature reports, **bleeding** is considered as a limit of endoscopic ear surgery. When it does occur, the surgeon is sometimes forced to interrupt or convert to an otomicroscopic bi-manual procedure [4, 24, 25]. In our experience, bleeding was never a relevant issue: in no instance did the procedure become so demanding and troublesome that it had to be converted to a microscopic intervention.

Bleeding can be handled in several ways. Injection of the EAC with epinephrine 1:1000 solution and then waiting for a few moments before incising the skin. Another hint is that after the incision prominent bleeding will be noticed at the beginning, one may shift and start harvesting the tragal perichondrium in order to provide enough time for spontaneous hemostasis to take place. During elevation of the TMF, it could be controlled by irrigation with warm saline and local application of pledgets soaked with a vasoconstricting agent.



**Figure 7.**  
*Single-handed transcanal endoscopic myringoplasty, steps A through L.*





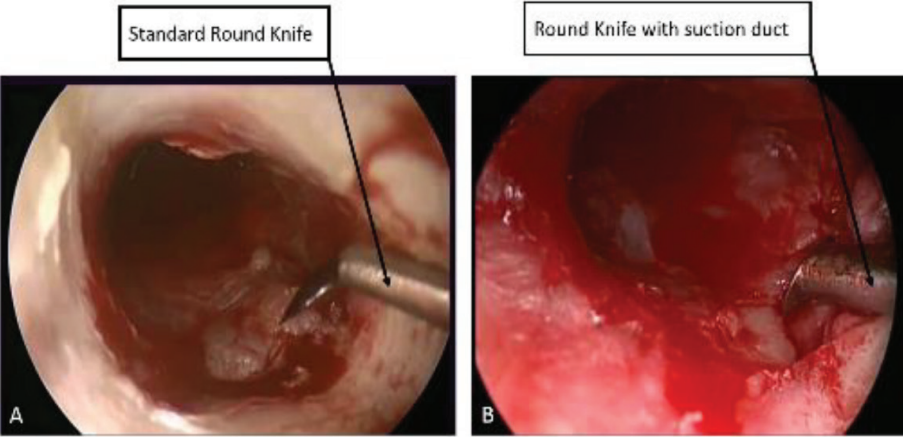
**Figure 8.**  
(A) Tympanomeatal flap elevated and malleolus is denuded. (B) Graft positioned under the osseous annulus and over the malleolus.

A very helpful tool recently introduced as an otological instrument to overcome the presence of blood in the surgical field is the round knife with suction duct. During the dissection and elevation of the tympanomeatal, it offers the advantage of going through the dissection until reaching the annulus without the need to interrupt and use suction to aspirate blood from the surgical field (**Figure 9**).

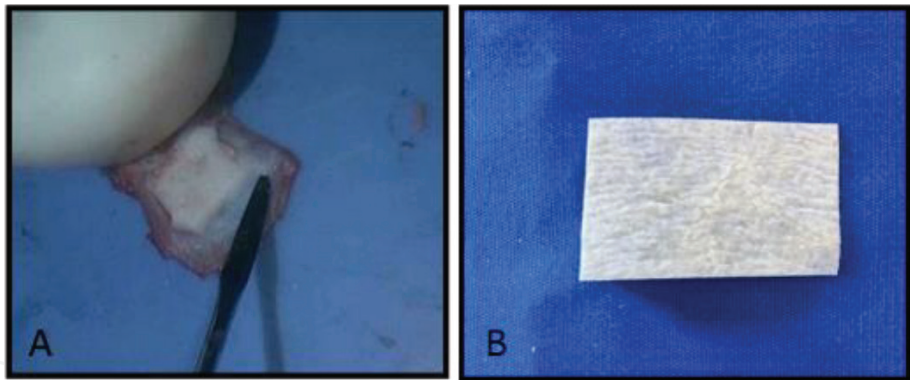
The choice of the **graft** depends upon the preference of the surgeon. In our department, we either use the tragus (perichondrium ± cartilage) harvested and trimmed otherwise using biologic tissue. The advantage of biologic tissue is that one can reduce the surgical time by up to 15 min (**Figure 10**).

As described in other studies, endoscopes with different lengths, such as 6, 11, 16, and 18 cm, can be used to carry out endoscopic management [2, 4, 23]. According to our experience, the optimal length is between 11 and 16 cm in order to avoid impingement of instruments such as that noted on ventilation tube placement [22]. The rigid **endoscope** to use according to our experience is 3.0 mm and 16 cm long. This diameter and length fits all; both in a stenotic canal and a normal one, it provides good luminosity and adequate distance between the scope and otologic instruments. A 2.7 mm diameter, 18 cm long endoscope is not advisable due to its small field of vision, less luminosity, and inadequate rigidity of the shaft that will bend upon exertion of pressure, determining a crescent black spot field laterally (**Figure 11**).

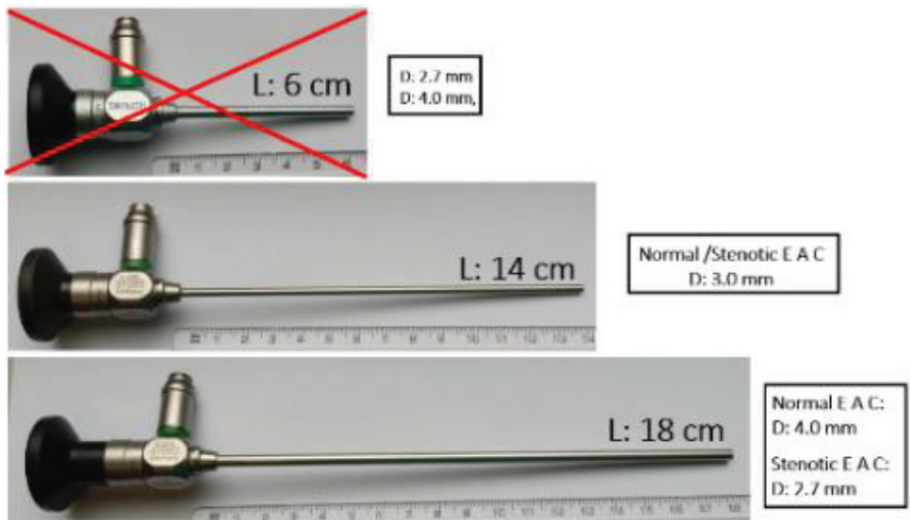
In conclusion, endoscopic-assisted transcanal myringoplasty is feasible in all cases of tympanic perforation in children of any age and can be considered as a valid, alternative approach to the microscope. It is less invasive, especially in



**Figure 9.**  
(A) Standard round knife and (B) round knife with suction duct. Notice the difference of the surgical field in B, which is free of blood.



**Figure 10.**  
(A) Autograft tragus perichondrium with cartilage isle and (B) xenograft acellular porcine small intestinal submucosa (Biodesign; Cook Medical Inc., Bloomington, IN).



**Figure 11.**  
Different lengths of endoscopes: 14 and 18 cm are indicated for ear surgery.

anterior perforations and in narrow and curved external canals where post-auricular or endaural approaches are otherwise required. An endoscopic approach grants better cosmetic outcomes and less psychological trauma with comparable anatomical and functional results vs. a traditional otomicroscopic technique.

### 5. Endoscopic approach to cholesteatoma

Endoscopy as a surgical tool in otosurgery is gradually evolving in daily practice when approaching middle and inner ear pathologies. Moreover, it is well known that cholesteatoma in a pediatric age, with an incidence that varies between 3 and 6 per 100,000 [26, 27], is an aggressive disease with respect to that in adults. The surgical approach is tailored according to the nature of cholesteatoma in being acquired or congenital, cystic or invasive. It often requires an extensive surgical approach, without undermining the preservation of hearing, as an attempt to eradicate the pathology due to its high rates of recidivism. The strategy to manage recidivism depends if it is residual, recurrent, or iatrogenic in nature. The standardized techniques at our disposition for such a destructive pathology, contrived upon the application of an operative microscope, are the transcanal (TC), canal wall-up (CWU), canal wall-down (CWD), and subtotal petrosectomy approaches. The surgeon should apply the indicated but least invasive and most effective approach, bearing in mind that the child will still have their entire life span ahead. Therefore, not only should

eradication of the disease be considered, but functional outcomes such as hearing, balance, and stability of the cavity must be taken into consideration.

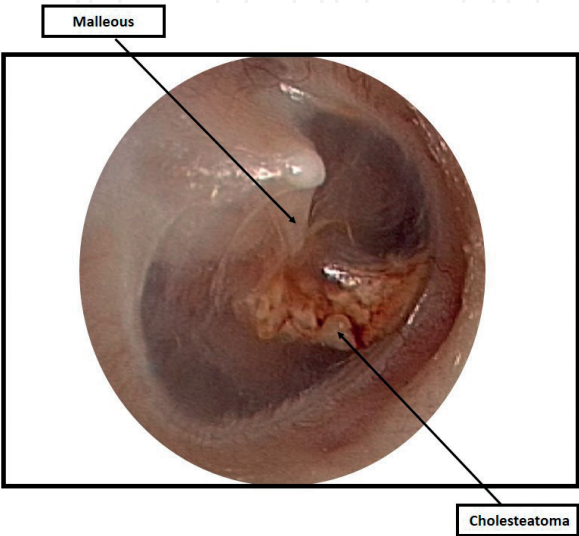
The application of otoendoscopy in recent years has allowed otosurgery to evolve and be less invasive in reconsidering certain standardized microscope operative techniques [28–30]. The major characteristic of endoscopy is to detect and dominate blind angles during surgery. Thus, in cholesteatoma surgery, endoscopy allows improved cholesteatoma removal while decreasing the rate of recidivism.

Cholesteatoma surgery is a step by step procedure that depends upon intra-operative findings. The approach cannot be decided a priori if it should be a TC, CWU, or CWD procedure. Radiologic work-up is another important element that is needed to plan the procedure. Nonetheless, during surgery, the extension of the disease may not be as expected due to the limits of radiology in defining the propagation of the pathology. Furthermore, the time elapsed between evaluating the result of radiology and the day of surgery may allow the disease to grow further and therefore invade and extend widely. For these reasons, a programmed, solely endoscopic surgical approach is not recommended, and an operative microscope is an indispensable tool to have next to the endoscope in the operating theater.

The advantages of endoscopy in ear surgery are to eradicate surgery and decrease morbidity, especially in children. According to our experience and that reported in the literature, the exclusive use of endoscopy for cholesteatoma removal should be limited when the disease involves only the tympanic cavity [31] and more precisely the mesotympanum and hypotympanum.

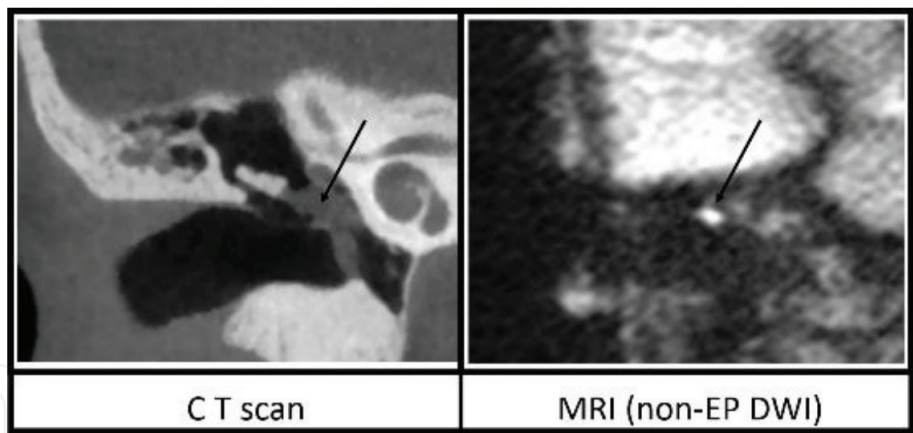
When cholesteatoma extends to the epitympanum, angled endoscopes offer a valid view to that area and for the aditus ad antrum. Therefore, the otosurgeon is at ease to decide the technical approach of the surgical procedure. Surgery may proceed as a TC approach, or extend to a combined endoscopic and microscopic one; therefore, mastoidectomy may become mandatory with a CWU or CWD approach in order to ensure that the pathology has been removed.

According to our experience, two major factors determine the choice of type or approach; the condition of the ossicular chain and nature and extension of the disease. In case of intact and healthy ossicles, and cystic cholesteatoma, such as congenital colesteatoma (**Figures 12–14**) being either lateral or medial to the ossicular chain, with an angled endoscope, there is a good chance of removing the cholesteatoma endoscopically.

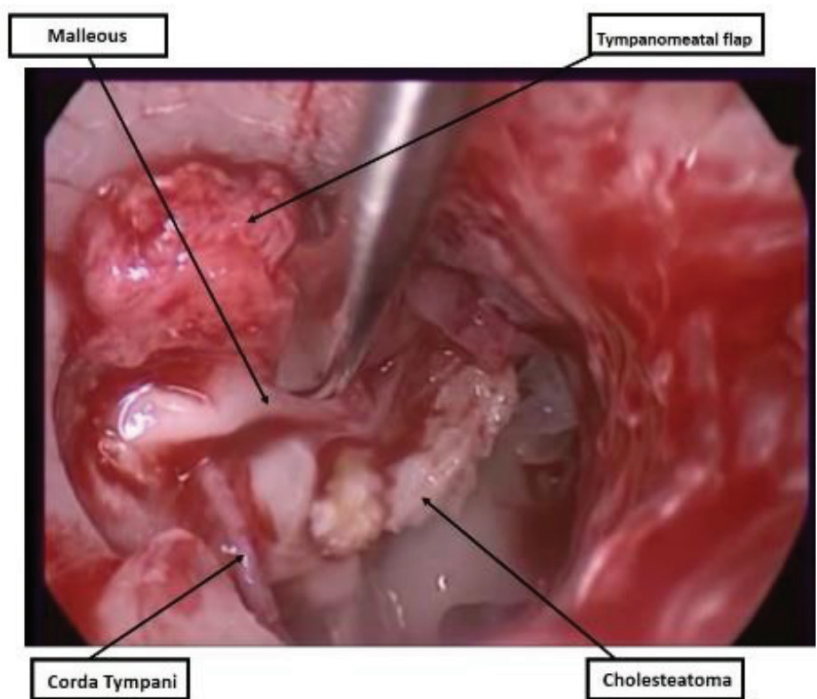


**Figure 12.**  
*Congenital cholesteatoma with an intact tympanic membrane.*





**Figure 13.**  
*Radiologic pre-operative work up: coronal CT and MRI showing the mass occupying the mesotympanum.*

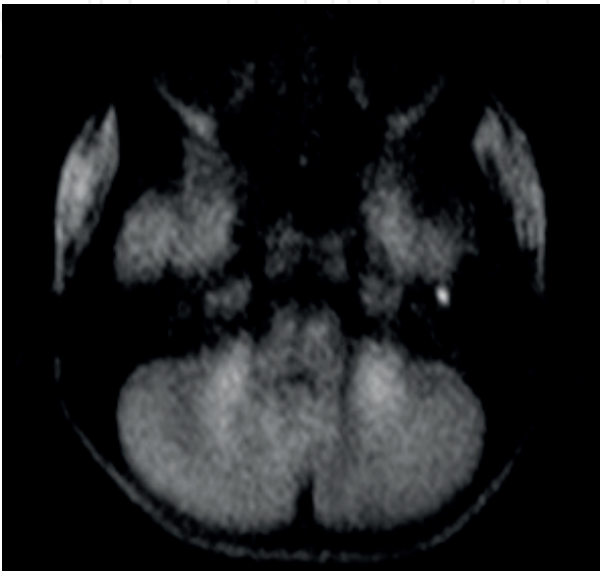


**Figure 14.**  
*Intraoperative endoscopic removal of cholesteatoma from the mesotympanum keeping the ossicles intact.*

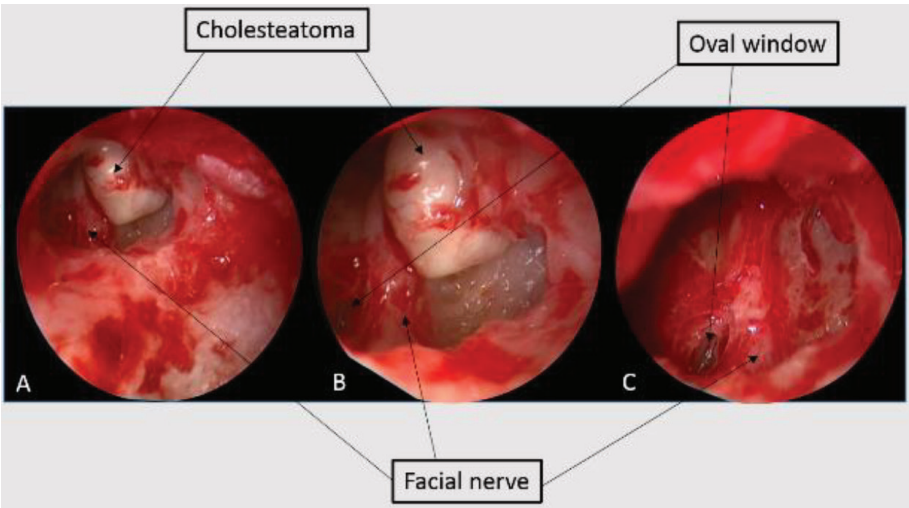
On the other hand, when the cholesteatoma is invasive and occupies the medial part of the head of the malleus and the body of the incus or extends to the antrum, it becomes a challenging task endoscopically. CWU mastoidectomy including antrostomy would be a plausible choice to remove the pathology and leave the ossicles intact. Conversely, in trying to approach such a pathology by an exclusive TC endoscopy, an extended atticotomy (reaching the antrum of the mastoid) and removal of the head of the malleus and the incus are required. This would determine the need to reconstruct both ossicles and the iatrogenic bony defect of the EAC with a piece of cartilage. In case of a small defect of the EAC, a small piece of cartilage may be adequate with good results in the future. If the defect is wide, a wedge of cartilage is needed to reconstruct the postero-superior part of the EAC. This closure would not be guaranteed in later years since the child is in growing phase. Therefore, an increase in the dimensions of the area of the EAC is inevitable with the consequence of a high probability of cholesteatoma recidivism, and CWD revision surgery would be necessary. As a consequence, otoendoscopy no longer has the advantages of being less invasive with reduced morbidity.

Children have an extremely active metabolism, and the risk of recidivism is higher than in adults. For this reason, children need closer follow-up and for a longer period, almost their entire lifespan. Non-EPI-DWI MRI is a very helpful tool in monitoring the disease and trying to avoid unnecessary surgical revisions. Most authors would consider MRI at 1 year postoperatively, otherwise explorative tympanoplasty is recommended [32].

In case of recurrence of disease, endoscopy plays an interesting role. If cholesteatoma is limited to the tympanic cavity such as the epitympanum, endoscopy grants fully transcanal removal of the disease without resorting to an post-aural approach (**Figures 15 and 16**).



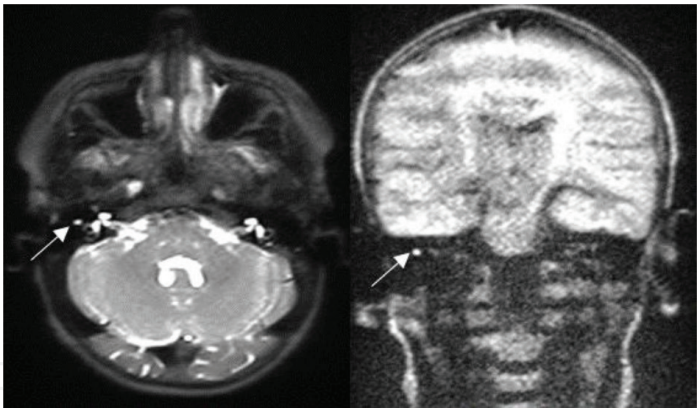
**Figure 15.**  
*Non-EPI-DWI MRI follow-up after 1 year of a 9-year-old child who underwent a CWU for cholesteatoma. Note the presence of the mass in the tympanic cavity.*



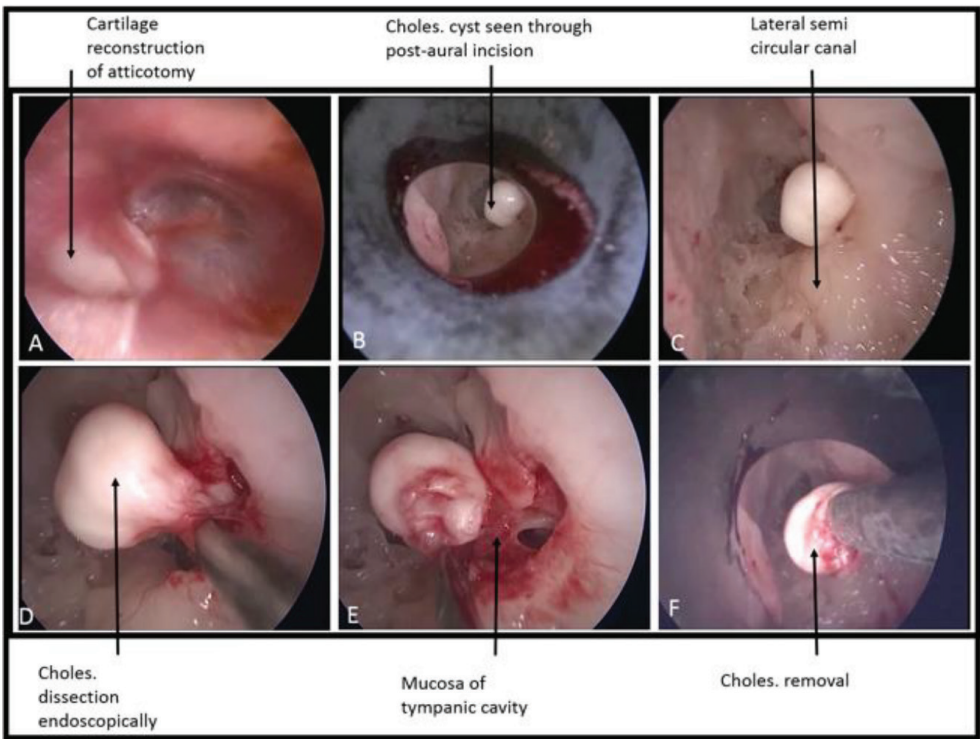
**Figure 16.**  
*Endoscopic transcanal of cholesteatoma removal for epitympanum.*

In the case that cholesteatoma recurrence is in the mastoid cavity (**Figure 17**), endoscopy can also be an interesting tool for removal of cholesteatoma in a less invasive fashion, as shown in **Figure 18**.

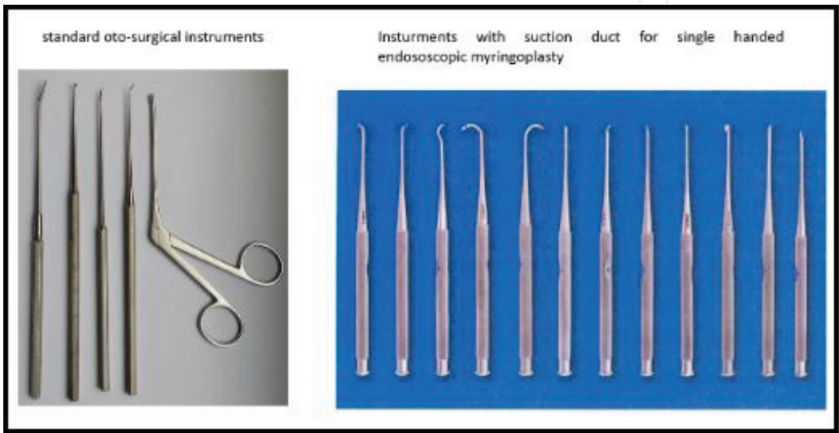
Instrumentation for endoscopic cholesteatoma removal should include dedicated tools to better control its dissection and removal. The ones that really are helpful, besides being elongated and curved shafts, include a suction duct. They can be dissectors, knives, and suctions with sharp edges (**Figure 19**).



**Figure 17.**  
*MRI at 1 year follow-up in CWU in a 7-year-old child showing recurrence of disease in the mastoid cavity in proximity of the lateral semicircular canal.*



**Figure 18.**  
*Intraoperative removal of cholesteatoma through a small 1 cm post-aural incision to gain access to the mastoid after positioning the ear speculum.*



**Figure 19.**  
*On the left, standard surgical tools for otosurgery; on the right, Panetti Endoscopic Instrument Set (Spiggle and Theis, Overath, Germany) of dedicated tools containing curved sharp tips containing suction ducts.*



## 6. Cochlear implantation

Nowadays, normal or near-normal low-frequency hearing threshold is present in many patients who are candidates for cochlear implantation, and combined electric acoustic stimulation can be proposed. Consequently, preservation of residual hearing is becoming a crucial issue. Avoiding trauma to inner ear structures when placing a multi-electrode array during the cochlear implant procedure is essential to preserve residual hearing, and the first important topic is the route of insertion of the multi-electrode array.

Scala tympani is the location for multi-electrode array cochlear implants when normal anatomy is present. The reasons for this are the greater sectional dimension compared to scala vestibuli, protection of cochlear duct by osseous spiral lamina and basilar membrane that are stronger than Reissner's membrane, close proximity to the spiral ganglion cell bodies and dendrites, and direct access through the round window (RW) [33, 34].

Access to the scala tympani to introduce the multi-electrode array during the cochlear implant procedure is obtained by opening the RWM, when the RW is sufficiently visible through a posterior tympanotomy or by performing a promontorial cochleostomy in the inferior-lateral wall of the scala tympani, when the RW exposure is not adequate. The advantages of RW access are: reduced risk of intracochlear trauma, wider stimulation surface, and facilitated perimodiolar position [35, 36].

Anatomical variations in the facial nerve, chorda tympani, and the RW niche may create obstacles to approach the RWM [37], and a classification of visualization to the RWM related to surgical approachability has been proposed. Following this classification, complete RWM exposure (considering the only one that guarantees a pure RW approach) was possible in 46% of children, while in 7% the RWM was not visible. [36].

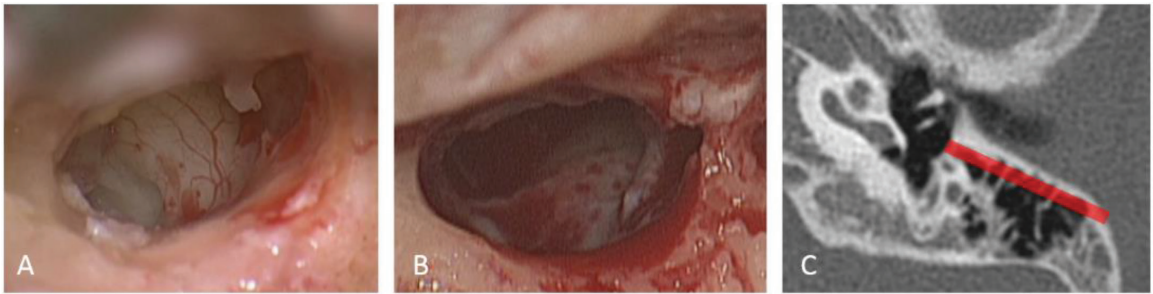
Even if the RWM is completely visible, opening of the RWM does not provide straightforward access to the scala tympani because of the presence of a sharp bony crest in the anterior-inferior border of the niche called the "crista fenestrae," the morphology of which is highly variable [38].

When the RW is not visible and a promontorial approach is needed to consent opening of the scala tympani using a cochleostomy approach without damage to the osseous spiral lamina and basilar membrane, Adunka et al. [34] demonstrated, with an anatomical study, that drilling should proceed from the inferior to the RW annulus, with gradual progression toward the undersurface of the lumen. However, the most basal part of the scala tympani forms a fish hook-like curvature in three dimensions called the "hook" region of the cochlea [39, 40]. This portion contains the cul-de-sac of the endolymphatic space where the osseous spiral lamina, spiral ligament, and basilar membrane merge [40]. The lateral wall of the "hook" region shows large size variations with the consequence of the absence of a reliable landmark for safe access to the scala tympani when promontorial access is performed.

Finally, the angle formed by a line along the plane of the basal turn and the midline (a line between the nasal septum and the internal occipital protuberance) is variable, being inversely proportional with age, thus increasing the risk of damage of the cochlear duct in children. [41].

Applying rigid endoscopy through posterior tympanotomy consents the surgeon to gain both a view of the RW, in case it is invisible, and direction of the scala tympani in children, thereby allowing soft and less traumatic insertion of the multi-electrode array during cochlear implantation (**Figure 20**).

The use of an endoscope to assist cochlear implant surgery has been reported as a transcanal endoscopy by creating a tympanomeatal flap; this approach has been recently questioned because the basal turn of the cochlea align with a more posterior angle than that of the ear canal [42]. The idea to use a rigid endoscope

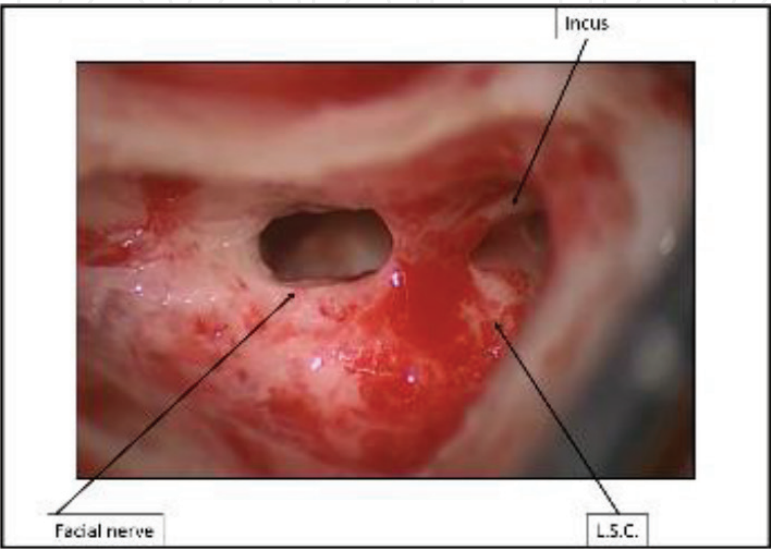


**Figure 20.**  
(A) RW visible through posterior tympanotomy, (B) case where RW is invisible, and in (C) the advantage of the endoscope to visualize the RW.

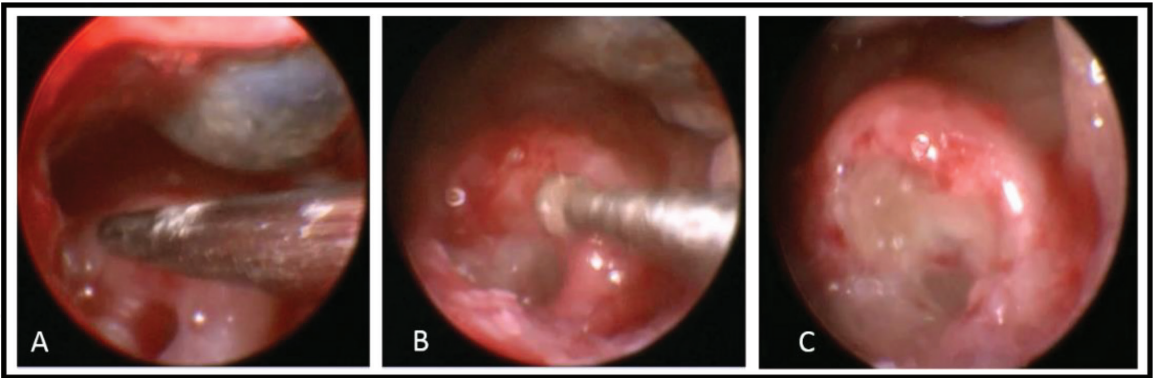
to completely visualize the RW region from posterior tympanotomy has been recently reported: 0° (3 mm outer diameter, 14 cm length) and 0 and 30° (2.7 and 4 mm outer diameter, 11 and 6 cm in length) [43, 44]. Endoscopes of 2.7–4 mm diameter cannot likely enter a standard posterior tympanotomy and, that is, in case of posterior location of the RW, there is still suboptimal visualization. With a posterior tympanotomy of 2 mm and the introduction of a 1.9 mm outer diameter endoscope, the RW niche is always completely visible so that the thinning of the lips of the RW niche under endoscopic view until the projection of the lateral wall of the ST and the region of insertion of the basilar membrane are evident; this thus avoids damage to functionally relevant structures when detaching the annulus of the RWM.

The technique consists of a standard mini-invasive surgical approach under general anesthesia performed with a postauricular access and transmastoid posterior tympanotomy of 2 mm (**Figure 21**).

The tip of a 0°, 1.9 mm diameter and 11 cm long endoscope is positioned in proximity of the upper part of the posterior tympanotomy to obtain a panoramic view of the inferior part of the medial wall of the tympanic cavity. The endoscope can be kept in place using a standard endoscope holder. The next steps are performed under direct endoscopic view. The bone overhanging the RW is lowered using a 1 mm microdrill under constant irrigation or irrigation/aspiration if an endoscope holder is used (**Figure 22**). At that point, exposure of the RW is now possible with a microscope through the posterior tympanotomy and the surgeon may proceed via the microscope approach.



**Figure 21.**  
RW not visible through posterior tympanotomy done by 2 mm burr.

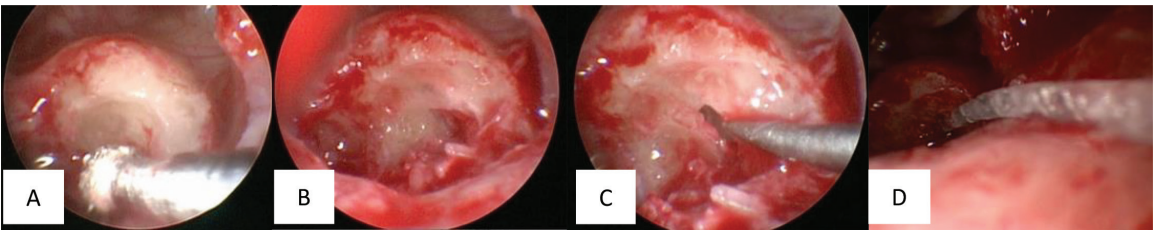


**Figure 22.**  
(A) Visualization of the RW by 1.9 mm endoscope through the posterior tympanostomy, (B) drilling of overhanging bone, and (C) RWM exposed.

Otherwise, the surgeon may continue endoscopically and exploit the best use of endoscopy. The bone overhanging the RW in the anterior inferior aspect of promontory is thinned (**Figure 23A**) until a “blue line” inferiorly (corresponding to the ST) and a white line superiorly (corresponding to the insertion of the basilar membrane) are evident (**Figure 23B**). The anterior inferior part of the annulus of the RWM is detached from its bone insertion with a needle to open the ST (**Figure 23C**). The corresponding thinned bone, the crista fenestrae, is removed by a microcurette or a very low speed 0.5 mm microdrill until the direction of the canal is clearly evident. This allows gaining centered access to the ST and permits smooth linear introduction of the multi-electrode array into the basal turn (**Figure 23D**); attention must be given to avoid bone dust or fragments from entering into the ST. The diameter of the opening of the ST is not previously planned, provided that it is larger than the multi-electrode array diameter to leave perilymph coming out during insertion (**Figure 23**). Dexamethasone 4 mg/ml is gently flushed into the middle ear cavity and cochleostomy site. The electrode array is slowly inserted into the ST in a standard manner.

Endoscopic assistance through posterior tympanotomy has other advantages: in cases of particularly curved external auditory canal or small facial recess over-thinning of the posterior wall with potential breakdown, extensive drilling of the fallopian canal with potential facial damage is no longer necessary; finally, in case of cochlear malformation, a panoramic view of the middle ear medial wall helps to identify the site for cochleostomy with no need of transcanal opening of the middle ear.

In conclusion, endoscope-assisted round window cochleostomy is a practicable alternative to the classical microscopic approach. It allows exposure of hidden RW niche, avoids over-thinning of the posterior external auditory canal by extensive drilling, and is useful to prevent luxation or removal of the external auditory canal when cochlear drillout is indicated. Thus, it optimizes array orientation and introduction into the scala tympani and leads to better results for residual hearing.



**Figure 23.**  
Left ear. (A) Drilling of the RW lips, (B) exposure of the ST, (C) RW partially elevated, and (D) array insertion along the direction of the ST.



## 7. The holder, a two-handed technique

Otosurgeons are often skeptic and hesitant for endoscopic ear surgery for several reasons. First, single handedness in endoscopy is a limitation, especially in bleeding fields. When it occurs, bleeding is often a disturbing event, and frequent suction is needed so that the surgeon may be prone to interrupt the procedure and convert it to a traditional bimanual microscope technique [24, 45]. Second, otosurgeons are experienced with double-handed stereoscopic vision. Their teachings and therefore their maneuvers are based on two hands, whereas with endoscopy, otosurgeons have to manage maneuvers with one hand and lose the characteristic of the depth of vision. Differently, surgeons who practice sinus surgery are acquainted with a one hand procedure and for them approaching middle ear surgery is much preferred to operative microscope. This is why it seems to be more acceptable to nondedicated otosurgeons than to dedicated ones.

One of the drawbacks of the technique is being single handed. In case of a bloody field, especially in hyperplastic mucosa of the middle ear, surgery can become demanding and time consuming. Trying to overcome this limit, since January 2016, we started using the STORZ endoscope mechanical holding system followed a few months later by the Unitrack pneumatic holding system.

Different from other endoscopic procedures where a dynamic field is required, that is, cholesteatoma removal [46], during myringoplasty, the endoscope seldom needs to be moved to adjust the field of vision, so that the application of an endoscope holder is particularly favorable. The immediate advantage noticed is the rapidity of the procedure in elevating the tympanomeatal flap and fibrous annulus without frequently stopping to aspirate blood. Washing and suctioning simultaneously always guarantees optimal vision and cleaning of the endoscope. Another advantage is evident during introduction of the flap in case of liquid in the middle ear: suction by the second hand is promptly made. Positioning the graft underneath the anterior annulus with two hands is much easier by avoiding its wrinkling, and application of gelatin sponges under the graft itself is much easier. Finally, in one-handed surgery, the scope often has blurred vision due to blood clot or liquid left by hair in the EAC during the frequent introduction and extraction of the scope. The most important advantages of the use of a holding system are control of bleeding and shorter duration of surgery.

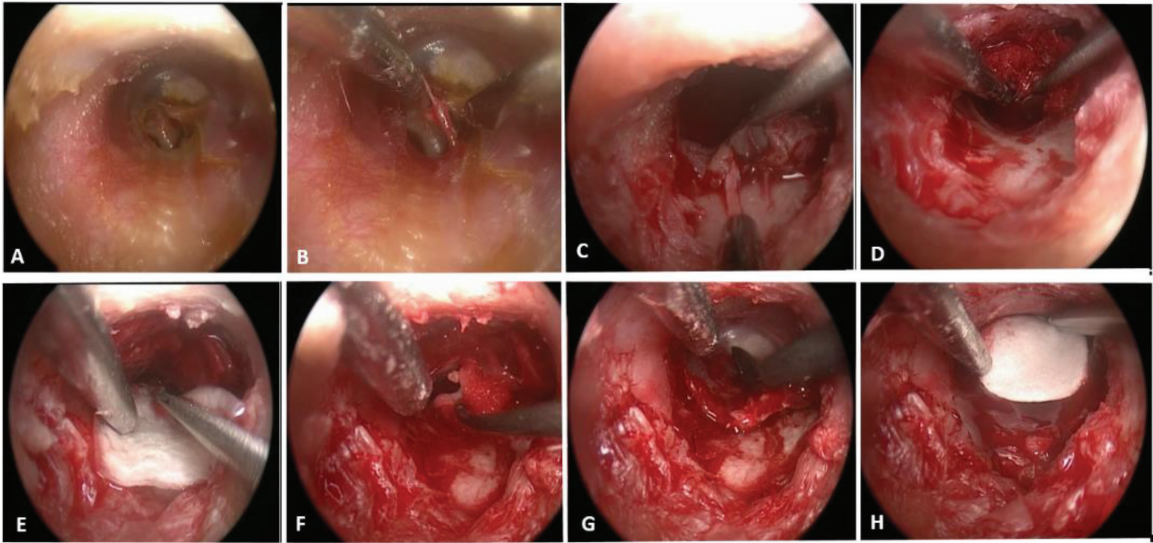
The endoscopic procedure consists of: (1) application of the endoscope holder on the operating table in front of the surgeon (**Figure 24**), (2) positioning of the endoscope at the mid level of the posterior part of the external auditory canal, (3) refreshing the margins of the perforation using a sickle knife and grasping forceps, (4) elevating a medial tympanomeatal flap with a semilunar incision at 12 and 6 o'clock, (5) inserting the graft under the malleus and the anterior margin of the perforation, and (6) applying gelatin sponges in the middle ear and, after repositioning the flap, in the ear canal. **Figure 25** shows the different steps of the endoscopic surgery and how it is handled bimanually, offering a clear advantage over a single-handed procedure.

The endoscopes used are 3 and 4 mm in diameter rigid 0° (Hopkins KARL STORZ GmbH & Co. Tuttlingen Germany), lengths 14 and 18 cm, respectively. The optic holder used is a mechanical articulating holding system (28,272 HC; 28,272 UGK; 28,172 HR: KARL STORZ GmbH & Co. Tuttlingen Germany) (**Figure 26**) or the Unitrack pneumatic holding system (Unitrac arm, RT040R, Aesculap AG, Tuttlingen Germany) (**Figure 27**). All procedures are performed under general anesthesia.

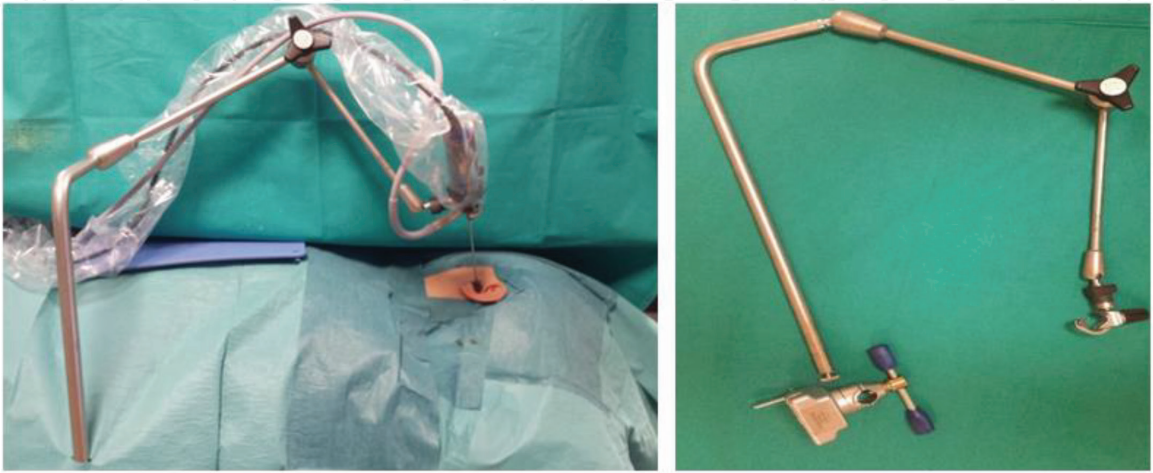
The surgical maneuvers are managed better using a 3 mm vs. a 4 mm endoscope; according to our experience, we would recommend the 3 mm thanks to the greater space offered. The reason for using an 18 and 14 cm endoscope and not 6 or 11 cm



**Figure 24.**  
*Position of holder in front of the surgeon and screen applying the same concept of standard microscope surgery using both hands.*



**Figure 25.**  
*(A–H) Steps of double-handed myringoplasty in an inferior perforation of the tympanic membrane.*



**Figure 26.**  
*Mechanical holding system.*





**Figure 27.**  
*Pneumatic holding system.*



**Figure 28.**  
*Observe the working distance and instrument length by using 14 and 18 cm long endoscopes.*

long is the possibility to maneuver both hands around the scope without encountering any obstacle by the camera and handle of the holder (**Figure 28**). The surgical instruments used for the microscope technique fit well with this technique.

There are some minor limitations of the technique: the endoscope is fixed in the canal, allowing a limited range of zooming and focusing. At the beginning of the procedure, the best view is to completely observe the ear canal, and then gradually magnify the middle ear throughout the surgery. Another limitation is that during the introduction of the graft in the EAC in some cases, the scope should be slightly pushed outward by the surgeon, which allows to see the graft lying completely on the posterior wall and therefore gliding it all the way through to the middle ear. It would be of a great help to have a camera with a foot pedal remote control in order to dynamically change the magnification and focus during the procedure and a motorized holder with fine movements to better manage the visual field.

## 8. Learning curve aspects

Learning curve varies upon both the complexity of otological procedure and prior experience of the otosurgeon with endoscopic sinus surgery. Furthermore, the profile of the learning curve is expressed through two factors.



The first factor is the variation of duration of the same surgery through time. According to our experience, surgical duration decreased with time in all types of endoscopic surgeries especially in ventilation tube positioning and tympanoplasty. For cholesteatoma endoscopic removal, since it was the last to introduce in our daily practice and therefore we were already acquainted with otoendoscopic surgery, duration of surgery did not undergo a tangible reduction.

The second factor is expressed by the anatomical results obtained through time. Concerning tympanoplasty, with time, we have experienced less reperforations in the reconstruction of the successive tympanic membranes. For cholesteatoma surgery, we become more confident in cholesteatoma removal from the hidden parts of the tympanic cavity, that is, sinus tympani and epitympanum. Such an experience permitted us to approach the middle ear less invasively such as creating less intracanal atticotomy or removing intact ossicles.

Concerning ossiculoplasties, stapedotomies, and cochlear implantation, it is preferable that they are advised after having obtained a certain confidence with otoendoscopic surgery.

## **9. Surgical training and young surgeons**

Otosurgery belongs to the micro-surgery procedures. In order to progress through various techniques of otosurgery, the microscope is fundamental to adequately understand the anatomy in its three dimensions. For a beginner, the best choice is to proceed training with both techniques contemporary in order to understand the different perspective of the middle ear. Not all surgeries could be completely done by endoscope, and also in case of a complication or bleeding, a microscope surgery is necessary. For experienced otosurgeons, it is preferable to start their endoscopic surgery with ventilation tube placement then move to myringoplasty and therefore to cholesteatoma removal.

## **10. Conclusions**

Endoscopy as a diagnostic and surgical tool in otology is now a valid instrument for different pathologies of the ear. Indications for solely endoscopic surgery should be well planned. Before starting endoscopic surgery, one should have good preparation in using the operating microscope and in certain surgeries should always be present in the operating theater. There are still some limits to endoscopy that in the future will be overcome thanks to technological advances such as miniaturization of 3D systems.

## **Conflict of interest**

No conflict of interest is present.

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## Author details

Luca Oscar Redaelli de Zinis<sup>1\*</sup> and Nader Nassif<sup>2</sup>

1 Department of Medical and Surgical Specialties, Radiological Sciences and Public Health, Section of Head and Neck Surgery, University of Brescia and Pediatric Otolaryngology Head Neck Surgery, Children's Hospital "ASST Spedali Civili", Brescia, Italy

2 Pediatric Otolaryngology Head Neck Surgery, Children's Hospital "ASST Spedali Civili", Brescia, Italy

\*Address all correspondence to: [luca.redaellidezinis@unibs.it](mailto:luca.redaellidezinis@unibs.it)

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