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# Endoscopic-assisted epitympanic approach: a feasible technique for cochlear implantation



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## Abstract

**Background:** The aim of this study is to discuss the detailed surgical steps of the endoscopic-assisted epi-tympanic approach (EAEA) to the round window (RW) as a safe, precise, and reliable approach for cochlear implantation (CI) and also to evaluate possible problems and limitations faced, their management strategies, and how to overcome.

**Results:** This study was carried on 40 patients admitted for cochlear implantation (CI). The patients were divided into two equal groups; the first group underwent CI via the endoscopic-assisted epitympanic approach (EAEA), while the second group was a comparison group and underwent CI via the classic posterior tympanotomy. There was a statistical significant difference as regards scalar location of CI electrodes; all EAEA cases were inserted through ST in comparison to 45% of conventional cases. There was no statistical significant difference as regards linear and angular insertion depth between the two groups. The EAEA group needed shorter time to finish the procedure taking from 90 to 195 min, whereas the conventional group consumed longer time ranging from 120 to 185 min; a difference that was found to be statistically significant. No facial nerve injury was reported in the endoscopic approach.

**Conclusions:** Endoscope-assisted epitympanic approach (EAEA) is a reliable and safe approach for soft surgery CI. Visualization of the RW and insertion of the electrode under endoscopic control was significantly reliable and successful in all cases.

**Keywords:** Endoscopic ear surgery, Cochlear implantation (CI), Round window (RW), Surgical approach

## Background

In recent years, cochlear implantation (CI) has been approved as a reliable and a safe procedure for the management and rehabilitation of bilateral severe to profound sensorineural hearing loss (SNHL). The first auditory prosthesis to be implanted in a totally deaf patient bypassing a non-functioning cochlea was done in 1957 by André Djourno and his colleagues [1]. Few years later, William House had brought their work to attention and developed the classic facial recess approach (posterior tympanotomy approach) for CI. Ever since,

this approach has been the most commonly used technique [2, 3].

In order to avoid the stressful drilling near the facial nerve, different techniques have been developed. These techniques are of a great help when there is anatomic constraint, such as a narrow mastoid, anteriorly displaced, or aberrant facial nerve; making the facial recess procedure more difficult and risky [4, 5]. While the canal wall up tympano-mastoidectomy is a commonly practiced surgical procedure in otology, the facial recess approach requires highly trained, experienced, and skilled otosurgeons. Recent studies reported facial nerve injury during facial recess approach (classic approach) for CI in a consistent incidence of 1% or less, with many other researches reporting an incidence of 0.7% [6–9].

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Since the classical approach has been used till present, different surgical approaches for CI have been detailed and thoroughly evaluated throughout the literature [10]. These included the suprameatal approach (SMA) described by J Kronenberg [11], the middle fossa approach, the transcanal wall (Veria) technique, the pericanal electrode insertion technique, the transmastoid labyrinthotomy technique, the combined approach technique, the endoscopic transcanal approach, and lastly the robotic-assisted CI technique.

The combined approach technique is a classic posterior tympanotomy with a contracted mastoidectomy, and an even narrow posterior tympanotomy, it is a safe and a simple modification especially designed for cochlear ossification, when extensive cochlear drilling is needed, whenever traditional cochleostomy has to be done anteriorly, or when the facial nerve is aberrant and does not allow for adequate visualization through the facial recess [12]. Adoption of the endoscope to the combined approach is considered a useful modification of this technique. The main target is to perform a transcanal endoscopic cochleostomy or round window (RW) exposure after microscopic elevation of tympano-meatal flap (TMF). This modification allows full visualization of the RW niche, which can sometimes be difficult to explore via the posterior tympanotomy. The optimal visualization of the RW niche ensures safe and precise insertion of the cochlear implant electrode into the scala tympani (ST) of the basal turn of the cochlea [13, 14].

Owing to the magnificent power of optics and the ability of the different angled endoscopes to see around the corners in different middle ear (ME) recesses, the use of oto-endoscopes in CI has gained a great concern, as safe alternative tool for other non-endoscopic approaches especially when difficult anatomical situations necessitate.

The purpose of this study is to describe the detailed surgical steps of the endoscopic assisted epitympanic approach (EAEA) to the RW as a safe, precise, and reliable approach for CI and also to discuss possible problems and limitations, their management strategies, and how to overcome.

## Methods

We carried out a prospective study of 40 patients admitted and treated at the Otorhinolaryngology Department. The current study was performed after approval from the ethical committee for research at the University Hospital and approved affiliated hospitals. Patients included in the study were children undergoing CI, whose preoperative radiologic evaluation revealed normal inner ear anatomy, while cases with congenital inner ear malformation, cochlear ossification from meningitis, or temporal bone fracture were excluded from the study. The investigators have

obtained written informed consent from the caregiver for each participant in this study.

The patients were divided into two groups; each group was composed of 20 patients. The first group underwent CI via EAEA. The second group was a comparison group, and surgery was done using the classic posterior tympanotomy (facial recess) approach.

All surgical procedures were recorded and stored digitally. The surgical steps were analyzed; the intraoperative and postoperative complications were also documented.

Postoperative radiological assessment was done using high-resolution CT scan to confirm the position of the array and also to measure both linear and angular depth of insertion of the electrode array for all cases.

### Surgical procedure for EAEA

A standard endoscopic ear surgery setup was done for the operating room. HOPKINS® oto-endoscopes of 0°, 30°, and 45° (diameter 3 mm, length 14 cm) (Karl Storz, Tuttlingen, Germany), coupled to a HD camera, and video-recording system (Karl Storz AIDA® system, Inc., Tuttlingen, Germany) were used in our study, in addition to the available operating microscope.

#### *Step (1): ME approach (microscopic step)*

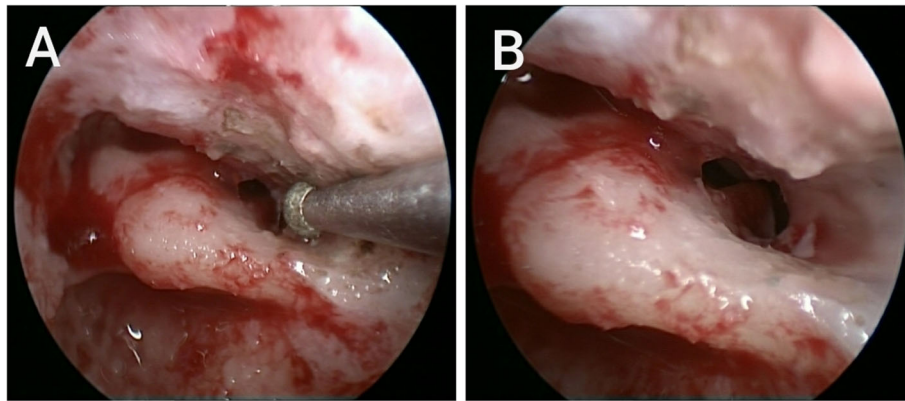
Using a standard retroauricular skin incision, TMF was elevated taking care to avoid trauma or perforation and not to damage the vascular strip.

Once the bottom of the EAC was reached, the fibrous annulus of the tympanic membrane (TM) was elevated and then TMF was reflected anteriorly till exposure of the handle of malleolus, without dissection. Microscopic and endoscopic inspection of the important anatomical structures of the ME such as the stapes-incus complex, the facial nerve, the promontory, the RW region, and the hypotympanum.

#### *Step (2): Creation of the epitympanic tunnel towards incus (microscopic and endoscopic step)*

A small bony tunnel was created through a mini mastoidectomy by drilling from behind the suprameatal spine to the posterior attic. The short process of the incus was exposed through a limited posterior attico-tympanotomy.

The space between the lateral edge of the short process of the incus, and the posterior canal wall (PCW) was enlarged by drilling with the diamond burrs (1.5–2 mm), till long process of the incus appears (or even the incudo-stapedial joint) (Fig. 1a, b).



**Fig. 1** **a** Endoscopic view of the right ear showing the drilling of a limited posterior atticotomy using a 1.5-mm diamond burr in order to create a connection between the epitympanic tunnel and ME. **b** The final view of the drilled space between the lateral edge of the short process of the incus and the posterior canal wall till exposing the incudo-stapedial joint

**Step (3): Making a connection between ME and tunnel (microscopic and endoscopic step)**

A gentle curved pick needle (right-angled hook) was introduced through the tunnel between incus (body and short process) and the PCW. The created connection between the tunnel and the ME cavity was checked using 30 or 45° oto-endoscopes to assure the patency and adequacy of the pathway for the electrode array.

**Step (4): Creation of the well for the cochlear implant device**

From the same incision, and after elevation of the skin and the subcutaneous tissue, a subperiosteal pocket was created. A bony well was created, according to the size of the cochlear implant used. A groove for the electrode cable was drilled from the well to the epitympanic tunnel.

**Step (5): Preparation of the RW (totally endoscopic step)**

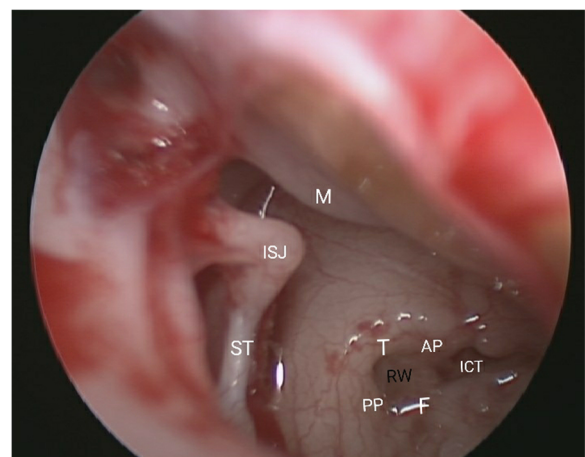
The RW region was identified and visualized using 0 and 30° oto-endoscopes after proper identification of ME main anatomic landmarks (Fig. 2), especially the anatomical structures that comprise the area of the RW prechamber (the tegmen, the anterior pillar, the posterior pillar, and the fustis).

The lateral bony overhang of sinus tympani was removed anterior to the facial nerve and inferior to the pyramid to allow clear visualization of the RW niche. The bony lip of the niche was drilled with a 1-mm diamond burr in order to expose the RW membrane (Fig. 3a, b).

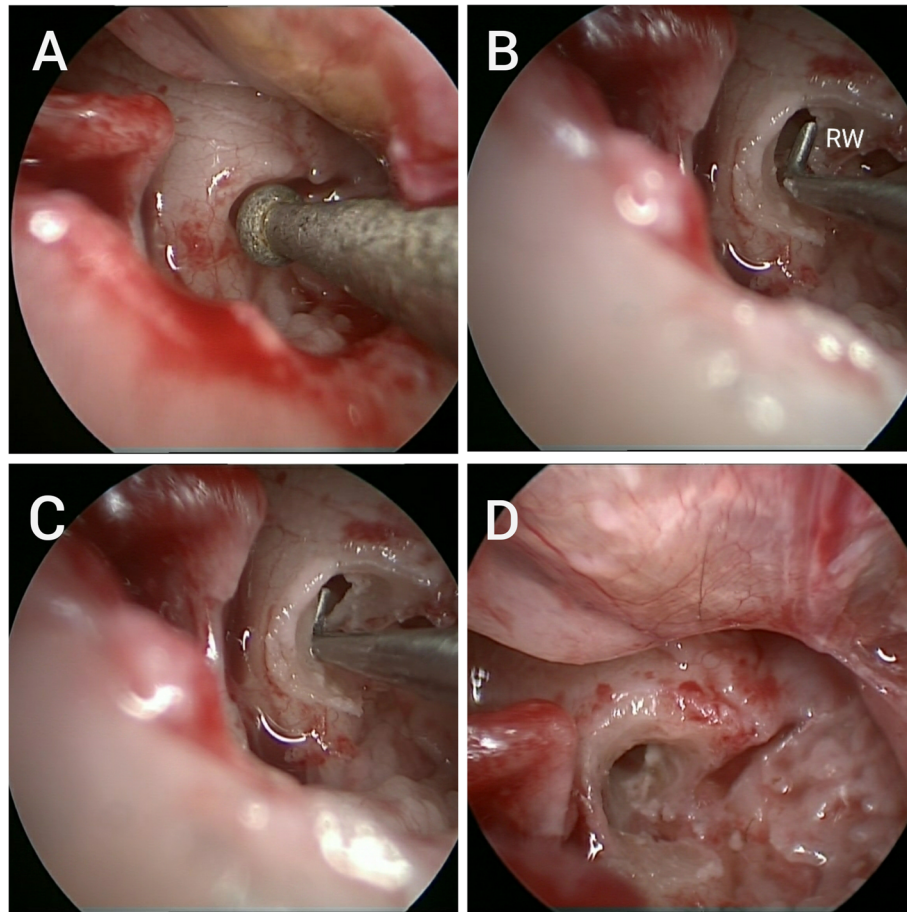
The mucosal fold or false membrane present was removed from the niche to expose the true membrane. The RW was opened by gentle removal of the RW membrane using a very fine hook (Fig. 3c) that enabled us to visualize the ST of the basal turn of the cochlea (Fig. 3d).

**Step (6): Insertion of the array via combined approach into the cochlea (microscopic and endoscopic step)**

- The electrode was guided through the epitympanic tunnel from the mastoid side under direct vision using the 30° oto-endoscope (Fig. 4a).
- The tip of the electrode was introduced into the ME through the epitympanic tunnel lateral to the incus, then through the EAC. The tip of the electrode was then visible and can be guided towards the already opened RW (Fig. 4b).
- The electrode was gently inserted into the cochlea, advancing the array 1 to 2 mm at a time till the point of first resistance, then tiny pieces of fascia or periosteum were placed around the electrode for sealing; if needed (Fig. 4c).



**Fig. 2** Endoscopic view of the right ear showing the detailed ME anatomy and RW niche. AP (anterior pillar), PP (posterior pillar), F (fustis), T (tegmen), RW (round window), ICT (infracochlear tract), M (malleolus), ISJ (incudo-stapedial joint), and ST (stapedius tendon)



**Fig. 3** **a** Endoscopic view of the right ear showing the start of drilling of bony lip of the RW niche using a 1-mm diamond burr. **b, c** Endoscopic view of the right ear showing opening of the ST by gentle removal of the RW membrane using a fine hook. **d** Endoscopic view of right ear showing the drilled-out RW niche and the opened ST

- This step is a four handed step, as under endoscopic vision the electrode is inserted through the EAC to the cochlea and the assistant is supporting and gently sliding it from the mastoid side through the epitympanic tunnel (Fig. 4d).

#### **Step (7): Array fixation and wound closure**

- The array was fixed well in the opening of epitympanic tunnel then the wound is closed in layers.

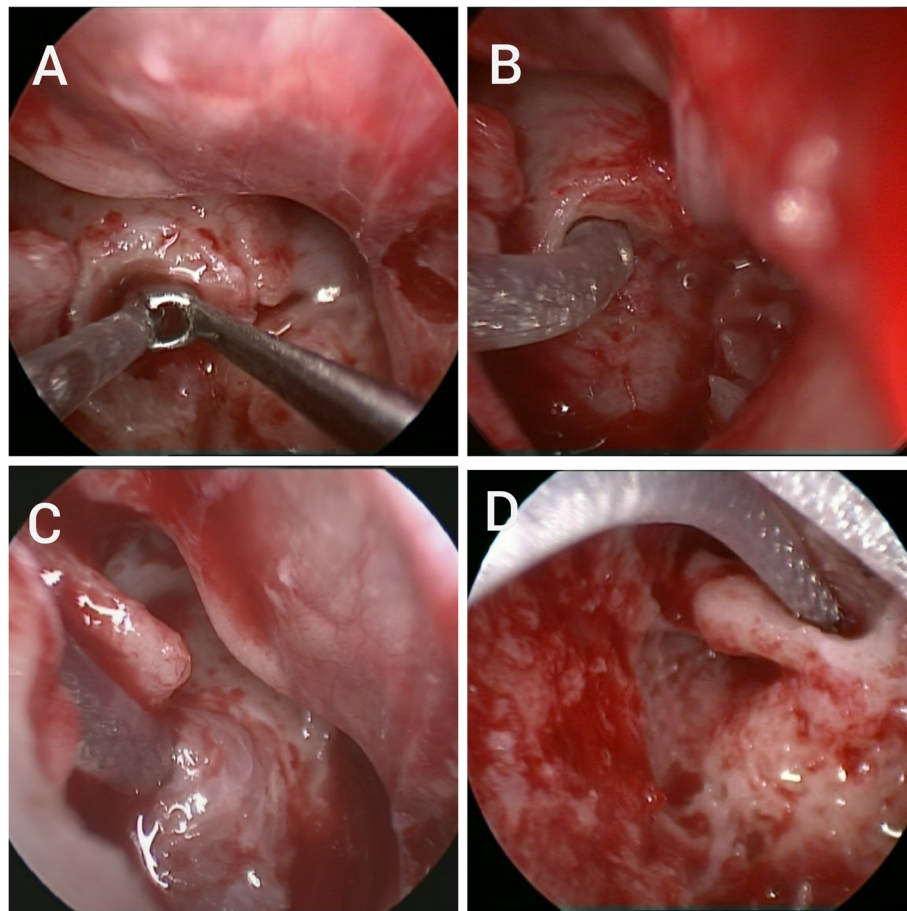
**Postoperative radiologic assessment** The CT was performed with a 64 multislice scanner (Siemens, Erlangen, Germany) with parameters of 104 mA, 130 kVp, matrix of 512 × 512, and section thickness of 0.63 mm. Scans were acquired in the axial plane while the patient lied in supine position. DICOM datasets were then transmitted to a post-processing workstation, where all other planes (coronal, sagittal, and oblique) were obtained. The oblique coronal plane was used for measurement of the

angular insertion depth. Curvilinear reformats were used to measure the linear insertion depth. As for the scalar location of the electrode array, oblique axial and oblique sagittal (Pöschl) views were used to assess the position of the array in relation to the interscalar (spiral) lamina [15, 16].

The implanted electrodes were evaluated using high-resolution CT scan to assess the scalar location and to calculate the linear and angular insertion depths of the electrode array.

#### **Statistical methodology**

- Data were collected and fed to the computer using SPSS (Statistical Package for Social Science) program for statistical analysis (VER21) [17].
- Kolmogorov-Smirnov test of normality revealed no significance in the distribution of the variables, so the parametric statistics was adopted [18].
- Data were described using minimum, maximum, mean, standard deviation, and 95% CI of the mean.



**Fig. 4** **a** Endoscopic view of the electrode insertion into the ST of the basal turn of the cochlea. **b, c** Endoscopic view of a fully inserted electrode into the RW sealed with piece of periosteum. **d** Endoscopic view of the final position of the electrode inserted through the (epitympanic) tunnel

- Comparisons were carried out between the two studied independent normally distributed groups using independent sample *t* test. When Levene's test for equality of variances is significant, Welch's *t* test is used, which is an adaptation of Student's *t* test.
- Chi-square test was used to test association between qualitative variables.
- Box and Whisker plot and clustered, bar chart was used accordingly.
- Histograms with the distribution curve, pie chart, and clustered bar chart were used accordingly.
- An alpha level was set to 5% with a significance level of 95%, and a beta error accepted up to 20% with a power of study of 80%.

## Results (Tables 1, 2, 3, 4, 5 and 6)

### Radiologic evaluation

Three parameters were assessed as follows:

- (1). The linear insertion depth was measured by unfolding the electrode array using curvilinear reformatting method followed and by direct linear measurement on the reformatted image.
- (2). The angular insertion depth was directly measured on the oblique coronal reformat.
- (3). The scalar location of the electrode array, oblique axial, and oblique sagittal (Pöschl) views were used to assess the position of the array in relation to the interscalar (spiral) lamina (Fig. 5).

### Discussion

The standard surgical procedure described by House in 1976 for CI involves mastoidectomy, posterior tympanotomy, and then approaching the basal turn of the cochlea guided by the RW, either through a cochleostomy over the promontory adjacent to the RW niche or through the RW niche itself to access the ST of the basal turn of the cochlea [10].

Despite of the multiplanar visualization of the anatomical spaces and depth perception provided by the microscope, it sometimes does not allow full visualization of the RW niche [13, 19]. In some occasions with abnormal

**Table 1** A comparison between the two studied groups according to scalar location, insertion depth, complications, and operative time

Conventional approach					Endoscopic approach				
Linear insertion depth (mm)	Angular insertion depth (°)	Scalar location	Complications	Operative time	Linear insertion depth (m.)	Angular insertion depth (°)	Scalar location	Complications	Operative time
23	540	V		155	30	680	T		195
27	550	V		160	25	450	T	Chorda tympani injury	170
22	340	T		180	22	300	T		180
24	480	T	TM perforation	165	24	540	T		155
18	320	T		140	23	420	T		160
31	720	V		165	20	270	T		135
24	680	V		180	26	450	T	PCW penetration	150
26	540	T		155	28	540	T		120
24	600	V		155	28	720	T		125
27	550	V		180	24	480	T		135
30	600	V		135	30	680	T	TMF perforation	125
30	680	T		120	23	320	T		120
23	400	T		165	24	360	T		150
28	450	T	Facial nerve paresis	160	22	340	T		135
27	550	V		140	17	360	T		115
18	320	T		185	23	480	T		110
21	500	V		135	21	360	T		90
22	460	T		120	20	360	T		125
28	680	V		135	24	380	T		90
31	630	V		165	26	540	T		110

V scala vestibuli, T scala tympani, PCW posterior canal wall, TM tympanic membrane, TMF tympanomeatal flap

pneumatization of the facial recess air cells with narrow posterior tympanotomy, prominent sigmoid sinus, temporal bone and facial nerve malformations, and cases with previous otological procedures; conventional surgery with posterior tympanotomy gets very difficult to achieve and surgeon can face great risks of injury to the facial nerve, the ossicular chain or TM, or may lead to misplacement of the electrode array into an abnormal extracochlear site [10, 11, 20].

When we incorporate the endoscope in such difficult cases, visualization and maneuverability get much better and offer the surgeon a tremendous help to achieve his goal in a much better way with less risks or complications. In the era of the growing need for minimally invasive approaches to CI, we chose to study and evaluate the safety and feasibility of EAEA for CI.

In their anatomical study of the facial recess region, Öztürk et al. [21] found that total RW exposure can be achieved through the facial recess in most of the temporal bones (79.2%). In another study by Leong et al.

[22], they reported that most adult (89%) and pediatric (78 %) cases had more than 50% of the RW visible after performing an optimal posterior tympanotomy. In cases of incomplete exposure of the RW niche, one must keep in mind that further dissection of the anatomic boundaries of the facial recess region may lead to complications such as facial or chorda tympani nerves injury.

With the help of endoscope, we found that the RW exposure has not been that difficult issue compared to posterior tympanotomy approach. The endoscopes offer a panoramic view of the main regional anatomical landmarks that delineate the RW niche including the anterior bony pillar, the posterior bony pillar, and the fustis. After endoscopic identification of these landmarks, direct visualization and magnification of the RW membrane will be an easy step. These findings were matching with the results of Modena group [10].

It has been established that the ST is the optimal region of the cochlea for CI electrode insertion [22]. In our study, we found that the EAEA achieved 100% ST

**Table 2** A comparison between the scalar location in both the posterior tympanotomy and the EAEA groups; 69% of the ST location was via the EAEA which represented 100% of the endoscopic cases in comparison to only 31% via the conventional approach which was only 45% of the conventional cases, a difference that was found statistically significant ( $p < 0.001^*$ )

Scalar location	Groups		Total (%) within group
	Conventional (n = 20)	Endoscopic (n = 20)	
<b>SV</b>			
▪ n	11	0	11
▪ % within Scalar location	100.00%	0.00%	27.500%
▪ % within group	55.00%	0.00%	
<b>ST</b>			
▪ n	9	20	29
▪ % within Scalar location	31.0%	69.0%	72.500%
▪ % within group	45.0%	100.0%	
<b>Total(% within group)</b>			
▪ n	20	20	40
▪ % within Scalar location	50.00%	50.00%	100.00%
<b>Test of Significance</b>	$\chi^2_{(df = 1)} = 15.172$ $p < 0.001^*$		

n number of patients, df degree of freedom, SV scala vestibuli, ST scala tympani, NS statistically not significant,  $\chi^2$  Pearson chi-square  
\*Statistically significant ( $p < 0.05$ )

location of the electrode compared to 45% ST location in the conventional approach.

Nowadays, it is a well-known fact that the RW insertion has many advantages over promontory cochleostomy [23]. One of the important advantages is the potential for reduced damage to intracochlear structures, as reported by several temporal bone studies [24, 25]. Another main advantage is the avoidance of inadvertent SV insertion of the electrodes [26].

In a study by Connor et al. [27], they concluded that the RW membrane intentioned approach was superior to the conventional promontorial cochleostomy approach in obtaining array placement within the ST. The RW electrodes achieved 94% ST retention compared with 64% for the bony cochleostomy group. All electrodes stayed in the ST in the RW group, whereas in the bony cochleostomy group, 9% crossed from the ST to the SV.

In another recent study by O’Connell et al. [28], they concluded that RW and extended RW approaches

showed higher rates of ST insertion when compared with promontorial cochleostomy. ST array insertion, younger age, and greater angular insertion depth were predictors of improved CNC word scores.

In their temporal bone studies, Salam et al. [15] concluded that the RW membrane approach was associated with statistically significant higher incidence of ST placement compared to SV placement. Also, Adunka et al. [29] reported that all arrays implanted via a RW approach of eight temporal bones were found in the ST of the cochlea.

The results of our study coincide with the study of Salam et al. [15] and Adunka et al. [29] as regards the scalar location of the inserted electrode array.

Our results of the scalar location of the electrode array can be explained by the endoscopic confirmation and visualization of the ST after opening of the true RW membrane in the EAEA cases in comparison to difficult microscopic visualization of the RW membrane itself in a good percentage of conventional CI cases.

**Table 3** The linear insertion depth in millimeters between the studied groups which ranged from 18.00–31.00 mm in the conventional group and 20.00–30.00 mm in the EAEA group, a difference that was found to be statistically insignificant

Linear insertion depth (mm)	Groups		Test of significance, p value
	Conventional (n = 20)	Endoscopic (n = 20)	
<b>Min-Max</b>	18.00–31.00	20.00–30.00	$t = 0.394$
<b>Mean ± Std. deviation</b>	25.20 ± 3.94	24.75 ± 3.24	$P_{(df = 38)} = 0.696$ NS
<b>95% CI for mean</b>	23.355–27.044	23.232–26.267	

n number of patients, Min-Max minimum–maximum, CI confidence interval, NS statistically not significant ( $p > 0.05$ )  
\*Statistically significant ( $p < 0.05$ )

**Table 4** The angular insertion depth in degree between the studied groups which ranged from 320 to 720° in the conventional group and 270 to 720° in the endoscopic group, a difference that was not found to be statistically significant

Angular insertion depth (degree)	Groups		Test of significance, <i>p</i> value
	Conventional ( <i>n</i> = 20)	Endoscopic ( <i>n</i> = 20)	
Min-Max	320.00–720.00	270.00–720.00	<i>t</i> = 1.587
Mean ± Std. deviation	529.50 ± 121.55	465.0 ± 135.08	<i>p</i> ( <i>df</i> = 38) = 0.121 NS
95% CI for mean	472.614–586.385	401.779–526.220	

*n* number of patients, *Min-Max* minimum–maximum, *CI* confidence interval, *NS* statistically not significant (*p* > 0.05)  
 \*Statistically significant (*p* < 0.05)

Additionally, insertion into the ST location makes the electrode in close proximity to excitable neurons of interest, those in the osseous spiral lamina, and the ganglion cells within Rosenthal’s canal. Also, the lumen of the ST has a slightly larger diameter than that of the SV for increased accommodation of the array. The importance of these points may be appreciated when considering “soft-surgery” in CI with minor intracochlear trauma to the osseous spiral lamina during electrode insertion that will lead to better postoperative audiologic performance [30].

As settled parameters in modern CI and “soft-surgery” program, linear and angular insertion depths of the electrode array have been important variables that may correlate with hearing preservation and word recognition after CI [31–33].

In the present study, the difference between the two studied groups as regards the linear insertion depth was found to be statistically insignificant. The linear insertion depth ranged 18–31 mm in the conventional group with a mean ± SD (25.20 ± 3.94) and 20–30 mm in the EAEA group with a mean ± SD (24.75 ± 3.24). Similarly, no statistical significant difference between the two studied groups as regards the angular insertion depth could be detected. The angular insertion depth ranged from 320 to 720° in the conventional group with a mean ± SD (529.50 ± 121.55) and 270 to 720° in the EAEA group with a mean ± SD (465.0 ± 135.08).

Upon reviewing of the literature, no available data comparing the EAEA and the classic posterior tympanotomy techniques of CI as regards the linear and angular insertion depth could be retrieved. However, there

**Table 5** The incidence of complications in between the two studied groups. No significant difference was found between the groups. However, the complications in the conventional group were graver than those in the endoscopic group. On the one hand, a case of TM perforation and another of facial nerve paresis occurred in the posterior tympanotomy group. On the other hand, a case of PCW perforation, another case of chorda tympani injury, and a third case of TMF perforation occurred in the endoscopic group

Complications	Groups		Total (%) within group
	Conventional ( <i>n</i> = 20)	Endoscopic ( <i>n</i> = 20)	
<b>No</b>			
▪ <i>n</i>	18	17	
▪ % within Complications	51.43%	48.57%	35
▪ % within group	90.00%	85.00%	87.50%
<b>Yes</b>			
▪ <i>n</i>	2	3	5
▪ % within Complications	40.00%	60.00%	12.50%
▪ % within group	10.00%	15.00%	
<b>Total (% within group)</b>			
▪ <i>n</i>	20	20	40
▪ % within Complications	50.00%	50.00%	100.00%
<b>Test of Significance</b>	X <sup>2</sup> ( <i>df</i> = 1) = 0.229 <i>p</i> = 0.633 NS		

*n* number of patients,  $\chi^2$  Pearson chi-square, *df* degree of freedom, *NS* statistically not significant  
 \*Statistically significant (*p* < 0.05)



**Table 6** The comparison of the length of the operative time between the studied groups. A statistically significant difference was detected; the EAEA group needed a shorter time to finish the procedure taking from 90.00 to 195.00 min, whereas the conventional group consumed longer time ranging from 120.00 to 185.00 min ( $p = 0.012$ )

Operative time	Groups		Test of significance, $p$ value
	Conventional ( $n = 20$ )	Endoscopic ( $n = 20$ )	
Min-Max	120.00–185.00	90.00–195.00	$t = 2.623$
Mean $\pm$ Std. deviation	154.75 $\pm$ 19.63	134.75 $\pm$ 27.88	$P_{(df = 38)} = 0.012^*$
95% CI for mean	145.561–163.938	121.699–147.800	

$n$  number of patients, *Min-Max* minimum–maximum, *CI* confidence interval, *NS* statistically not significant ( $p > 0.05$ )

\*Statistically significant ( $p < 0.05$ )

are few studies used these parameters for the comparison and assessment of different routes of electrode insertion, namely promontorial cochleostomy versus RW insertion.

Three studies compared the two different routes of insertion using the classical posterior tympanotomy approach. Briggs et al. [25] concluded that there was no significant difference in angular insertion depths between RW membrane and cochleostomy approaches, with a mean of  $240^\circ$  for the former group and  $255^\circ$  for the latter group.

Adunka et al. [29] reported a mean angular insertion depth in the RW membrane approach group of  $393.88^\circ$  and a mean linear insertion depth of 26.5 mm.

Salam et al. [15] concluded that there was no significant difference either in angular or linear insertion depths between the RW membrane and cochleostomy approaches. The mean of the angular insertion depth was  $406^\circ$  for RW membrane approach group and  $488^\circ$  for the cochleostomy group. The mean linear insertion depth for the RW membrane group was 21.5 mm and 22.2 mm for the cochleostomy group.

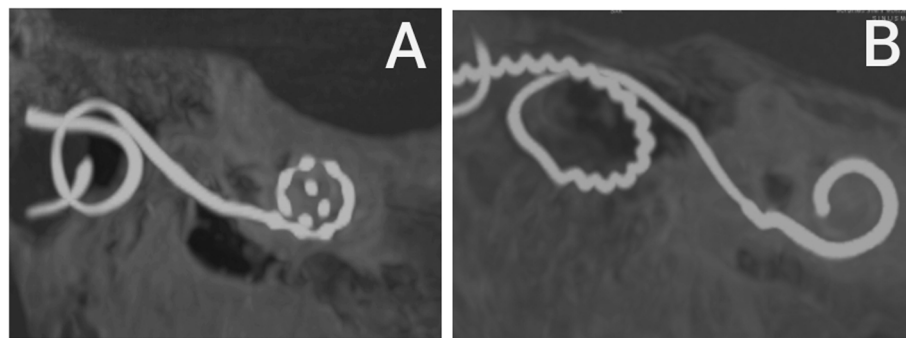
The difference in angular insertion depth between the previous studies was most probably due to variance in the cochleostomy site, electrode design. Also, it might be

related to variance in radiological assessment tools among different studies [15].

According to general guidelines of “soft-surgery” CI, it is recommended to avoid advancing the array past the point of first resistance encountered during insertion, which generally occurs between 17 and 20 mm, in order to guard against rupture of the basilar membrane, fracture of the osseous spiral lamina and/or ligament, and buckling of the array [30, 31, 34].

Angeli and Goncalves considered the insertion was deep when the electrode was placed at least 23 mm into the cochlea. They reported a possible deep insertion in 25 out of 35 patients. They found a statistically significant correlation between “cochlear height” and “insertion depth.” They concluded that the linear assessment could permit and help the preoperative “selection” of the appropriate electrode array [35].

In our opinion and from the data obtained from the present study, we agree that the most important factors that will determine the linear insertion depth is the preoperative radiological evaluation of the cochlear length and the avoidance of advancing the electrode array past the point of the first resistance. Otherwise, the technique of CI will not make a difference in the insertion depth parameters.



**Fig. 5** Oblique coronal reconstruction CT images of two patients underwent CI through EAEA: **a** - right ear), showing a full insertion of the electrode array to apical turn in ST with a linear insertion depth of 30 mm and angular insertion depth of  $680^\circ$ . **b** - (right ear), showing a partial insertion to the end of middle turn of the electrode array in ST with a linear insertion depth of 22 mm and angular insertion depth of  $340^\circ$

As regards the incidence of complications that was recorded in the present study, there was no statistically significant difference between the EAEA the conventional approach. However, the complications in the conventional group were graver than those in the EAEA group. On the one hand, a case of facial nerve paresis and another of TM perforation occurred in the conventional group. The case of the facial nerve paresis resolved totally within 4 weeks postoperatively. On the other hand, a case of PCW perforation due to excessive drilling, another case of chorda tympani injury, and a third case of TMF perforation occurred in the EAEA group.

The results in the present study as regards the overall incidence of complications including facial nerve injury coincide with the results of Postelmans et al. [36], Zernotti et al. [37], and Migirov et al. [38].

In concordance with our results, Marchioni et al. [13] reported a case of chorda tympani injury out of 6 endoscopic CI cases. Our case of chorda tympani injury in the ME occurred while creating a pathway to connect the epitympanic tunnel to the ME in an EAEA case. The injury happened could be explained by that the free part of chorda tympani in the ME is liable to injury during some ear surgeries in which manipulation of the free part of chorda tympani is inevitable such as stapedotomy and tympanoplasty.

So, we can conclude that the EAEA is safe concerning the facial nerve but may be less for the chorda tympani. We should put in consideration that injury of the free chorda tympani nerve could happen in the ME.

In the current study, a statistically significant difference between both groups was found as regard the length of the operative time ( $p = 0.012$ ). The EAEA procedure needed shorter time to finish taking from 90 to 195 min, whereas the classic procedure consumed longer time ranging from 120 to 185 min. Notably, our first EAEA procedure lasted for 195 min and by the end of three working years the procedure took only 90 min with a mean  $\pm$  SD ( $134.75 \pm 27.88$ ). Unlike in the classic posterior tympanotomy group where with our best results the mean  $\pm$  SD ( $154.75 \pm 19.63$ ) was significantly higher.

In his preliminary study about the endoscopic CI, Marchioni et al. [13] reported an average operative time of mean  $\pm$  SD ( $120 \pm 21$ ) minutes for his procedures.

Postelmans et al. [36] reported a statistically significant difference between the two approaches with a mean operative time 111.7 min for the SMA and 132.2 min for the classic approach. Moreover, they noted a reduction in surgery time for the classic CI program in the first 4 years. They started with a mean operative time of 300 min at the onset of their CI program and leveled off to a plateau of 100 min.

In our study, the reduction of the operative time length with in the EAEA group signifies an improvement in our learning curve. Matching these results with our best results as regards the timing with in the classic group indicates that the EAEA consumes less operative time and consequently lesser anesthesia exposure hazards.

This could be explained by many factors as follows: firstly, because of the improvement in our hand skills and performance through the temporal bone trial study we did before the start of our clinical study, secondly, elimination of time consumed in drilling an optimal mastoidectomy and posterior tympanotomy and its replacement by a small epitympanic tunnel (mini-mastoidectomy), and lastly, because we started this study in coordination with a big shift to endoscopic ear surgery in many other procedures such as endoscopic stapedotomy, tympanoplasty, and cholesteatoma surgeries.

By the progression of our work in this study, we improved and refined our EAEA technique at many aspects. First, we started with a relatively large mastoidectomy and ended with a very small sized mastoidectomy (epitympanic tunnel). This modification coordinates with the principle of preservation of mastoid air cell system, which regulates ME pressure and gas exchange, subsequently minimizing negative ME pressure and TM retraction [39, 40].

Second, we adopted a (four-hand) technique to manipulate and facilitate the electrode insertion, in which the assistant can hold the endoscope while the main surgeon use both hands during electrode insertion. Also, the assistant can gently push the electrode array from the epitympanic tunnel bit by bit to help the main surgeon in advancing the electrode into the cochlea. Additionally, controlled gentle endoscopic drilling of the RW niche tegmen was done to prevent kinking of the electrode array and to obtain a better angle of array insertion. These modifications were done based on the data mentioned by Postelmans and his colleagues concerning the angle of electrode insertion in SMA technique, that is 30° more vertical than the classic approach, to avoid the risk of electrode damage and insertion trauma to the spiral ligament, modiolus, osseous spiral lamina, and basilar membrane [5, 36].

As a drawback of the EAEA technique, it is restricted to certain models of CI, as it is not suitable for CI devices using the advance off-stylet insertion tool. Moreover, concerns about the preservation of residual hearing during CI surgery arise as there is an increased risk of conductive hearing loss via hindering the ossicular chain mobility by the electrode array [5].

Other limitations of the EAEA technique are related to the known endoscopic surgery limitations such as one-hand surgery and loss of depth perception [41].

Otosurgeons are expected to overcome these obstacles by improving their learning curve and adoption of four-hand technique in certain steps.

## Conclusions

From the results of the current study in addition to previously mentioned evidence-based data about the EAEA for modern CI, we can consider it a good feasible alternative to the conventional posterior tympanotomy technique especially when it is technically difficult to achieve an optimal posterior tympanotomy in the classic approach. It harmonizes with the principles of the minimally invasive CI surgeries. In this technique, we gained the maximum benefit from combining both the microscope and the endoscope.

Although, as many other endoscopic ear surgeries, the EAEA for CI needs a learning curve but it deserves to master it and consider it in our armamentarium.

## Abbreviations

EAEA: Endoscopic-assisted epitympanic approach; CI: Cochlear implantation; RW: Round window; SMA: Suprameatal approach; TM: Tympanic membrane; TMF: Tympanomeatal flap; SV: Scala vestibuli; ST: Scala tympani; PCW: Posterior canal wall; ME: Middle ear

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## Authors' contributions

Prof. MB and Prof AM are the principal investigators and contributed to the selection of the cases, performing surgery, and article writing. Dr. M F assisted in all surgeries, data collection, and data analysis. Prof. M E contributed to postoperative radiologic evaluation. The author(s) read and approved the final manuscript.

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## Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

## Ethics approval and consent to participate

This study is an original research involving human participants which all agreed to participate. The ethical committee at Alexandria University approved our research. A written "Consent to Participate" in this study was obtained from all cases included in this study, or their parent or legal guardian in the case of children under 16. The reference number is not applicable in our university records.

## Consent for publication

It was included in the written consent to participate in the study by the cases or the care providers for cases below 16 years. No participant person data are included.

## Competing interests

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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