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Review

Endoscopic ear surgery

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ABSTRACT

Objectives: This article reviews the advantages and disadvantages of endoscopic ear surgery (EES).
Method: Pubmed, Google and the Proquest Central Database at Kırıkkale University were queried using the keywords “endoscopic ear surgery”, “ear surgery” and “endoscopy” to identify the literature needed for the review.
Results: Endoscopes allow for enhanced surgical visualisation. The distal part of the apparatus is illuminated and contains lenses angled to allow a wider view of the operative area. Transcanal endoscopic techniques have transformed the external ear canal (EAC) into an operative gateway. The benefits EES can offer include wider views, enhanced imaging capabilities and increased magnification, and ways to see otherwise poorly visualisable portions of the middle ear. EES permits surgeons to operate using minimally invasive otological techniques. When compared with microscope-assisted surgery, endoscopic tympanoplasty has been shown to require a shorter operating time in some instances. There are a number of drawbacks to EES, however, which include the fact that it is a single-handed technique, that the light source may produce thermal injury and that visualisation using the endoscope is severely curtailed if bleeding is profuse.
Conclusion: EES is a safe and effective technique. The current literature supports the idea that the results achieved by endoscopic methods are usually comparably beneficial to results obtained using conventional microscopic methods.

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1. Introduction

In contrast to how the endoscope has been readily taken up for the practice of sinus surgery in the last few decades, use of the endoscope for middle ear surgery has been a highly contentious subject within otology. Currently, the surgical operating microscope is mainly used to visualise the ear. However, although it is true that contemporary equipment offers unprecedented visualisation of the surgical field whilst permitting both binocular vision and leaving both the surgeon's hands free, the visualisation of cavities situated deep down the canal in the middle ear is undoubtedly constrained. To extend as far as the surgical plane, a microscope's optical capabilities depend on adequate illumination. As a result, present day microscopic surgical approaches not infrequently necessitate soft tissue retraction, with or without drilling of the bone, if the instrument is to visualise the diseased area satisfactorily (Kozin et al., 2015).

In contrast to the otomicroscope, the otoendoscope's source of illumination is at the distal end of the apparatus, which ensures that visualisation will be optimal. Angled lenses allow a wider field of view of the surgical area. Transcanal endoscopic techniques have transformed the external ear canal (EAC) into an operative gateway. However, since the instrument itself occupies part of the ear canal, it is only practicable to operate in a single-handed manner, which renders dissection more challenging, particularly when the surgical field becomes swamped with blood. Although a number of endoscope holders have been developed, which should allow bimanual surgery (Nomura, 1982), in fact the technical difficulties in developing a holder with sufficient accuracy for use in middle ear surgery have yet to be overcome. Furthermore, owing to the heat generated by the endoscope when operating in the middle ear, concerns have been raised with regard to long-term safety aspects (Kozin et al., 2014, 2015; Bottrill et al., 1996).

Originally, rigid endoscopes were utilised within the ear as an aid to microscopes in determining diagnoses (Nomura, 1982; Takahashi et al., 1990). The enhanced visual clarity, wide-angled imaging, and superior illumination offered by endoscopes allowed images of the middle ear cavity through a transmastoid, transtubal or transtympanic approach, to be obtained relatively easily. Accordingly, earlier reviews of the use of the endoscope in middle ear surgery concentrated on the structures within the middle ear. In the 1990s, following on from these anatomical studies, surgeons also studied the use of endoscopes as experimental aides in revision surgery for cholesteatoma, with the aim of establishing their effectiveness in detecting residual or recurrent disease (Yung, 1994; Thomassin et al., 1993; Rosenberg et al., 1995; Good and Isaacson, 1999; Haberkamp and Tanyeri, 1999). However, over the last 15 years there has been a growing tendency to use the endoscope as a device for observation, as well as the only tool suitable for imaging the middle ear and for surgical dissection, similar to the way paranasal sinus operations are currently performed. In ear surgery, endoscopes are utilised both for imaging and to carry out surgical interventions (Endoscopic ear surgery-EES) (Kozin et al., 2015).

2. Method

Pubmed, Google and the Proquest Central Database at Kırıkkale University were queried using the keywords "endoscopic ear surgery", "ear surgery" and "endoscopy" to identify the literature needed for the review.

3. Safety aspects of EES

It has been suggested that, given the noteworthy absence of evidence to the contrary, using the endoscope has demonstrated an adequate safety profile in patients, regardless of age. Similarly, there is undoubted scope for the endoscope to be used further in the detection of ear pathology. In view of the data gathered so far, it appears reasonable to suggest the endoscope be routinely utilised for examination, both intra-operatively and in the clinic (Kozin et al., 2015).

The reviews of surgical endoscopic ear surgery so far written are incomplete. This field of enquiry is relatively new and more knowledge must be gathered before the endoscope can reasonably be proposed as a substitute for the microscope. Endoscopic ear surgery is performed by only limited numbers of surgeons at present, possibly following specialised training. However, with the potential benefits in mind, experimental trials of endoscopic ear surgery may lead to a richer range of applications for the technique, and ideally this will be accompanied by a broader range of published studies (Kozin et al., 2015).

Since light energy is transmitted from the source to the tissue, the tip of the endoscope has the potential to cause thermal tissue injury. In line with the manufacturer's recommendation, it is strongly advised that the light intensity be maintained below 50% (Kozin and Daniel, 2017).

4. Advantages of EES and microscopic ear surgery

The initial endoscopic ear operations were myringoplasty and cholesteatoma extraction (Thomassin et al., 1993). However, cochlear implantation, ossiculoplasty, tympanoplasty and middle or inner ear tumours have now been added to the other clinical indications (Thomassin et al., 1993; Tarabichi et al., 2016; Kiringoda et al., 2016). Several meta-analyses and reviews of EES emphasise the safety of the method, whilst citing low levels of associated morbidity (Thomassin et al., 1993; Ayache et al., 2008; Tarabichi, 2004).

Alongside the introduction of endoscopic methods to apply in middle ear surgery, the idea of minimally invasive operative procedures has been further advanced. Unlike the traditional microscopic methods, this approach may circumvent soft tissue dissection and external incisions, and reduce the need for mastoidectomy (Yung, 1994).

4.1. Advantages of EES

EES affords a number of benefits when linked to conventional binocular microscopy, including enhanced optics with higher

amplification, and visualisation of the otherwise concealed canals of the middle ear (Kiringoda et al., 2016). However, it cannot completely replace the older surgical technique. Whilst binocular otomicroscope-assisted operative techniques remain the standard for most otologists, in a number of clinics in the United States, EES is gradually becoming a viable option for performing otological surgery (Kiringoda et al., 2016).

The high-resolution image and wide-angle of view offered by use of the endoscope permits a richer visualisation of the surgical field than the binocular microscope. The endoscope enables the otolaryngologist to introduce angled optics and a high-contrast light source to middle ear surgery (Figs. 1–4), thus decreasing the necessity for a post-auricular approach and extensive bony dissection (Kozin and Daniel, 2017).

Minimally invasive otological surgery has recently been introduced alongside the endoscopic methods. Endoscopic ear surgery, first attempted in the 1990s (Thomassin et al., 1990), has proven to be popular, as it provides greater anatomical and physiological insight into the middle ear (Marchioni et al., 2010). There are several advantages associated with otoendoscopic rather than traditional otomicroscopic surgery, in particular, it helps avoid endaural vertical and post-auricular incisions, as well as mastoidectomy, by providing a wider field of vision (Ayache et al., 2008; Migirov et al., 2011). The conventional transcanal endoscopic method involves raising a tympanomeatal flap. The advantage of these procedures is to circumvent other unnecessary incisions and soft tissue dissection. Furthermore, unexposed areas within the middle ear canal, such as the epitympanic recesses (both anterior and posterior), the facial recess, and the sinus tympani, including the hypotympanum, are afforded greater visibility via an endoscopic approach. The occurrence of residual cholesteatoma or its recurrence may also be reduced when otoendoscopic surgery is performed for the removal of cholesteatoma (Thomassin et al., 1993; Ayache et al., 2008; Good and Isaacson, 1999; Presutti et al., 2008).

The successful use of endoscopes to assist in cholesteatoma removal during conventional otomicroscopic surgery is well documented in the literature (Thomassin et al., 1993; Migirov et al., 2011; Badr-el-Dine, 2002; Dundar et al., 2014; Choi et al., 2017;

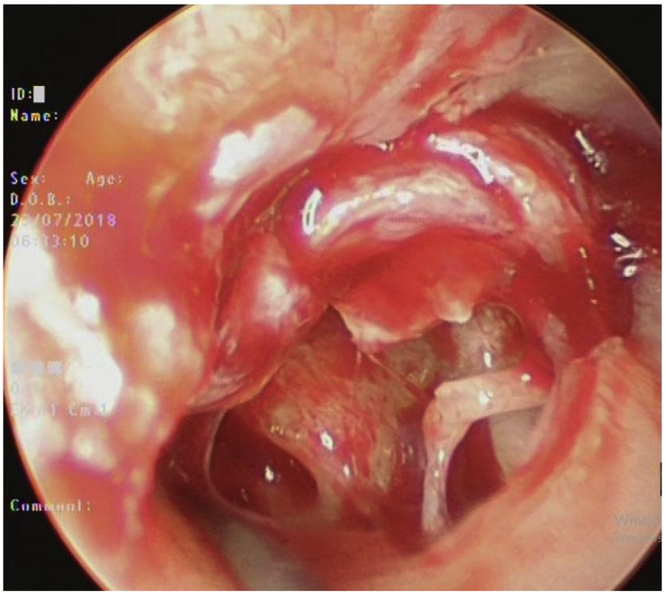

Fig. 1. Endoscopic view of incudostapedial joint, stapes, stapedial tendon, pyramidal eminence, and round window in the right middle ear cavity. Courtesy of Associate Professor Abdullah Dalgıç.

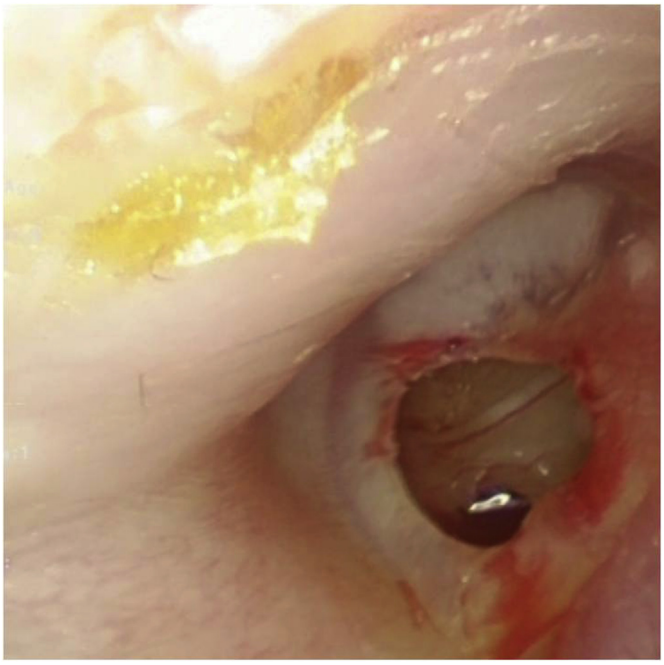

Fig. 2. Endoscopic view of the Jacobson nerve. Courtesy of Associate Professor Abdullah Dalgıç.

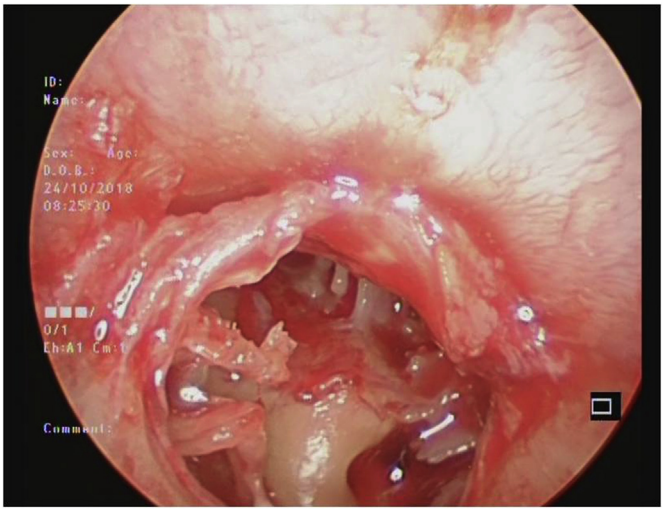

Fig. 3. Endoscopic view of over-underlay tympanoplasty and ossicles. Courtesy of Associate Professor Abdullah Dalgıç.

Marchioni et al., 2009; Tarabichi, 2010; Bottrill et al., 1996; Nogueira and Cohen, 2017; Remenschneider and Cohen, 2017; Lee et al., 2011). In addition to the adjunctive role of the otoendoscope in the treatment of cholesteatoma, the otoendoscope has been employed during tympanoplasty to make feasible minimally invasive surgery (Kozin et al., 2015; Dundar et al., 2014; Choi et al., 2017). Contemporary endoscope design features a wide angled lens (Bottrill et al., 1996), and the light emanating from the distal tip of the instrument enables superior imaging of the complete tympanic membrane (TM) of the middle ear (Kozin et al., 2015). With the introduction of 3-CCD camera systems and wide-format digital screens, endoscopes now provide an immersive and high fidelity visual experience both for the surgeon as well as any observers. Advocates for the greater use of EES emphasise the improved image clarity and magnification provided by the endoscope whilst noting

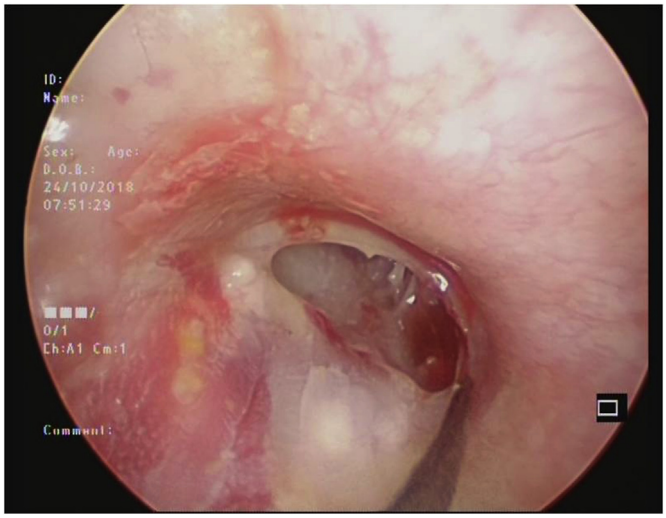

Fig. 4. Endoscopic view of an anterior perforation in the tympanic membrane. Courtesy of Associate Professor Abdullah Dalgıç.

other benefits, such as the diminished requirement for drilling and/or resection of soft tissue. Use of the otoendoscope means that the external auditory canal may in effect be used as a minimal-access operative gateway (Kozin and Daniel, 2017).

The principal advantages of EES are as follows (Choi et al., 2017):

- Endoscopic methods reduce the necessity for tympanoplasty to rely on invasive methods.
- Clearer imaging of the surgical area via a small entry point
- Less post-operative discomfort.
- Otoendoscopic tympanoplasty required a shorter operating time in some cases than tympanoplasty using the otomicroscope.

4.2. Advantages of microscopic ear surgery

There are still a number of significant advantages to otomicroscopic surgery. It not only permits a significantly amplified operative view, but also makes a binocular view possible. Two handed operations are feasible whilst using a microscope, which is greatly advantageous when attempting to clear blood from the surgical field. Nonetheless, the microscope limits the visibility of the deeper and concealed areas within the attic, epitympanum, sinus tympani and facial recess (Ayache et al., 2008; Presutti et al., 2008; Marchioni et al., 2009; Tarabichi, 2010). The limited visibility afforded by the otomicroscope and the need to access the hidden recesses is the reason why drilling of the bone and additional soft tissue dissection or resection is needed (Kozin et al., 2015).

Microscopes are indispensable for otological surgery as they provide (1) outstanding lighting, (2) depth awareness and magnification, (3) binocular vision, (4) the ability to undertake two-handed surgery, and, more recently (5) the capability of capturing high definition still images or videos. Despite these benefits, the microscope is restricted in its capabilities by limited operative gateways such as the external auditory canal. Similar restrictions also applied to earlier endoscopes. In such instances, where a surgical canal is evidently too narrow, further cutting away of the soft tissue (endaural or post-auricular) or bone removal (atticotomy, canalplasty, mastoidectomy (canal up or down), and removal of ossicles) is required to access the diseased parts of the middle ear. This is particularly the case where the external auditory canal is narrow, when there is a noticeable bony overhang of the anterior canal, and when middle ear disease extends to the attic, retrotympanum, or other cavities (Kozin and Daniel, 2017).

5. Disadvantages of EES

Endoscopic surgery also has certain disadvantages. Single-handed surgery is feasible with the endoscopic method (Choi et al., 2017), however, the limitation to a single-handed approach can become a hindrance in certain circumstances such as where extensive haemorrhage has occurred, where the endoscopic image could be obscured by blood, and proceeding with the surgery prove troublesome. Moreover, the otoendoscope itself could cause injury, including thermal damage, because of the light emitted from the tip of the endoscope (Kozin et al., 2015; Bottrill et al., 1996).

6. EES equipment

The basic tools needed for endoscopic middle ear surgery includes: (1) a light source, (2) rigid endoscopes—0º and 30° (and in some cases 45°), and (3) An HD3-CCD camera plus video screen. Different light sources are readily obtainable at different prices, such as halogen lamps, light-emitting diodes and xenon lights. There is no conclusive information that would favour any of the sources of light above the others, and at present the choice is dependent on the surgeon's inclinations and access to the devices (Kozin and Daniel, 2017).

Endoscopic camera systems are obtainable from an assortment of sellers. The fundamental requirement is for a 3-CCD camera. 3-CCD cameras allow for high-definition and clear video picture quality by depending on separate CCDs (charge-coupled devices) for red, green and blue light. Single CCD cameras tend to red out and become saturated when used in an area where bleeding occurs. Currently, otological and sinus surgery light sources are interchangeable and are commonly accessible in otolaryngology operating theatres. The diameters for the rigid endoscopes utilised in ear surgery are usually 2.7, 3, and 4 mm. If the outer canal is sufficiently wide, EES can be completed using a 4-mm diameter scope. EES endoscope shafts are typically 11, 14 or 18 cm in length. There is no evidence to conclude that there is an ideal endoscopic measurement, and the choice therefore depends on the surgeon's inclination, accessibility, and patient anatomy (Kozin and Daniel, 2017).

7. Indications and contraindications for EES

Otoendoscopes may replace the otomicroscope in situations where dissection is challenging. The otoendoscope offers a wider field of view and can pass around bends, extending the capabilities of the otomicroscope (Kozin and Daniel, 2017).

The following are indications for endoscopic ear surgery (Kozin et al., 2015; Kozin and Daniel, 2017):

1. External ear: Canalplasty, repair of exostosis, cholesteatoma, debridement and biopsy.
2. Middle ear: myringotomy, myringoplasty, medial graft tympanoplasty, lateral graft tympanoplasty, retraction of the tympanic membrane, acquired cholesteatoma, congenital cholesteatoma, neoplasms of the middle ear (eg, glomus tympanicum), ossiculoplasty, stapes surgery.
3. Inner ear/skullbase: Intracochlear schwannoma, small symptomatic neoplasms of the facial nerve in the internal auditory canal fundus, petrous apex cyst, repair of perilymph fistulas (congenital or traumatic).
4. Middle cranial fossa: repair of superior canal dehiscence.

5. Posterior fossa/cerebello-pontine angle: Establishing the existence of enduring schwannoma in the IAC fundus, localization and sealing of externalized air cells during the decompression of IAC to reduce the risk of CSF leaks.

There are no proven contraindications for EES. Any otological surgery that can be conducted with a microscope may also utilise an otoendoscope (Kozin and Daniel, 2017).

8. Current EES approaches

Endoscopic surgery calls on the surgeon to perform the operation with one hand. Although this requires a higher degree of control and precision, current data supports the conclusion that endoscopic tympanoplasty can be competently accomplished by a proficient and experienced surgeon. When comparing both endoscopic and microscopic procedures, the graft success rate in both endoscopic and conventionally operated cases are similar (Dundar et al., 2014; Choi et al., 2017). It is important to note that this data includes patients with more complex conditions such as TM perforation or anterior bony overhang. The duration of the procedure for the group who underwent endoscopic surgery is also significantly shorter than that of the microscopic tympanoplasty group. This may be a result of the time needed to close the post-auricular incision in microscopic tympanoplasty, thus extending the overall operative duration. The results of previous studies also lend support to this interpretation (Dundar et al., 2014; Choi et al., 2017).

Furthermore, as the endoscopic technique allows for a wider line of sight which can be achieved with minimal canal cuts, the overall risks related to the procedure, such as manipulation of soft tissue, bony drilling and bleeding, are also lessened (Nogueira and Cohen, 2017).

An additional advantage of the endoscope is that it provides a wider field of vision thanks to its angled perspective. This allows the surgeon to access diseased areas that may not be within the direct line of sight and also enables the surgeon to view multiple structures simultaneously. Although the endoscope has been widely recognized for its success in the field of endoscopic ear surgery, its role in combined approaches should not be overlooked. The combined approach is suitable for treating middle ear disease, where the multifocal function of the endoscope is able to detect occult mastoid disease (Nogueira and Cohen, 2017).

EES has achieved positive results in the treatment of congenital cholesteatoma within the tympanic cavity. A case ideally suited to endoscopic surgery would have the following features: a delineated, unfissured congenital cholesteatoma, an intact EAC wall; and the lack of secondary complications such as labyrinthine fistula, middle fossa extension, or facial nerve paresis (Remenschneider and Cohen, 2017).

Patients with an air-bone gap must undergo otomicroscopy in order for the surgeon to try and identify retraction of the tympanic membrane, tympanosclerosis, ossicular chain erosion or malformations, cholesteatoma or middle ear fluid. Furthermore, pneumatic otoscopy and ossicular palpation, both of which are procedures undertaken in the clinic, can be utilised to ascertain lateral chain fixation (Lee et al., 2011).

For patients who require ossicular chain reconstruction (OCR) for conductive and, more notably, mixed hearing loss, enlargement of the EAC is a viable choice that should be considered. It has already been demonstrated in a great number of patients that EES can treat tympanic membrane or ossicular pathology. Caution should be exercised for EES if a congenital or acquired stenotic outer canal exists. In some such cases, a limited canalplasty can be carried out, together with a micro drill or curette to assist the insertion of the endoscope into the canal (Zhu et al., 2016).

There are many benefits of EES for intervention in other pathological processes involving the stapes, including congenital fixation, crural fracture, subluxation, a residual attached lenticular process, and tympanosclerosis. EES permits the surgeon to visualise the whole of the oval window, usually with nominal or no difficulty arising from the scutum. However, scutum removal may be required in stapes surgery, as it often hinders instrumentation and prosthesis placement (Hunter et al., 2016). Similarly to the situation in management of ossicular fixation, a laser or drill canal can be utilised with EES to treat stapes pathology (Zhu et al., 2016). The displacement of the prosthesis or autologous ossicular reconstruction is one of the most common reasons underlying an unsatisfactory outcome in terms of hearing. Although EES is a common means to assess the presence of a round window reflex, which confirms the necessary coupling between the tympanic membrane and the inner ear, EES also has the added benefit of being able to assess the position of the ossicular prosthesis following repositioning of a tympanomeatal flap to its final position (Isaacson et al., 2017).

Almost all pathologies affecting the tympanic membrane, from small perforations to total drum replacement, can be treated endoscopically. A post-auricular approach can be prevented when using endoscopic techniques. The particular approach and choice of technique are comparable to those of otomicroscopic tympanoplasty, with minor alterations put in place to facilitate the one-handed operative technique (Kiringoda and Cohen, 2017). Endoscopes may even be used in the repair of superior semicircular canal dehiscence (Kozin and Lee, 2017).

Recently transcanal endoscopic stapes surgery has been considered another option to a conventional otomicroscopic procedure. The main advantage put forward by supporters of the endoscopic approach is the enhanced visualisation. On the other hand, the key restriction with the endoscopic technique is that it necessitates single-handed surgery. Operating with one hand hinders the capacity to apply suction and to apply retraction with the non-dominant hand. The stages involved in endoscopic stapedotomy or stapedectomy are normally similar to those used with the microscope. It has, however, been proposed that the use of an endoscope decreases the necessity for bony removal of the posterosuperior canal wall and reduces manipulation of the chorda tympani nerve (Hunter et al., 2017).

8.1. Hearing improvement in EES

A number of case studies have involved assessment of hearing results after endoscopic ear surgery. One such study concluded that there were noticeable improvements in infants and their ability to hear after undergoing endoscopic tympanoplasty (Dundar et al., 2014). A separate review identified considerable positive benefit after endoscopic middle ear surgery for the removal of cholesteatoma (Hanna et al., 2014). As has previously been noted, important improvements in the air-bone gap following endoscopic tympanoplasty were observed. The endoscopic method has been utilised for essential revision surgery or primary resection of middle ear cholesteatoma. The benefits of this method include a reduced rate of repetition, averting retraction pocket formation, better clarity while observing the middle ear canal and protection of the ossicles (Rosenberg et al., 1995; Haberkamp and Tanyeri, 1999; Presutti et al., 2008; Barakate and Bottrill, 2008). It was reported that no patients presented with cholesteatoma, and the graft success rate was 100%, over a 3-month period. Additionally, there were no cases of recurrence of otorrhea 3 months after endoscopic tympanoplasty. It is expected that the endoscopic method may very well be conducive to eliminating pathological

processes like granulation tissue formation, adhesions and cholesteatoma within the middle ear (Choi et al., 2017).

9. Conclusion

Endoscopic ear surgery is a safe and feasible procedure. The latest data confirm that results attained with endoscopic methods are generally similar to those achieved with traditional otomicroscopic techniques. However, there is potentially a long learning curve, and further adaptations in instruments and techniques are needed.

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Author contribution and responsibilities

Ismet Emrah Emre: Planning, literature survey, language editing.

Cemal Cingi: Planning, literature survey.

Nuray Bayar Muluk: Planning, literature survey, writing the manuscript, submission.

João Flávio Nogueira: Planning, literature survey.

Ethical approval

There is no need to take ethical approval, because this paper is review.

Informed consent

There is no need to take informed consent, because this paper is review.

Declaration of competing interest

Author **Ismet Emrah Emre** declares that he has no conflict of interest.

Author **Cemal Cingi** declares that he has no conflict of interest.

Author **Nuray Bayar Muluk** declares that she has no conflict of interest.

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