Future of Endoscopic Ear Surgery

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KEYWORDS

- Endoscopic ear surgery • Transcanal endoscopic ear surgery • Ear surgery
- Minimally invasive ear surgery • Otoendoscopy

INTRODUCTION

Endoscopic ear surgery (EES) has gained popularity in recent years, becoming standard practice in otology centers around the world as an adjunct to conventional microscopic surgery and as a sole tool for limited disease.

Reports on EES started to appear in the literature in 1990 thanks to the work of Thomassin and colleagues,[1,2] Tarabich and colleagues,[3] and Poe and colleagues.[4] Thomassin used the endoscope as an adjuvant tool to work on the epitympanic recess and posterior sinus. Later, McKennan[5] described the technique of endoscopic "second look," establishing the effectiveness of the endoscope in detecting residual or recurrent disease. Magnan and colleagues[6] used the endoscope in the cerebellopontine angle and they were the first to use the expression "looking around the corner," now widely cited by endoscopic ear surgeons as one of the advantages of the endoscope over the microscope. In 1997, Tarabichi[3] was the first to describe a fully endoscopic technique for removal of middle ear cholesteatoma.

In 2004 we started seeing a gradual introduction of transcanal endoscopic techniques to treat middle ear diseases. Endoscopes were primarily used for the visualization of hidden areas, such as the posterior epitympanum during classic microscopic tympanoplasties.[7] Gradually, it was also used during operations, such as myringoplasty, tympanoplasty, ossiculoplasty, and cholesteatoma resection, to replace the microscope as the main tool in middle ear surgery.[8,9]

Now we like the term "transcanal endoscopic ear surgery" (TEES) to describe fully endoscopic minimally invasive procedures. Such surgeries offers several benefits when compared with conventional binocular retroauricular microscopic

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approaches, including a wide visualization of the surgical field,[10] enhanced optics with higher amplification, ocular access to hidden areas of the middle ear, avoidance of unnecessary incisions and soft tissue dissections, and a decreased operative time and less postoperative morbidity. However, the main disadvantage of EES is that the surgery has to be performed with one single hand, which is certainly restrictive for an ear surgeon who has been trained operating with two hands under otologic microscopic views for years and this certainly requires a learning period and perseverance.

Endoscopic instrumentation, techniques, and knowledge have improved during the last few years, and we believe that, in the future, endoscopic surgical techniques will gain even more importance in otologic surgery.

ENDOSCOPIC EAR SURGERY EQUIPMENT

Fundamental tools needed for endoscopic middle ear surgery incorporates[11] a light source, rigid endoscopes (0° and 30°, and in some cases 45°),[12] and an HD3-CCD camera and video screen.[13] Choices of different lights at different prices are easily accessible, such as halogen, light-emanating diode (LED), and xenon lights. There is no conclusive information advocating any of the sources of light and presently the choice depends on the surgeon's inclinations and accessibility.[14] It is important to mention that any of these light sources should never be at fully 100% capability. The middle ear cavity is small and to have a great view the surgeon needs no more than 40% of light power. This also reduces the probability of thermal injuries in middle ear structures.

Endoscopic camera systems are accessible through an assortment of sellers. The fundamental necessity for a camera system is a 3-CCD camera. The 3-CCD cameras allow for high-definition and clear video picture quality by depending on individual CCDs for red, green, and blue light. Single CCD cameras tend to "red out" and become saturated when used in a small area that contains bleeding. Currently, otologic and sinus surgery light sources are indistinguishable and are commonly accessible in otolaryngology operating theaters. Although not essential, nowadays there are 3-CCD high-definition (1080p) and 4K cameras. These produce a high-quality image (Figs. 1–3).

The diameters for the rigid endoscopes used in ear surgery are usually 2.7, 3, and 4 mm. If the outer canal is wide enough, EES or TEES is completed using a 4-mm

Fig. 1. 3-CCD HD camera.

Fig. 2. Examples of the most used endoscopes in current EES.

diameter scope. TEES endoscopic shaft lengths are ordinarily 11, 14, and 18 cm in length. There is no evidence to conclude that there is an ideal endoscopic measurement and the choice depends on the surgeon's inclination, accessibility, and patient anatomy.[14]

HOLDER

Endoscope/camera holders have been designed to facilitate and allow two-handed EES. An ideal endoscope holder should be easy to set up, easily controlled, provide

Fig. 3. Example of a 4K camera.

a variety of angled views, and allow the surgeon to operate with two hands, thus facilitating tympanomeatal flap elevation, delicate dissections of diseases from the ossicular chain, and allowing constant suctioning when needed for a blood-free operative site.[15]

Although endoscope holders have been designed to facilitate two-handed procedures, there are still some certain technical difficulties: (1) because of the narrowness of the external ear canal, in addition to the endoscope, there must be sufficient room for two surgical instruments; (2) during hemorrhage, the manipulation of the endoscope in and out of the operative field may be time consuming; (3) if the patient moves abruptly during the operation, an endoscope placed in the fixed position could cause injury to the outer and/or middle ear canal; and (4) because of the heat generated and thermal trauma risk of the stationary endoscope in the middle ear certain questions are raised regarding its long-term safety (**Fig. 4**).[16]

THREE-DIMENSIONAL ENDOSCOPIC EAR SURGERY

EES started to gain popularity with the release of high-definition camera systems with image quality a thousand times more detailed than with a standard camera. Considering the microscopic size of middle ear structures and the presence of important neurovascular structures in a small space the use of low-definition systems could negatively affect the performance and outcomes of EES. Since the studies by Presutti[7] and Marchioni and colleagues[9,17,18] who used the new high-definition system to study the endoscopic anatomy of the attic and retrotympanum, EES started to become a widely accepted technique for the management of middle ear disease.

Despite these technical improvements, the lack of depth perception provided by the two-dimensional (2D) vision and the need to operate with only one hand are the most cited limitation in EES. Even though an experienced endoscopic surgeon could overcome the loss of the sense of depth using other visual cues and anatomic knowledge,

Fig. 4. Example of a holder model for two-handed EES.

a system that provides a three-dimensional (3D) image could be beneficial for beginners and more experienced surgeons.

The use of a 3D high-definition system has already been reported in some experimental studies in the laparoscopic and gynecologic fields.[19,20] However, the diameter (more than 4 mm) of the endoscope limited their use in ear surgery because the diameter of the external auditory canal is an important limiting factor.

With the release of a 4-mm high-definition 3D endoscope, this technology is now suitable for use in ear surgery (**Figs. 5** and **6**).

In their study, Bernardeschi and colleagues[21] used 4-mm 0° and 30° angled 3D endoscopes. These endoscopes incorporated the HD camera with a resolution of 1920 × 1080 pixels with two integrated video chips. The frame rate was 50/60 Hz, working length was 175 mm, and weight was 295 g. The light source was a POWER LED 300 cold light source. It was possible to change from 3D to 2D high-resolution images with the click of a button, which is an attractive feature for those surgeons who are not comfortable with 3D vision.[21]

However this new system showed some limitations: (1) no diameters less than 4 mm are available, and this could be an issue when dealing with a narrow external auditory canal or in pediatric cases; (2) only two angled endoscopes (0° and 30°) are currently available; and (3) the 3D endoscope has digital zoom capability compared with the 2D system, which has optical zoom, and this could induce some loss of resolution when zooming with the 3D system.

THREE-DIMENSIONAL EXOSCOPES

The microscope has long been considered the best tool for microsurgical visualization.[22] However, it is limited by positioning at extreme angles, and otolaryngologists are often forced into awkward positions with little freedom of motion for extended periods of time, which can explain the high prevalence of neck and back pain with long-term detrimental effects.[23]

A new surgical visualization system called the 3D exoscope system is a viable alternative to surgical microscopes for otologic and neurotologic surgery.[24,25] The 3D exoscope is meant to be exterior to the body surface like a microscope and to have dual image sensors for 3D visualization. The images obtained from the 3D exoscope are visualized on a monitor, and a surgeon observes 3D stereoscopic images wearing 3D glasses (**Figs. 7** and **8**).

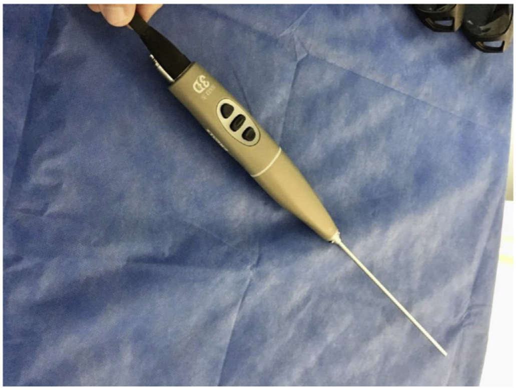

Fig. 5. Example of a 3D endoscope.

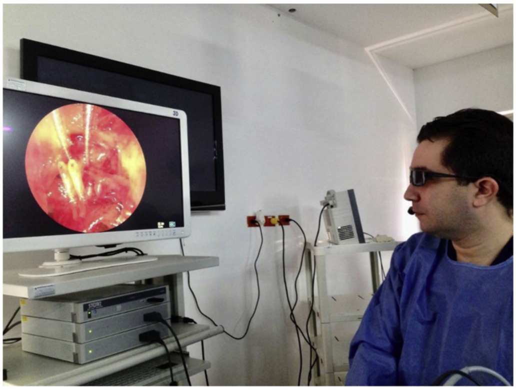

Fig. 6. Example of 3D endoscope.

An exoscope allows for excellent visualization at extreme angles because the surgeons are able to independently position themselves and they no longer depend on the eyepiece but operate using the monitors. Better ergonomics also extends to the assistant and the entire surgical team, which also allows better instrument exchange and communication between team members (including residents, anesthesiologists, and nurses), allowing an active participation in procedures and education and thus increasing patient's safety.[26]

The main drawbacks of exoscopes are: (1) limited depth perception, which is overcome using newer monitors, such as 3D or 3D 4K monitors; (2) low lighting, especially when visualizing through narrow surgical fields; and (3) lower image quality when compared with the microscope, which can be improved with continued device development.

4K TECHNOLOGY AND NARROW-BAND IMAGING IN OTOLOGY

Some of the greatest advantages of using an endoscope includes the higher magnification and wide angled views, allowing the surgeon to access and remove disease from delicate areas in a safer manner.

Fig. 7. Example of 3D exoscope.

Fig. 8. Exoscope in action during live surgery.

Advances in optical technology have led to the development of high-definition visualization, such as 4K technology, which increases the magnification even further. The increased resolution improves image sharpness and provides a much more detailed view of all anatomic and pathologic structures (when compared with standard systems currently in use), which is particularly important when working around delicate and critical structures, improving the safety and efficacy of the surgical procedure.

Narrow band imaging (NBI), which has been implemented in oncologic surgery in all fields,[27] uses a filter that allows different wavelengths of narrow band light (415 and 540 nm wavelengths), in a sequential red-green-blue illumination, to pick up hypervascularity,[27] which could indicate areas of dysplasia. Recently there has been interest in using this technology in noncancer cases.[28]

In otologic surgery there is a difference in how structures and disease in the middle ear appear under the narrow band filter compared with ordinary white light. Because of the avascular nature of tympanosclerosis and cholesteatoma, they appear whiter than usual on NBI, whereas hypervascular structures, such as granulation tissue, are highlighted by the filter.[28]

The association of 4K magnification with NBI technology could improve the identification and dissection of middle ear pathology, such as cholesteatoma during middle ear surgery. The 4K magnification would allow a better visualization of the sinus tympani, facial recess, and stapes foot plate while dissecting the disease. However, NBI not only allows assessment of the extent of disease, but also ensures small residual disease is not left behind at the time of operation.

Further studies using the same NBI technology combined with 4K resolution and rigid scope are necessary to validate this extremely interesting potential.

NEURONAVIGATION

Advances in microsurgical techniques have led to an expansion of minimally invasive otologic/neurotologic procedures. Simultaneously, the complexity and proximity of critical anatomic structures, particularly on the skull base, sometimes requires the intraoperative use of navigation techniques.

Surgical approaches through the temporal bone require some form of temporal bone drilling to create an adequate access toward the surgical target. Skull base surgeons use anatomic landmarks as means of orientation during temporal bone drilling, to optimize access creation while minimizing bone removal and evading critical structures, such as the facial nerve and sigmoid sinus. However, these landmarks are subject to high interindividual variability[29] and is eroded by tumor, inflammation, or previous surgery.

To reduce the risks during the procedure, surgical navigation systems have been increasingly used in otologic surgery.[30,31] These image-guidance systems are developed to help surgeons to identify critical anatomic landmarks intraoperatively; however, it cannot substitute a thorough knowledge of the surgical anatomy. Initially developed for neurosurgical procedures, these systems use computerized tracking devices to monitor the position of the endoscopes or instruments relative to the patient's anatomic landmarks. The system displays the location of the tip of a tracked drill, and other instruments, in real-time, on a navigation map of the patient's preoperative anatomy image (computed tomography or MRI).[32,33]

However, the cost and lack of portability make the current image-guidance systems unavailable in many institutions and hard to transport to different hospitals.[32,34]

In their study, Nogueira and colleagues[35] used a third-generation camera and a predefined black and white pattern for optical tracking. The camera was attached in a holder at a distance from 60 cm to 100 cm from the patient's marker, and it was linked to an up-to-date laptop through a standard firewire port. This port provides a power supply and a fast hub for information exchange, because the orientation functions needed to be performed repeatedly at real-time rates.[35]

The laptop-based image-guidance system achieved an accuracy rate of 1.16 mm, showing its effectiveness and possible use in real patients (**Figs. 9** and **10**).

NEW SURGICAL APPROACHES

In recent years, technical improvements and growing expertise in the handling of the endoscope allowed introducing an exclusive endoscopic approach to the middle ear, lateral skull base, middle cranial fossa, and posterior fossa/cerebellopontine angle pathologies.

Although the endoscope has been commonly used in transcanal middle ear surgeries, which have proved to be highly successful, EES has also proven to be a feasible option in the approach of cochlear schwannoma involving internal auditory canal.

Fig. 9. Neuronavigation in EES.

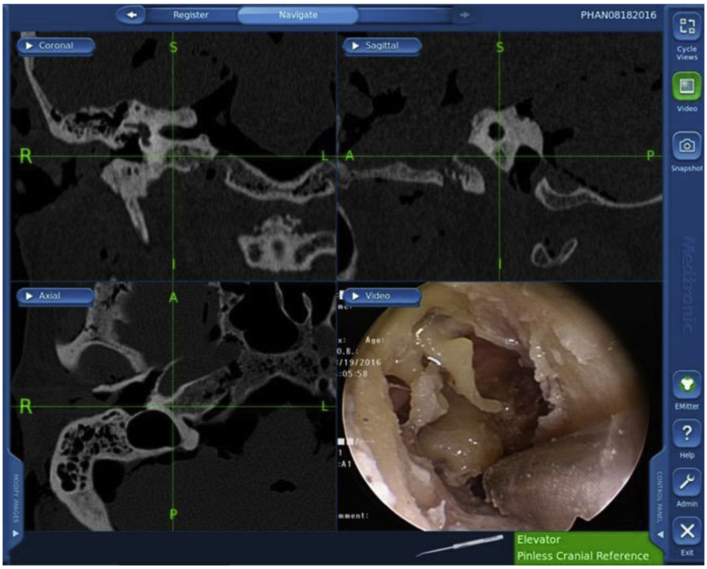

Fig. 10. Neuronavigation in EES.

There are no proven indications against the advisability of EES. Any otologic surgery that is conducted with a microscope can also use an endoscope. Therefore, these are some of the current indications for EES.

1. External ear: Cholesteatoma, exostosis repair, canalplasty, debridement, and biopsy.
2. Middle ear: Myringotomy, myringoplasty, medial graft tympanoplasty, lateral graft tympanoplasty, the retraction of the tympanic membrane, acquired cholesteatoma, congenital cholesteatoma, neoplasms of middle ear (eg, glomus tympanicum), ossiculoplasty, and stapes surgery.
3. Inner ear/skullbase: Intracochlear schwannoma, small symptomatic neoplasms of internal auditory canal fundus of facial nerve, petrous apex cyst, and the repair of perilymph fistulas (congenital or traumatic).
4. Middle cranial fossa: The repair of superior canal dehiscence.
5. Posterior fossa/cerebellopontine angle: Establishing enduring schwannoma in internal auditory canal fundus, and localization and sealing of externalized air cells during the decompression of internal auditory canal to reduce the risk of cerebrospinal fluid leaks.

DISCLOSURE

The Authors have nothing to disclose.

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