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Endoscopic stapes surgery: our clinical experience and learning curve

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Abstract. *Objective:* The purpose of this study was to assess the audiological results and surgical outcomes of patients who underwent endoscopic stapes surgery (ESS).

Methods: This study included 40 consecutive patients who underwent stapes surgery with a fully endoscopic approach at Dr. Ersin Arslan Research and Training Hospital between January, 2015 and April, 2018. We retrospectively evaluated the patients' audiological results, surgery duration, surgical findings, and complications. To assess the learning curve, participants were divided into two groups based on their date of surgery: first twenty patients (FTPs) and last twenty patients (LTPs).

Results: The mean operative duration was 43.4 ± 11.3 minutes among all patients, 51.5 ± 9.2 minutes among FTPs, and 35.3 ± 3.9 minutes among LTPs ($p < 0.05$). The average air-bone gap (ABG) values were 33.7 ± 8.5 dB preoperatively and 8.7 ± 6.9 dB postoperatively ($p < 0.05$). The incudostapedial joint (ISJ) of 24 patients (60%) and the stapes footplate of 13 patients (32%) were directly visible without requiring bone curettage. None of the patients experienced major complications, such as facial paralysis or sensorineural hearing loss.

Conclusions: The present results show the surgical and audiological outcomes of exclusively endoscopic transcanal stapes surgery, indicating the advantages, limitations, and learning curve for this procedure. ESS appears to be a safe and effective alternative technique that produces reasonable surgical and functional outcomes.

Introduction

Otosclerosis is a disease involving bone resorption and sclerotic bone formation phases, limited to the otic capsule in the temporal bone, which was first described by Valsalva in 1704. Various techniques and approaches for stapes surgery have been described over time, with otosclerosis surgery development showing three distinct eras: mobilization, fenestration, and stapedectomy. Shea described a method that involves stapes removal, covering the oval window with a vein autograft, and then providing sound transmission with an artificial prosthesis.[1] This technique gained wide acceptance and has been improved since it was first reported. Ugo Fisch first implemented a small fenestration stapedotomy technique, which is also now widely accepted.[2]

The use of endoscopic techniques in otology began approximately 20 years ago, gradually spread among surgeons, and has been widely adopted.[3,4] Fully endoscopic or endoscope-assisted microscopic approaches are applicable in almost all types of ear surgery, including stapes surgery, tympanoplasty, and cochlear implantation.[5,6] Endoscope-assisted laser stapedotomy was first described by Poe in 2000.[7] Surgical microscopes provide a high-quality image, stereoscopic vision, and enable double-handed surgery; however, they may be insufficient in cases involving a hidden footplate and/or a narrow and curved outer ear canal. Although a transcanal approach is commonly preferred in stapes surgery, an endaural or post-auricular approach may be a better choice in certain cases, such as in the presence of a narrow or protruding ear canal. Transcanal stapes surgery can be technically challenging due to anatomical variations of the external auditory canal, the stapes position, a hidden oval window, and the facial nerve bulging over the oval window. In cases where the

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

microscopic transcanal approach is inconvenient, an endoscope can facilitate stapes surgery and usually enables transcanal surgery.

Frequently encountered problems, particularly with the postauricular and endaural approaches, include postoperative pain, sensation of numbness at the auricula, and dysgeusia.[8] With the microscopic transcanal approach, scutum curettage is performed to obtain an adequate view of the incudostapedial joint (ISJ) and footplate, which may result in incus dislocation and chorda tympani injury.[9] In this context, endoscope use in stapes surgery has many advantages, including excellent exposure of stapedial structures and the ISJ, less need for bony resection (canaloplasty and scutum removal), chorda tympani preservation, a panoramic view of the middle ear structures, minimal invasiveness, and almost no postoperative pain.[2,3,10] Despite these advantages, endoscopic techniques are limited by the lack of 3-D vision, requirement of experience, prolonged learning curve compared to the microscopic technique, and necessity of performing single-handed surgery.[7,10]

In the present study, we aimed to evaluate the advantages, limitations, and learning curve of the endoscopic transcanal technique for stapes surgery, along with the surgical and functional results.

Materials and methods

The present study included 40 consecutive patients (23 females and 17 males) who underwent fully endoscopic stapes surgery (ESS) at Dr. Ersin Arslan Training and Research Hospital (tertiary referral centre) between January 2015 and April 2018. The inclusion criteria were having a conductive type of hearing loss without ear discharge, type A tympanogram results, and a poor stapedial muscle reflex. Temporal bone computed tomography was obtained for all patients to determine whether they had any other middle ear pathology blocking sound transmission. The duration of postoperative follow-up ranged from 6 to 12 months (mean, 8.2 months). Informed consent was obtained from all participants, and this study was approved in advance by the local ethical committee.

All cases involved primary stapes surgery, performed by the same surgeon. ESS was performed using rigid endoscopes (Karl Storz Endoscopes, Tuttlingen, Germany), with angles of 0 and 30 degrees, diameter of 2.7 mm, and length of 11 cm. Images were acquired using endoscopes connected to a camera head (Karl Storz, Germany), and transferred to a high-definition monitor located in front of the surgeon. Illumination was provided by an LED light source (Karl Storz, Germany). To reduce bleeding, the external auditory canal was infiltrated with lidocaine and adrenaline solution (Jetokain®, Adeka, Samsun, Turkey). All patients received a polytetrafluoroethylene (PTFE) prosthesis loop (Xomed, Jacksonville, Fla, USA), with a shaft thickness of 0.4 mm, and a length of 4, 4.5, 4.75, or 5 mm based on the distance between the long process of the incus and footplate.

In all patients, stapes surgery involved the following steps performed in the same order (Figure 1). (1) Elevation of the tympanomeatal flap. (2) Accessing the middle-ear space by separating the fibrous annulus from the tympanic sulcus. (3) Removal of the scutum (while preserving the chorda tympani nerve) to expose the ISJ and footplate, when necessary. (4) Confirming stapes fixation and ensuring the mobility of the incus and malleus with gentle palpation of ossicles. (5) Separating the ISJ, cutting the stapedial tendon, and removing the stapes superstructure. (6) Evaluation of the distance between the incus long arm and footplate utilizing the measuring rod. (7) Small fenestration of the footplate using 0.4-mm, 0.5-mm, and 0.6-mm perforators, respectively. (8) Insertion of the PTFE prosthesis, and stabilization by placing the gelfoam around the footplate. And finally, (9) restoring the tympanomeatal flap to its original position and packing the external ear canal with gelfoam.

Preoperative and postoperative pure-tone audiometry (PTA), surgical findings, complications, and surgery duration were recorded to the patients' personal files, and retrospectively analysed. Air conduction (AC) and bone conduction (BC) thresholds at frequencies of 0.5, 1, 2, and 4 kHz were measured preoperatively and six months postoperatively. The preoperative and postoperative air-bone gap (ABG) values were calculated, using the averages from the frequencies 0.5, 1, 2, and 4 kHz. To assess the ESS learning curve, patients were divided into two groups based on the date of surgery: first twenty patients (FTPs; n = 20) and last twenty patients (LTPs; n = 20). The parameters used to evaluate the learning curve were operative times and auditory improvements.

Statistical analysis was performed using the statistical package for social science (SPSS)

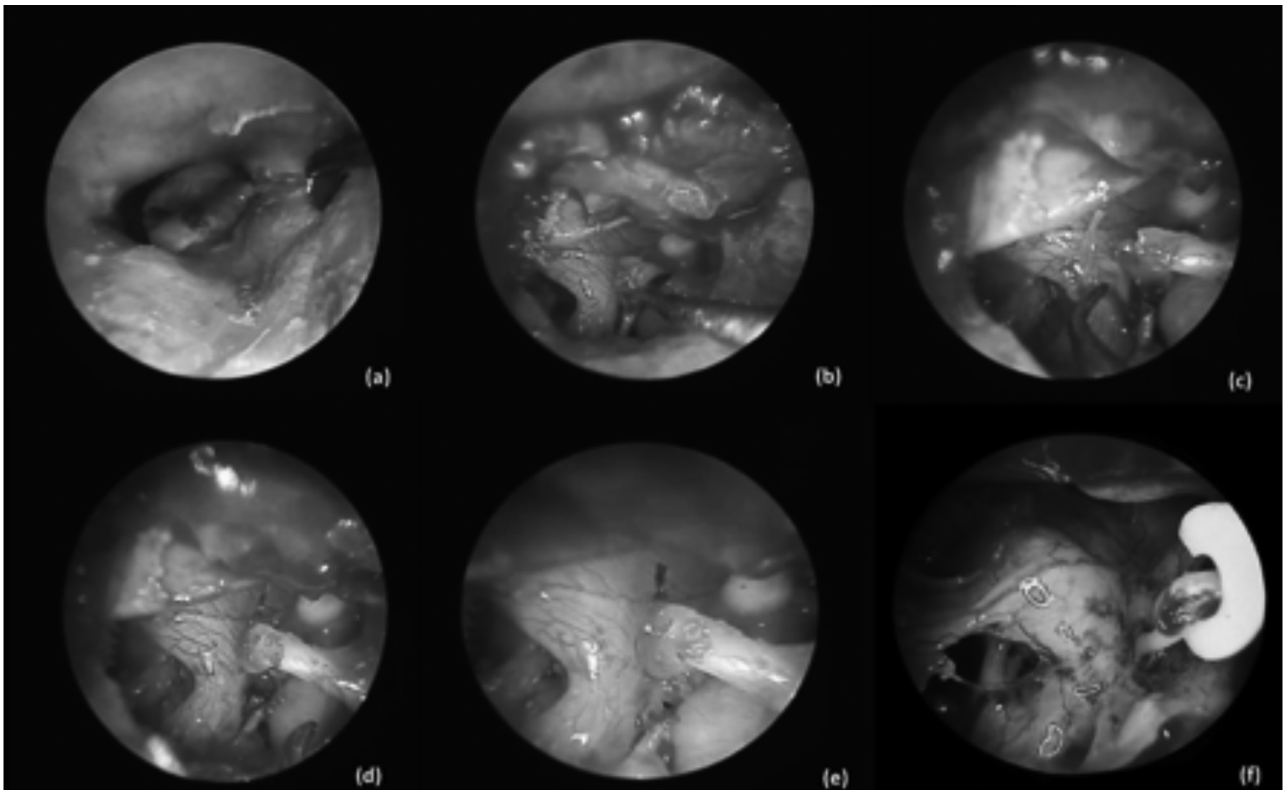

Figure 1

Endoscopic stapes surgery. (a) Elevation of the tympanomeatal flap. (b) Palpation of ossicles. (c) Removal of the stapes superstructure. (d) Measuring distance between incus long process and footplate. (e) Small fenestration of footplate. (f) Insertion of the artificial prosthesis.

software version 22. Continuous variables were reported as mean ± standard deviation. Preoperative and postoperative air-bone gaps and operative times were compared using the paired sample *t*-test and independent *t*-test, respectively. The chi-square test (post-hoc power analysis, 72.41%) was utilized to compare FTPs and LTPs with regards to complication rates, including dysgeusia, pain, and dizziness. A p value < 0.05 was considered to indicate statistical significance.

Results

A total of 40 patients underwent fully endoscopic stapes surgery performed by the same surgeon. Table 1 presents the demographic and clinical features of the study participants. Among the patients, 17 were male and 23 were female, and the average age was 36.9 years (range: 19-62 years). ESS was performed on the right ear in 13 patients, and on the left ear in 27 patients. The mean postoperative follow-up period was 8.2 months (range: 6-12 months).

PTA was performed for all patients preoperatively and at the 6-month follow-up. The results revealed that postoperative ABG decreased to ≤10 dB in 27 patients (67.5%), decreased to 10-20 dB in 12 patients (30%), and remained >20 dB in 1 patient (2.5%) (Table 2). While the mean preoperative ABG was 33.7 ± 8.5 dB (range: 22-55 dB), the mean postoperative ABG decreased to 8.7 ± 6.9 dB (range: 0-22 dB), showing a statistically significant postoperative ABG improvement (p < 0.05). Moreover, separate analyses of the FTPs and LTPs showed that these groups significantly differed in terms of auditory improvement (Table 1). The average postoperative ABG values were 11.8 dB among FTPs, and 4.9 dB among LTPs (p < 0.05). The overall mean auditory gain (preoperative mean ABG value minus postoperative mean ABG value) was 25 ± 5.2 dB, whereas the postoperative auditory gains were 21.9 dB among FTPs and 28.6 dB among LTPs (p < 0.05).

The mean operative time was 43.4 ± 11.3 min (range: 30-75) among all patients, 51.5 ± 9.2 min (range: 41-75 min) among FTPs, and 35.3 ± 3.9 min (range: 30-42 min) among LTPs (Table 1). The mean operative time significantly differed between the FTPs and LTPs (p < 0.05). Moreover, ESS

Table 1

Clinical characteristics and surgical outcomes of endoscopic stapes surgery

		FTPs (n = 20)	LTPs (n = 20)	p	Total (n = 40)
Age (Mean–Range)		38.4 (21-62)	35.5 (19-55)	NS	36.9 (19-62)
Gender	Male	6	11		17
	Female	14	9		23
Direction	Right	8	5		13
	Left	12	15		27
Preoperative ABG, average, dB		33.7	33.6	NS	33.7 ± 8.5
Postoperative ABG, average, dB		11.8	4.9	S	8.7 ± 6.9
Auditory gain, average, dB		21.9	28.6	S	25 ± 5.2
Dysgeusia, n (%)		4 (20)	1 (5)	NS	5 (12.5)
Almost no pain, n (%)		5 (25)	12 (60)	S	17 (42.5)
Mild pain not requiring analgesics, n (%)		14 (70)	8 (40)	S	22 (55)
Moderate pain requiring analgesics, n (%)		1 (5)	0	NA	1 (2.5)
Dizziness, n (%)		4 (20)	2 (10)	NS	6 (15)
Iatrogenic perforation, n (%)		1 (5)	0	NA	1 (2.5)
Floating footplate, n (%)		1 (5)	0	NA	1 (2.5)
Mean operative time, min ± SD		51.5 ± 9.2	35.3 ± 3.9	S	43.4 ± 11.3

$p < 0.05$ was considered to indicate statistical significance. S: Significant, NS: Not significant, NA: Not available, SD: standard deviation, FTPs: First twenty patients, LTPs: Last twenty patients.

Table 2

Audiometric results of endoscopic stapes surgery

Postoperative Air-Bone Gap (dB)	FTPs (n = 20)	LTPs (n = 20)	Overall (n = 40)
≤10 dB, n (%)	9 (45)	18 (90)	27 (67.5)
11-20 dB, n (%)	10 (50)	2 (10)	12 (30)
>21 dB, n (%)	1 (5)	0	1 (2.5)

FTPs: First twenty patients, LTPs: Last twenty patients.

duration showed a decreasing trend with increasing experience. Figures 2 and 3 illustrate how the number of cases was related to the operative duration and postoperative ABG values, respectively.

The endoscopic approach without bone curettage enabled direct visualization of the ISJ in 24 patients (60%) and of the stapes footplate in 13 patients (32%). In these latter 13 patients, ESS was performed without bone curettage and manipulation of the chorda tympani. In 19 patients (47.5%), ESS was performed without requiring manipulation of the chorda tympani. Only one patient (2.5%) had a minimal iatrogenic perforation in the tympanic membrane, which was left alone for secondary healing without grafting and spontaneously improved without any issues. One patient (2.5%) developed a floating footplate complication. In this case, the footplate was removed, and the prosthesis was placed following endoscopic positioning of the vein graft on the oval window.

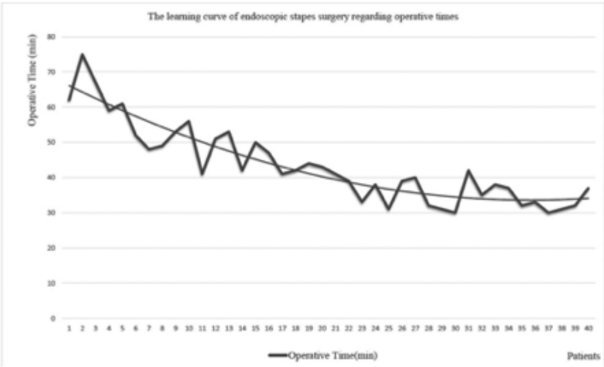

Figure 2

Learning curve of endoscopic stapes surgery, showing changes in average operative duration over time. After the performance of 25 endoscopic stapes surgeries, sustainable and significantly shorter average operative times were achieved.

Although the integrity of the chorda tympani nerve was preserved in all patients, some complications were recorded. Five patients (12.5%)

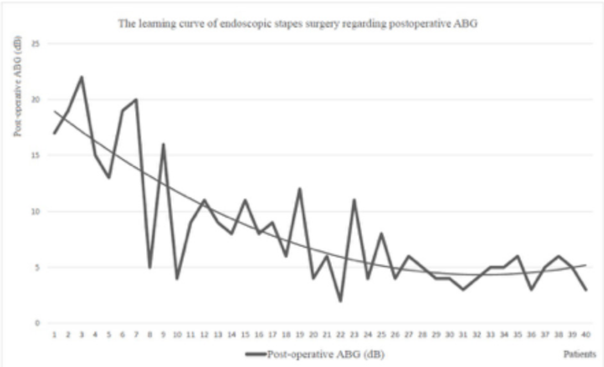

Figure 3

Learning curve of endoscopic stapes surgery, showing changes in postoperative ABG over time. ABG: Air-bone gap

patients experienced dysgeusia, which spontaneously resolved within 3 months in all cases. Six patients (15%) reported dizziness, which resolved within 2 days with bedrest and sedatives. The one patient who developed a floating footplate experienced pain in the area where the vein graft was taken, which required analgesic treatment. The remaining 39 patients experienced mild or almost no pain, which did not require analgesic treatment. Table 1 presents information regarding complications, including dysgeusia, dizziness, and pain. The complication rates were higher among FTPs than LTPs. However, this difference was not significant with regards to postoperative dysgeusia ($p = 0.151$) and dizziness ($p = 0.658$) (Table 1). No patient experienced temporary or permanent facial paralysis or sensorineural hearing loss.

Discussion

Recent decades have seen great advances in endovision systems, including the production of endoscopes with various diameters, angles, and lengths; and with high-resolution cameras and monitors. These developments have facilitated wide use of endoscopes in all ear operations, including stapes surgery, chronic otitis surgery, and cochlear implantation.[3,5,6,7] This increased use has been accompanied by a gradual increase of articles related to endoscopic ear surgery in the literature. Indisputable advantages of ESS include excellent exposure, panoramic view, detailed viewing of ISJ and stapes structures, and the ability to view the stapes footplate without bone curettage in some cases.[4,11,12] However, ESS also has some limitations, such as the need to operate with a single hand, lack of stereoscopic vision, requirement of experience, and longer learning curve than a microscopic approach.[3,10,11]

Naik and Namade reported that for endoscopic ear surgery, conventional nasal endoscopes with a 4-mm width and 18-cm length are easier to use and provide a larger panoramic view.[13] For ESS, we preferred 0-degree and 30-degree endoscopes with a 2.7-mm width and 11-cm length. We encountered no problems with exposure during surgery. Additionally, in our experience, these instruments were easier to manipulate in the external auditory canal.

With regards to postoperative hearing results, Naik and Nemade assessed audiogram results at six weeks after endoscopic stapes surgery, and found that the ABG was closed in 55% of the patients and ABG had regressed to <20 dB in 30% of the patients.[13] In another study, Hunter et al. reported that ABG decreased to <20 dB in 90% of patients who underwent ESS.[14] Kojima et al. found that postoperative hearing results did not significantly differ between those who underwent stapes surgery with an endoscopic approach (ABG < 20 Db, 93.3%) versus a microscopic approach (ABG < 20 Db, 97.5%).[10] Iannella and Magliulo reported that ABG decreased to <20 dB in 95% of patients after ESS, and found that the hearing results did not significantly differ between the endoscopic and microscopic approaches.[15] In a recent study, Guneri et al. also reported that hearing outcomes did not significantly differ between endoscopic and microscopic stapes surgery.[16] Our present results were consistent with the literature in terms of the hearing results, with postoperative ABG decrease to below 20 dB in 97.5% of the patients (Table 2). In this context, the endoscopic approach to stapes surgery appears to be a reliable alternative technique with regards to hearing results. Moreover, we observed a progressive decrease in postoperative ABG values with increasing experience with ESS (Figure 3).

Manu et al. introduced a quantitative method for estimating the experience required to achieve proficiency in surgical procedures. According to this method, the authors found that 15 microscopic stapes surgeries were adequate for obtaining surgical sufficiency in otosclerosis surgery.[17] In contrast, Hughes argued that a minimum of 50 stapes surgeries using a microscopic technique were required to reach the end of his learning curve, i.e., to achieve sustainable audiometry results, with a maximum postoperative ABG of 10 dB in 90% of patients.[18] Important parameters that influence postoperative ABG values include the shaft diameter of the utilized prosthesis, and the frequencies measured upon audiometry, which should be considered when determining the learning curve with respect to postoperative ABG. In all of our presently analysed cases, we used a PTFE prosthetic loop (Xomed, Jacksonville, Fla, USA) with a 0.4-mm shaft thickness, and the hearing thresholds were measured at the same frequencies. We found that the mean postoperative ABG values were consistently regressed to <10 dB after the performance of 30 endoscopic stapes surgeries. Notably, even after reaching a high level of expertise in ESS, reduced surgical and functional results may still occur in challenging cases.

A review of the literature revealed variable results with regards to operative times. Previously reported mean operative times for ESS have included 71 min. (Hunter et al.), 31 min. (Naik and Nemade), 45 min. (Iannella and Magliulo), and 46.4 min. (Guneri et al.).[13–16] In a study comparing endoscopic and microscopic stapes surgery, the mean operative time for the endoscopic group was 52.4 for the first 10 patients, and 37.5 minutes for the last 10 patients ($p = 0.003$).[15] With regards to microscopic stapes surgery, the authors found no differences between the initial and the long-term average operative times ($p > 0.05$).[15] Thus, the authors concluded that ESS has a longer learning curve compared to the microscopic approach. The primary surgeon (and first author) of our present study was already trained in microscopic stapes surgery, and now has three years of experience with endoscopic stapes surgery. The present study includes the first and subsequent cases operated by this surgeon after he began performing endoscopic stapes surgery. The mean operative time was 43 ± 11.3 minutes among all cases, 51.5 ± 9.2 min among the first twenty patients, and 35.3 ± 3.9 min among the last twenty patients ($p < 0.05$). Increasing experience with ESS was accompanied by a significant decrease in the operative time (Figure 2).

A surgeon's learning curve with regards to ESS may be influenced by multivariable factors, including the diversity of the surgical instruments, pistons, and utilized techniques.[19] Surgeons who are experienced in the field of endoscopic sinonasal surgery may have shorter initial operative times in endoscopic ear surgery due to their familiarity with endoscope use and experience in single-handed work.[21,22] Moreover, otologists experienced with ear surgery may have a shorter ESS learning curve compared to inexperienced otologists.[22,23] In our study, after 25 cases, we reached a sustainable and significantly shorter average operative time. We have performed 40 endoscopic stapes surgeries over three years, and our current annual number of stapes surgeries is approximately 15, and is gradually increasing. With intensive use of the endoscope in stapes surgery, the operative time may decrease in a short period of time. Additionally, performing stapes surgery at frequent intervals is essential to preserve the surgeon's dexterity and to quickly reach the end of the learning curve.

Kojima et al. reported that ESS could be performed even in patients with a narrow and curved auditory canal, and was associated with decreased postoperative pain and chorda tympani damage due to the reduced need for bone curettage.[10] In our study, only one patient experienced postoperative pain that required analgesic treatment. In the literature, taste disturbances and ossicular dislocation are predominantly reported after surgery using a microscopic approach, since further curettage of the chordal crest is often needed to provide an adequate view of the stapes and oval window.[9,10,16] Iannella and Magliulo found that dysgeusia may occur in both endoscopic and microscopic operations without damage to the chorda nerve.[15] In our present study, chorda nerve manipulation was not required in 19 patients (47.5%), and none of these patients experienced postoperative dysgeusia. Despite preservation of chorda nerve integrity, 5 patients (12.5%) patients had temporary dysgeusia that recovered within 3 months. Balasubramanian and Venkatesan reported posterior-superior retraction pocket formation during the late postoperative period due to excessive curettage of the scutum.[20] In our present study, no retraction pocket formation was observed in any of the cases during the follow-up period. Notably, the complication rate was higher in the FTPs than in the LTPs (Table 1), revealing that complication rates had a tendency to decrease with increasing experience. However, the sample sizes in our study were relatively small; therefore no clear conclusions could be drawn regarding postoperative dizziness and dysgeusia.

Based on an animal study, authors claimed that ESS might lead to sensorineural hearing loss due to the increased heat in the subject's middle ear and inner ear.[24] However, technological advancements enable the use of LED light sources with low heat dissipation in endoscopes rather than radiant halogen and xenon light sources, thus minimizing the heat increase. None of the patients in our present study exhibited sensorineural hearing loss. Moreover, none of our cases had any complications, such as prosthetic dislocation and reparative granuloma, during the follow-up period.

The endoscopic approach does not require any of the time-consuming moves needed for the microscopic approach, such as continuous zooming in and out, changing the position of the microscope, or changing the position of the patient for appropriate exposure. The forward and backward movement of the endoscope is sufficient to provide appropriate exposure and magnification. Moreover, the endoscopic approach does not entail the loss of resolution in the magnification achieved by zooming in the microscope. The approximation of the endoscope to the target area by simply pushing it forward allows magnification without resolution loss.

Finally, in our opinion, the endoscopic approach can be better for educational and training purposes, because it offers a panoramic and detailed view of complex middle ear structures. In a study including otorhinolaryngology assistants, the authors stated that endoscopic stapes surgery facilitates an easier understanding of the surgical technique.[25]

Conclusion

The endoscopic approach facilitates transcanal stapes surgery in patients with a narrow and curved external auditory canal where the microscopic transcanal approach is technically challenging. The learning curve of ESS depends on multivariable factors, such as intensive use of the endoscope, dexterity and experience of the surgeon, recruitment of an adequate annual number of cases, and diversity of the utilized instruments and techniques. Our present results indicated that endoscopic stapes surgery is a safe and effective alternative to the microscopic approach, with comparable surgical and functional results.

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