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An early report of exoscope-assisted otologic surgery

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Abstract

Background: Exoscope has been used in otoneurologic surgery in several reports. However, most ear surgeries are performed using either microscope or endoscopy today. The purpose of this study is to present our subjective and objective experience of using this instrument in our institution.

Methods: Sixteen ears with different severity and condition in 15 consecutive patients were enrolled. A questionnaire with 12 questions was sent to different participants, including surgeons, residents, medical students, and scrub nurses in the operation room. The total score and average score of each item were calculated and analyzed.

Results: Exclusive exoscopic operation was performed on 13 patients with 14 procedures. A combination of endoscopy-exoscope and microscope-exoscope was used in one patient, respectively. There were no complications. Hearing recovery or disease extirpation was achieved in most patients. Twenty participants in the operation room filled out the questionnaire. There was no significant difference between the different groups. High ratings were reported in terms of image quality, stereoscopic effects, magnification rate, and the same field of view as the surgeon. Worse ratings were reported in items related to limited working space, increase in eye strain by video observation, and focusing difficulty.

Conclusion: Exoscopic ear surgery is feasible, safe, and effective in managing various otologic conditions involving external ear, middle ear, mastoid, and lateral skull base. Its high-definition image quality, stereoscopic effects, sufficient magnification, reliability and teaching value made it a potential instrument in general ear surgeries. Further improvements to current drawbacks can be anticipated.

Keywords: Ear surgery; Exoscope; Otologic surgery

1. INTRODUCTION

Operative microscopy has been used widely for ear surgeries since a century ago. The high resolution and high magnification with binocular vision have made them an almost indispensable equipment in the operation room.[1] Although endoscopic surgery had great progress with its wide-angle view and ability to detect anatomic details through a narrow surgical corridor,[2] the transition from microscopy to endoscopy requires a period of learning and practice to get used to one-handed surgery.[3] In recent years, the development of high-resolution extracorporeal video telescopes, namely the exoscope, has greatly evolved due to technological advancement.

Unlike endoscopes, surgeons do not put the exoscope into the ear canal. Instead, the exoscope lies exterior to the body and has a focal length of 20 to 50 cm. Its dual image sensors allow the surgeon to visualize stereoscopic images on a 4K screen using 3D spectacles. Similar to microscopes, surgeons can operate with two hands. The posture is also more ergonomic.[4] In addition, as assistants or students share the same image as the surgeon on the screen, education undoubtedly can be better carried out as compared to microscopic or endoscopic operations.[5]

3D exoscope has been employed in various otoneurologic surgeries, including middle ear and mastoid surgery,[4] stapes surgery,[4] vestibular schwannomas,[6] lateral skull base surgery, and cochlear implant surgery.[7] Nevertheless, there is still room for improvement in its popularization and application.[8] Advantages of exoscope, as stated in previous studies, include superior ergonomics, compact size, teaching potential, and a better tent drape to prevent virus transmission by aerosols during the COVID pandemic.[9] But the experience of exoscope utilization in Asian countries is lacking, and there is a paucity of subjective questionnaires among different attendants in the operation room. In this study, we tried to perform the 3D exoscope in various otology surgery practices including external ear lesions, middle ear and mastoid diseases, temporal bone cancer, and bone conduction device implantation, combining objective operation results and subjective questionnaire reports of surgical team members,

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to evaluate the safety and effectiveness and understand the pros and cons of exoscope from multiple points of view.

2. METHODS

2.1. Patients and technology

Between December 2021 and February 2022, 15 consecutive otological cases with different severity and condition were enrolled (Table 1). After obtaining the approval of the Institutional Review Board of Chang Gung Memorial Hospital, Linkou, Taiwan (202201281B0), all medical records of these patients were reviewed in detail. Operations were performed mainly by an experienced otologist (K.C. Chan).

The exoscope device (VITOM 3D by Karl Storz, Tuttlingen, Germany) was introduced to our operation room (Fig. 1A, B). The camera is put in front of the main operator, and the screen is set on the opposite side of the operative field. The base of the exoscope is located at the head position. The scrub nurse is positioned next to the operator. All the staff, including the main operator, resident assistant, medical students, and scrub nurse, wore 3D glasses to obtain a stereoscopic effect. Operative microscopy and endoscopy were reserved and readily prepared for cases when confronting difficulty or if the surgeon wished to use them.

2.2. Questionnaire

A questionnaire was adapted from the usage of an exoscope in dacryocystorhinostomy by Pirola et al.[10] A total of 12 questions on different aspects of the evaluation of this new technology were translated into Mandarin Chinese and included in this questionnaire. The participants can choose three different ratings for each question (2 points for "good," 1 point for "acceptable," and 0 points for "unacceptable"). The total score is 24 for good responses in all items. Twenty staff members in the operating room completed the questionnaire. The staff includes surgeons, residents, medical students (postgraduate year and clerk), and scrub nurses. The total score of each questionnaire was calculated and analyzed. Descriptive statistic data were presented as mean ± standard deviation. The difference between different groups was calculated with the SPSS 25.0 software (SPSS Inc., Chicago, IL, USA) and the level of statistical significance was set at $p < 0.05$.

2.3. The result of operations

The medical record of patients was reviewed retrospectively. The age, gender, laterality, preoperative diagnosis, operation methods, operation time, operation results, follow-up duration, and complications were collected. The hearing evaluation was performed by pure-tone average (0.5K,1K,2K, 4K Hz) in general patients. For one patient with a bone conduction hearing implant, aided audiometry, and sound field test were measured.

3. RESULTS

3.1. Patients

Fifteen patients with sixteen ears were operated under an exoscope (Table 1). The etiology and presentation differed widely between different patients. Patients were divided into three groups. Group 1 contains three patients with external ear lesions, including two external ear benign lesions (auricular pyogenic granuloma and EAC cyst) and one external auditory canal (EAC) cancer. Group 2 contains three middle ear disease patients with otosclerosis. Group 3 contains ten ears with miscellaneous otomastoid diseases including otomastoiditis (1), cholesteatoma (3), cholesterol granuloma (1), jugular bulb dehiscence (1), glomus tympanicum tumor (1), congenital aural stenosis (1), and bilateral microtia with aural atresia status post left canalplasty complicated with restenosis and cholesteatoma. The mean age is 41.5 ± 17.9 years old (range 7-71). There were nine males and six females. The right ear was operated on seven patients, and the left on nine patients. Of them, one patient had simultaneous bilateral surgeries (case no. 9).

3.2. Surgical approaches and outcomes

Two patients from group 1 with auricular pyogenic granuloma and EAC epidermoid cyst were eradicated by simple excision without recurrence. Another patient of group 1 with EAC cancer T2N0M0 received a lateral temporal bone resection with parotidectomy, neck lymph node dissection, and free flap reconstruction smoothly without evidence of recurrence so far. In group 2, three patients with otosclerosis received stapedotomy with a big easy piston successfully without complication. In group 3, there were three with extensive cholesteatoma conducted by canal wall down tymapnomastoidectomy with ossiculoplasty and meatoplasty, one with bilateral microtia with bilateral aural atresia (left recurrent EAC stenosis after canalplasty with EAC cholesteatoma and profound hearing loss) receiving simultaneous right-side Bonebridge implantation and left-side subtotal petrosectomy with blind sac closure of EAC, one with mastoid cholesterol granuloma receiving cortical mastoidectomy, one with jugular bulb dehiscence, one with congenital aural stenosis with EAC cholesteatoma undergoing meatocanalplasty, one with chronic otitis media and mastoiditis receiving canal wall up tympanomastoidectomy and ossiculoplasty, and one patient with glomus tympanicum receiving canal wall up tympanomastoidectomy and ossiculoplasty.

Exclusive exoscopic operation was performed on 13 patients with 14 procedures, one case (case no. 11 jugular bulb dehiscence) combined with endoscopy for the resurfacing jugular bulb dehiscent wall in the hypotympanum, and another one (case no. 15 glomus tympanicum type B) with operative microscopy for the better tumor bleeding control in the middle ear cavity.

All 16 ear procedures were performed smoothly without immediate complications. The mean follow-up time is 6.3 ± 1.6 months (range 2-8). There were no postoperative complications till the current time follow-up.

As for the audiometry, five patients (case no. 1, 2, 3, 11, 14, 15) received an operation that did not focus on hearing; Cases 11 and 15 presented with pulsatile tinnitus because of jugular bulb dehiscence and glomus tympanicum, the tinnitus handicap index decreased from 66 to 18 and from 36 to 2, respectively. Of the other nine patients, there are three patients with otosclerosis (averaged preoperative air-bone gap [ABG] = 32, averaged postoperative ABG = 12, averaged improved ABG = 20), one patient with congenital aural stenosis (preoperative 73 dB with 62 dB ABG, and postoperative 25 dB with 20 dB ABG), one patient with chronic otitis media with mastoiditis (preoperative 50 dB with ABG 37 dB, postoperative 31 dB with ABG 20 dB), and all had improved hearing. In the other three patients with extensive cholesteatoma, the postoperative mastoidectomy cavities were all dry and well epithelization. One patient had improved hearing, one patient had stationary hearing, and the other with labyrinthine fistula had worse hearing after the operation (ABG became 48 dB from 35 dB). The possible explanation for the worsening may be attributed to the severe damage to the endolymphatic system from cholesteatoma, and this patient did not suffer from vertigo after the operation. One patient (case no. 12) with bilateral microtia underwent simultaneous Bonebridge implantation and contralateral subtotal petrosectomy with EAC closure. The postoperative course has been uneventful so far. As for the audiometry performance of Bonebridge after activation, the functional gain was 35 dB (from 60 to 25 dB), and speech

Table 1

Patient characteristics and operation details

ID	Age	Gender	Laterality	Diagnosis	Operation method	Operation time (minutes)	Result	Follow-up duration (months)	Complications
Group 1: External ear lesions									
1	58	F	Left	EAC cancer	Lateral temporal bone resection with parotidectomy, neck dissection and free flap reconstruction	909	Free tumor margin. No evidence of recurrence	8	Nil
2	48	M	Right	EAC epidermoid cyst	Simple excision	71	Tumor excised smoothly without recurrence	2	Nil
3	29	F	Left	Auricular pyogenic granuloma	Simple excision	36	Clean wound without recurrence	7	Nil
Group 2: Middle ear diseases									
4	54	F	Right	Otosclerosis	Endaural approach stapedotomy with piston	136	Improved hearing. AB gap improved from 33 to 15 dB	8	Nil
5	46	M	Right	Otosclerosis	Endaural approach stapedotomy with piston	166	Improved hearing. AB gap improved from 24 to 6 dB	5	Nil
6	39	F	Right	Otosclerosis	Endaural approach stapedotomy with piston	152	Improved hearing. AB gap improved from 39 to 16 dB	9	Nil
Group 3: Otomastoid diseases									
7	28	M	Right	Cholesteatoma	CWD tympanomastoidectomy and mastoid obliteration with meatoplasty	222	Stationary hearing. No recurrence of cholesteatoma	7	Nil
8	71	M	Left	Recurrent cholesteatoma with labyrinthine fistula	CWD tympanomastoidectomy with meatoplasty and repair labyrinthine fistula	321	Dry ear with stationary hearing. No dizziness or vertigo events after operation	7	Nil
9	23	M	Left	Cholesteatoma	CWD tympanomastoidectomy and mastoid obliteration with meatoplasty	183	Dry ear with well epithelium. Improved hearing. AB gap improved from 35 to 27 dB	7	Nil
10	50	F	Left	Chronic otitis media and mastoiditis	CWU tympanomastoidectomy with PORP ossiculoplasty	245	Improved hearing. AB gap improved from 37 to 20 dB.	8	Nil
11	22	F	Right	Jugular bulb dehiscence	Combined endoscope exploratory tympanotomy and mastoidectomy + bone cement resurfacing for dehiscent jugular bulb	233	THI improved from 66 to 18	4	Nil
12	29	M	Bilateral	Bilateral microtia with conductive hearing loss, left aural stenosis with EAC cholesteatoma s/p canalplasty	Left subtotal petrosectomy with blind sac closure of EAC and simultaneous right Bonebridge 602 implantation	539	Improved hearing. Functional gain was 35 dB (from 60 to 25 dB) and SRT improved from 50 to 20 dB HL for the aided condition. No recurrence of cholesteatoma	7	Nil
13	7	M	Left	Congenital aural stenosis with EAC cholesteatoma	Endaural approach meatoplasty	413	Improved hearing. AB gap improved from 52 to 25 dB	7	Nil
14	59	M	Left	Mastoid cholesterol granuloma	CWU mastoidectomy	123	Improved swelling and postauricular pain after operation. No evidence of recurrence	6	Nil
15	60	M	Left	Glomus tympanicum	Combined microscopic CWU tympanomastoidectomy with glomus tumor excision and PORP ossiculoplasty	251	THI improved from 36 to 2. Improved hearing. AB gap improved from 26 to 19 dB	6	Nil

AB gap = air-bone gap; CWD = canal wall down; CWU = canal wall up; EAC = external auditory canal; F = female; M = male; PROP = partial ossicular replacement prosthesis; SRT = speech recognition threshold; THI = tinnitus handicap inventory.

reception threshold improved from 50 to 20 dB HL for the aided condition. Overall, hearing can be preserved and expected to improve after most otologic surgery performed under an exoscope in our series.

3.3. Results of the questionnaire

Twenty staff, including four surgeons, six residents, six medical students (postgraduate year and clerk), and four scrub nurses, filled out the questionnaire. The mean score and standard deviation were calculated. The total score was relatively high in the surgeons' group (21.3 ± 0.5) and medical students' group (21.7 ± 1.4), followed by the residents' group (20.5 ± 5.1) and lowest in the scrub nurses' group (17.5 ± 4.8). There was no significant difference between the different groups ($p > 0.05$ by Kruskal-Wallis test).

As for the detailed items of the questionnaire (Table 2), high ratings were found in subjects of image quality (2), stereoscopic effects (2), magnification rate (1.9), and the same field of view as the surgeon (1.9). On the other hand, worse ratings were reported with surgical working space (1.4), eye strain by video observation (1.5), and focusing difficulty (1.5). In the main surgeon group, ratings were well except for focusing difficulty (1.3),

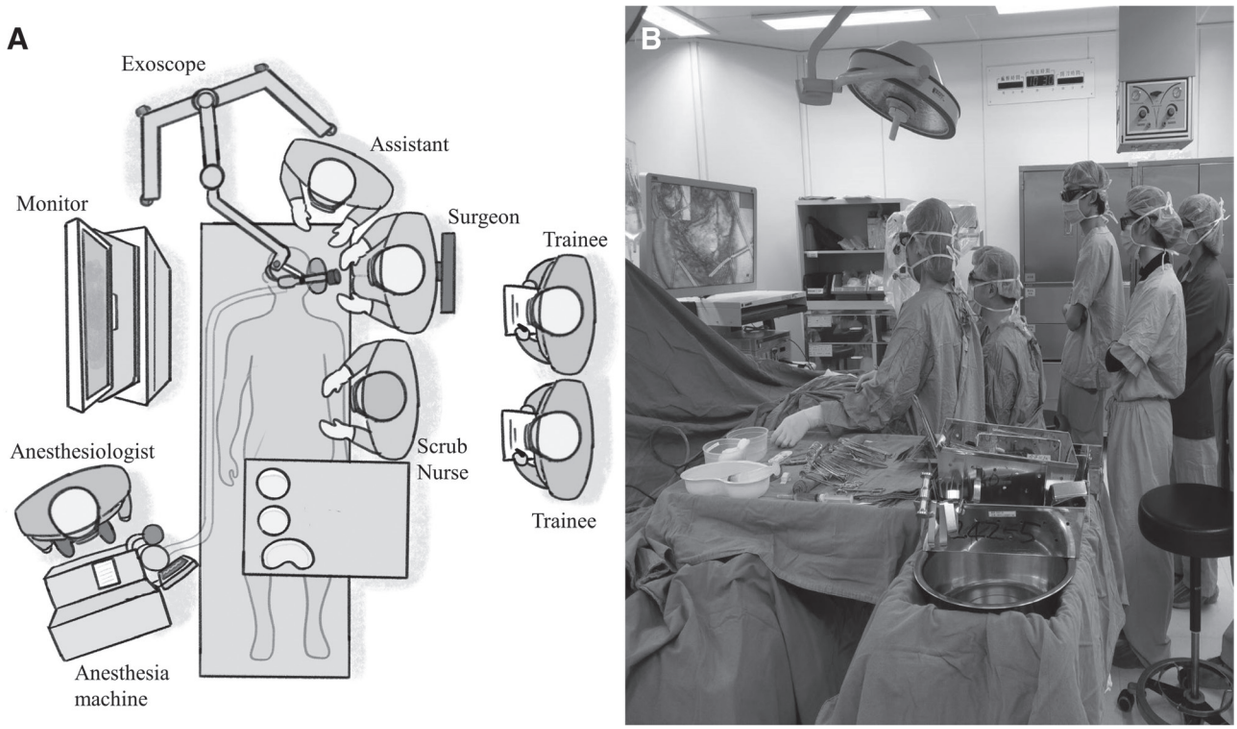

Fig. 1 A, Surgical position and operating room setting (VITOM Exoscope). B, Three 3D monitors were used during the surgery while the whole surgical team wore 3D polarization glasses. This setting enabled all surgical team members to see the operation performed in 3D.

Table 2

Average score of each question in the questionnaire (total score is 2 for each item)

	Main operator	Resident	Medical student	Nurse	All
OE has image quality for surgery	2	2	2	1.8	2
OE has stereoscopic effect for surgery	2	2	2	2	2
OE has sufficient magnification rate for surgery	1.8	1.8	2	1.8	1.9
OE has sufficient range of motion of arm for surgery	1.8	1.5	2	1	1.7
There was sufficient luminance for an operation	2	1.5	1.7	1.3	1.7
Eye strain by video observation is not an obstacle for surgery	1.8	1.5	1.5	1	1.5
There was no effect on the temperature of the surgical field	1.5	2	2	1.5	1.8
Surgery is possible in a natural posture	2	1.5	1.8	1.3	1.7
There is a wide surgical working space	1.5	1.3	1.5	1	1.4
Focusing is easy	1.3	1.3	1.7	1.5	1.5
OR members can share the same field of view as the surgeon	2	2	1.7	1.8	1.9
Manual controller installation is easy	1.8	1.5	1.8	1.8	1.7

OE = operative exoscope; OR = operative room.

surgical working space (1.5), and effects on the temperature of the surgical field (1.5).

4. DISCUSSION

In this short-term follow-up retrospective study, we have demonstrated the application of a 3D exoscope in otological practice including external ear benign tumor excision, middle ear surgery (tympanoplasty, ossiculoplasty, stapedotomy with piston), mastoid surgery (CWU/CUW mastoidectomy, subtotal petrosectomy, and Bonebridge implantation) and lateral skull base surgery (lateral temporal bone resection) is feasible, safe, and effective. The postoperative course in patients with either external ear or middle ear/mastoid tumor excision was smooth without evidence of recurrence. The postoperative hearing level in most patients with middle ear and mastoid surgeries was acceptable or significantly improved.

Our surgical results with cholesteatoma and stapes surgery were comparable with previous exoscope surgery reports.[4,11] We also confirmed the feasibility and safety of the 3D exoscope as an alternative to the microscope for lateral temporal bone resection for EAC cancer which is similar to the report of Raymond et al.[12] Besides, this is the first report of the application of an exoscope under conditions such as Bonebridge implantation, meatocanalplasty for congenital aural stenosis, glomus tumor excision, and resurfacing for jugular bulb dehiscence.

Most (14/16, 87.5%) surgeries were completed solely with the 3D exoscope system in our series. However, there were two cases that required the additional aid of an endoscope or microscope. One patient (case no.11) had jugular bulb dehiscence area involving hemotympanum and mastoid parts (Fig. 2). Combining an endoscope for resurfacing with bone cement on the middle ear part via transcanal approach was performed because of poor visualization and low lighting in a small surgical corridor under the exoscope. The other one (case no. 15) had glomus tympanicum involving the middle ear and antrum. Because a part of the details is lost in high magnification under an exoscope, for better bleeding control during tumor resection in high magnification, we conjugated the operation with a microscope. This is probably due to the use of a digital zoom instead of an optical one as used in a traditional microscope.[13]

Ever since the prevalence of endoscopy in otologic surgery, it has gained popularity and changed the conventional concepts of

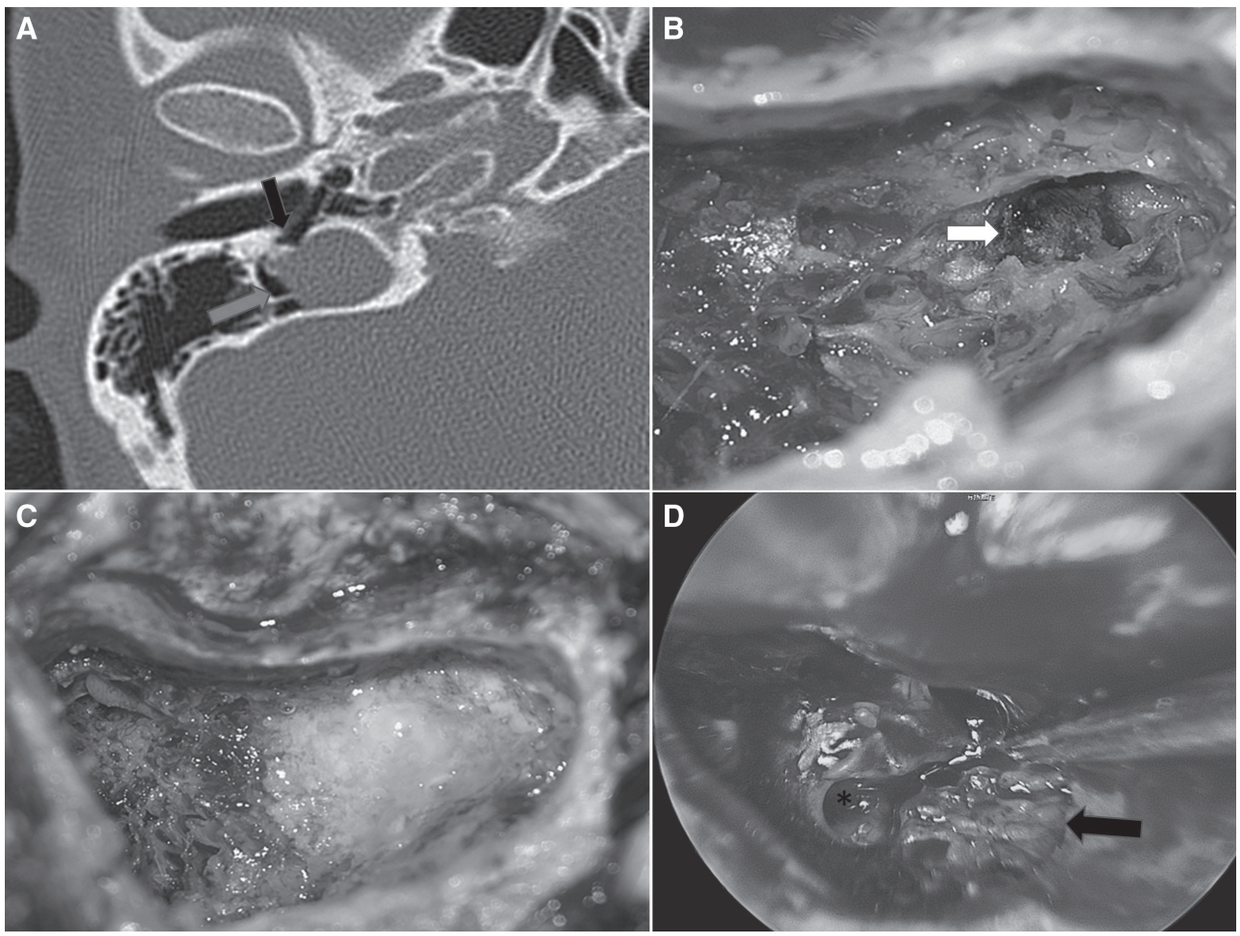

Fig. 2 A, Computed tomography of temporal bone (case no. 11) showed jugular bulb dehiscence over mastoid (red arrow) and hypotympanum(black arrow). B, Jugular bulb dehiscence noted under exoscope (white arrow). C, After resurfacing of the dehiscence. D, Endoscopic view of dehiscence over hypotympanum (black arrow). ∗: round window.

tympanomastoidectomy, as some operations were shifted to the transcanal approach. On the contrary, the newly developed exoscope does not change the current methodology and approach to ear surgery. The exoscope is more like an alternative to the microscope, as the surgeon can perform the operation with two hands, and the difficulty of a one-hand operation encountered in endoscopy does not exist in an exoscope. However, the advantages of endoscopy, such as wide-angle view, are absent from the exoscope.

Shifting from an operative microscope to an exoscope is easy though wearing 3D glasses during operation is an entirely new experience for most otology surgeons. The surgeon in our study did not spend much time learning to manage a new device. Besides, due to a narrow surgical field at high magnification under the microscope, surgeons need to move and frequently refocus to make the target clear and avoid being out of sight. On the contrary, the exoscope can provide a wide view of the operation field under high luminance. On the other hand, although the size of the exoscope is compact, the base of the exoscope is bulky and limits the space for other staff. In addition, a poorer resolution was found in deep structures through a narrow surgical corridor, such as ossicles during middle ear manipulation under the exoscope when compared with that under the microscope.[14] Despite the drawback, our surgical experience on ossicular chain manipulation including ossiculoplasty or stapes surgery with an exoscope could proceed smoothly and the surgical results were acceptable. Future improvement in enhancing the current downside is expected.

Pirola et al[10] developed a questionnaire to understand the usage of an exoscope in dacryocystorhinostomy, but the detailed results were lacking in their article. Therefore, we adopted this questionnaire to different members of our surgical team and tried to find the positive and negative aspects of different users. In our series, we found a lower average score in the nurses' group, which is similar to Pirola's result. This can be attributed to limited hands-on manipulation of the microscope in their previous participation during operations.

Overall, the whole team appreciated the image quality, stereoscopic effects, magnification rate, and the same field of view as the surgeon. The 4K three-dimensional (3D) exoscope system offers delicate image quality with fair stereoscopic effects. A magnification rate of 8-30× allows the surgeon and team members to catch details of anatomical structures in the surgical field. With the aid of 3D polarization glasses or 3D clip-on glasses, all members in the operation room can have the same field of view as the surgeon. Therefore, it is a very useful aid in educating the residents and medical students.

However, there are some concerns found during our investigation. First, limited surgical working space was reported in all groups. As mentioned above, the exoscope base is bulky, and further adjustment may be considered. Second, the focusing issue showed worse ratings in all groups and worst in the

surgeon group. Unlike the microscope, surgeons need to use the control knob instead of buttons on the handle. Although exoscopes have a greater depth of field, unfamiliarity with this device may lead to problems during operations. Third, eye strain by video observation had low average ratings. Interestingly, the main surgeon group had fair ratings in this item, and this may be different among different subjects. Last but not the least, the surgeon group found effects on the temperature of the surgical field. Similar effects were also observed in microscopic surgeries.

There are several limitations of this study. First, this is a retrospective study of patients with various disease conditions and operative goals. The result of the operation is diverse and hard to evaluate systemically. Second, the case number is small, and the follow-up time is limited. Long-term hearing results of the operation and the recurrence rates under such settings are insufficient. Future prospective studies with meticulous design are warranted.

In conclusion, our early experience showed the application of 3D exoscope is feasible, safe, and effective in surgical management on various otologic diseases including external ear, middle ear, mastoid, and lateral skull base. However, endoscope or microscope should not be abandoned and should be reserved as supplementary in some cases. A subjective good perception was acknowledged by the surgical team members. Its high-definition image quality, stereoscopic effects, sufficient magnification, reliability, and teaching value made it a good and novel instrument in general ear surgeries.

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