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Computer-based three-dimensional image system for endoscopic transcanal transpromontorial approach for vestibular schwannoma

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Corresponding Author:	Li-Chun Hsieh TAIWAN
Corresponding Author's Institution:	
Corresponding Author E-Mail:	lichunhsieh1978@gmail.com
Order of Authors:	Chin-Kuo Chen
	Li-Chun Hsieh
	Yu-Jen Lu
	Chu-Po Lin
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TITLE:

An Endoscopic Transcanal Transpromontorial Approach for Vestibular Schwannomas using a Computer-Based Three-Dimensional Imaging System

AUTHORS AND AFFILIATIONS:

Chin-Kuo Chen[1], Li-Chun Hsieh[2,3], Yu-Jen Lu[4], Chu-Po Lin[5]

[1]Department of Otolaryngology-Head and Neck Surgery and Communication Enhancement Center, Chang Gung Memorial Hospital and Chang Gung University, Taoyuan, Taiwan
[2]Department of Otolaryngology-Head and Neck Surgery, Mackay Memorial Hospital, Taipei, Taiwan
[3]Department of Audiology and Speech Language Pathology, Mackay Medical College, Taipei, Taiwan
[4]Department of Neurosurgery, Chang Gung Memorial Hospital and Chang Gung University, Taoyuan, Taiwan
[5]Department of Medical Education, Chang Gung Memorial Hospital and Chang Gung University, Taoyuan, Taiwan

E-mail Addresses of Co-authors:

Chin−Kuo Chen (dr.chenck@gmail.com)
Li−Chun Hsieh (lichunhsieh1978@gmail.com)
Yu-Jen Lu (alexlu0416@gmail.com)
Chu-Po Lin (jester3009123@gmail.com)

Corresponding author:

Li−Chun Hsieh (lichunhsieh1978@gmail.com)

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SUMMARY:

Here, we present a transcanal transpromontorial approach for vestibular schwannomas using a computer-based three-dimensional (3D) imaging system combined with a two-dimensional (2D) endoscope. This system provided stereoscopic vision, better depth perception and reduced visual fatigue. This 3D imaging system enabled the application of 3D vision technology in endoscopic lateral skull base surgery.

ABSTRACT:

A 2D monocular endoscope has been used in transcanal transpromontory vestibular schwannoma surgery instead of craniotomy. However, the absence of depth perception is the limitation of this approach. With the loss of depth perception, the surgeon will be not able to perform delicate and particularly complicated surgery. A binocular endoscope has been developed to provide stereoscopic vision with better depth perception for complicated anatomic structures and has been applied in some endoscopic surgeries. However, the diameter of the endoscope is a limitation in the performance of transcanal otologic surgeries. A small diameter endoscope facilitates easier surgery in a restricted space. A computer-based 3D imaging system can obtain 3D images in real-time using a small monocular endoscope. In this study, to evaluate the feasibility of a computer-based 3D imaging system for endoscopic lateral skull base surgery, we applied this 3D imaging system in a transcanal transpromontorial approach in two patients with vestibular schwannomas. The surgical procedure was completed without complication in these two cases. There was no mortality, perioperative complications, nor notable postoperative complications. Using this computer-based 3D imaging system, a better depth perception and stereoscopic vision was observed compared to a conventional 2D endoscope. The improvement in depth perception offers superior management of the complicated surgical anatomy.

INTRODUCTION:

Minimally invasive surgery has become mainstream. Many techniques have been developed, such as the da Vinci robot system and the endoscope. However, the equipment and cost of da Vinci robotic surgery are bulky and very high, respectively. Compared to the conventional craniotomy surgery, the endoscopic transcanal transpromontorial approach for resection of vestibular schwannoma has been developed to decrease the risks of vestibular dysfunction and cerebrospinal fluid leak[1]. However, lack of stereoscopic vision is still the main limitation of endoscopic surgery, especially for complicated ear surgeries[2]. Hence, the 3D endoscope was developed to imitate the binocular disparity to generate stereopsis of operative vision[3,4]. However, the caliber of the currently available 3D binocular endoscope is equal to or greater than 4 mm, making its application in transcanal endoscopic ear surgeries difficult. In addition, when the 3D binocular endoscope is used at close range, its large binocular parallax may lead to double vision.

A monocular 3D endoscope was first introduced in sinus surgeries in 2013[5]. This monocular 3D endoscope system incorporates a microscopic array of lenses in front of a single video chip in the endoscope, acting as separate visual receptors. This method mimics “insect eye” technology, which in turn generates 3D vision. A novel computer-based 3D imaging system was first applied in transurethral endoscopic surgery in 2015[6]. The processor simulates a 3D image by converting the conventional 2D endoscopic image into a pair of images, as received from two viewpoints. The major advantage of this computer processing system is that it can be adapted to conventional monocular endoscopes of any diameter. Both abovementioned 3D imaging systems have not been previously used in otologic surgery. We applied the computer-based imaging processor to endoscopic ear surgeries, including tympanoplasty, mastoidectomy, ossiculoplasty and cochlear implant[2]. This image system has some advantages for transcanal endoscopic ear surgeries. First, we can use all the equipment from the 2D endoscope system and do not need to change the whole system. Second, the caliber of the scope is no longer a concern. The average diameter of the external ear canal is 7 mm in width[7]; the caliber of the instruments (e.g., hook, dissector, and forceps) is approximately 1–2 mm. Thus, the proper caliber of the endoscope is restricted for transcanal ear surgeries. The common calibers of the 2D endoscope for otologic surgery are 3, 2.7 and 1.9 mm, and all of them could be used with this computer-based processor. Therefore, a smaller diameter 2D endoscope equipped with a novel 3D imaging system can be easily and conveniently applied in otologic surgery and enable ear surgeons to operate with 3D vision. In our previous work, we also found that there is no time delay and no visual fatigue when performing ear surgeries using this computer-based 3D endoscopic system[2].

In this study, to evaluate the feasibility of the computed-based 3D imaging system for endoscopic lateral skull base surgery, we applied this 3D imaging system to the transcanal endoscopic transpromontorial approach for two patients with vestibular schwannomas with nonserviceable preoperative hearing.

PROTOCOL:

The protocol follows the guidelines of Chang Gung Memorial Hospital's Human Research Ethics Committee. Ethical approval for the experiment was obtained from the Institutional Review Board of the hospital (IRB No. 201600593B0).

1. Patient position and skin marking

1.1. After general anesthesia, place the patient in a supine position on the operating table, with the head gently rotated to the contralateral side and elevated 15–30°.

1.2. Elevate the head of the bed approximately 15–30° to avoid blood recruitment to middle and inner ear and decrease bleeding.

1.3 Use an electrophysiologic facial nerve monitor to assist the surgeon in facial nerve location and dissection.

1.3.1 Use the detector probe to touch the suspected facial nerve or tissue to make sure that the operating direction is correct.

1.3.2 Set a current of 1 A on the monitor. If the monitor alarms, stop the procedure. Then, decrease the current to 0.5 A and 0.2 A to ensure that the facial nerve will not be damaged.

2. Local anesthesia and incision in the ear canal

2.1. Using a 3 mL syringe with a 21 G needle, provide local anesthesia by injecting the anesthetic (2% lidocaine with 1:100,000 epinephrine) subcutaneously to the external auditory meatus until the skin of ear canal become blanching.

2.2. After sterilizing the surgical area, including the external auditory canal, use a round knife to make a circumferential skin incision of the ear canal (EAC) at the osseo-cartilaginous junction.

2.3. Use a round knife to carefully elevate the lateral EAC skin to form a skin flap for postoperative closure of the ear canal.

2.4. Use the cotton ball soaked with epinephrine or electric cauterization to control the wound bleeding.

3. Canaloplasty

3.1. Remove the medial side of the EAC skin and tympanic membrane.

3.1.1 Under the endoscope, use a round knife to elevate the EAC skin connected to the tympanic membrane.

3.1.2 Use an alligator clamp to completely remove the skin and tympanic membrane.

NOTE: Try not to retain any epithelium in the external ear canal or middle ear cavity to avoid possible risk of external ear and middle ear cholesteatoma postoperatively.

3.2. Widen the ear canal transmeatally with a 2 mm diamond burr.

3.2.1. Using an endoscope with the four-hand technique, enlarge the diameter of the canal to directly visualize all of the middle ear cavity. The assistant holds the endoscope with two hands, and the surgeon can also perform the surgical procedure with two hands.

3.2.2. Otherwise, under the microscope, use both hands of the surgeon to enlarge the diameter of the canal with a 2 mm cutting burr.

3.2.3. Use a silicone sheet or cotton ball to separate the middle ear and external auditory canal in order to avoid getting bony chips or the epithelium of the canal into the middle ear cavity.

4. Insertion of the endoscope and setting of the 3D imaging system

4.1. Hold a 3.0 mm endoscope with the left hand and insert it into the canal after the bleeding is well-controlled.

4.2. Place both monitors of the 2D and 3D images in front of the operative table. Click **Open** to open software.

NOTE: The 2D and 3D monitors provide 2D and 3D images, respectively, from different machines.

4.3. Have the surgeon and all observers wear stereoscopic glasses for 3D vision.

NOTE: Real time 3D reconstruction of the endoscopic ear image is carried out throughout the surgery by the processor. There is simultaneous display of the 2D (shown on one monitor) and 3D (shown on the other one) images. With or without goggles, observers can compare the 2D and 3D images of the surgical field. Any change in brightness, sharpness and color, and time delay could be perceived.

4.4. Use a 45° 3 mm endoscope to confirm that the residual skin of the external auditory canal and remnant of the eardrum have been completely removed to avoid possible cholesteatoma after the surgery.

4.5. To avoid heat injury, keep the light resource under 40% throughout the surgery, and frequently move the endoscope forward and backward in the canal.

4.6. Use antifog solution to clear the endoscope if the endoscope lens is contaminated with blood.

5. Approach to the inner ear and tumor resection

5.1. Cut the chorda tympani nerve with the scissors and remove the remnant chorda tympani nerve with the retrieval device (e.g. Alligator) and suction.

5.1.1. Remove all the ossicular chain (malleus, incus and stapes).

5.1.2. Under the endoscope, carefully remove the incus, malleus and stapes by the retrieval device, respectively.

5.2. Carefully preserve the function and the path of the facial nerve with a facial nerve monitor.

5.2.1 Under the endoscope, observe the facial nerve canal, and avoid touching or damaging the facial canal.

5.3. Remove the outer portions of the basal and middle turn of the cochlea and some of the lateral wall of the modiolus to expose the tumor with a piezosurgery instrument.

NOTE: Similar to the surgical procedure introduced by L. Presutti[8], the vestibular schwannoma can be visible after entering the fundus of the IAC.

5.4. Remove the tumor carefully.

5.4.1 When the tumor is visible, separate the tumor from the facial nerve and the cochlear nerve and remove the tumor.

5.4.2 Set a stimulus of 0.05-0.1 mA, and use the probe to touch the suspected tissue to result in a facial nerve response. Be careful not to use the suction tube to touch the nerve.

5.5. Pack the defect with abdominal fat and hemostatic agents (e.g. Surgicel and Floseal).

5.6. Suture the lateral EAC skin flap to the tragal skin in a watertight fashion for cosmetic reasons.

6. Post-operative procedure

6.1 Admit the patient postoperatively to the intensive care unit for 24-48 hours.

6.2 Transfer the patient to general ward if no postoperative complications occur.

REPRESENTATIVE RESULTS:

We had performed two cases of vestibular schwannoma resection through the transcanal endoscopic transpromontorial approach in our hospital.

Case 1

A 35-year-old male was diagnosed with neurofibromatosis type II with multiple cranial nerve schwannomas and a left side vestibular schwannoma. He had almost complete hearing loss for 1 year before the operation. He underwent the transcanal endoscopic transpromontorial approach because of the sudden worsening of left facial palsy to HB grade V[9]: grossly asymmetric face at rest and slight movement of mouth angle. The surgery was completed without difficulty. There were no intraoperative or postoperative complications noted. The patient had an uneventful postoperative course. His facial function improved to HB grade 3 at his first postoperative visit 2 weeks after surgery and almost completely recovered after 1 month (**Table 1**).

Case 2

A 78-year-old female had a right side Koos grade I vestibular schwannoma[10]. The tumor was approximately 1 cm and located within the internal auditory canal. She had no serviceable hearing before the operation (**Table 1**). This means that a pure tone audiometric test reported profound sensorineural hearing loss (mean 95 dB threshold). Because her vertigo became worse, she underwent the transcanal endoscopic transpromontorial surgery for tumor resection as shown in **Figure 1.** There were no intraoperative or postoperative complications noted. There was no facial palsy postoperatively. At the end of the surgery, we placed the sutures between the EAC flap and tragal skin. She was regularly followed in the outpatient department, and she had uneventful and good cosmetic postoperative results.

During the surgery, the surgeon carried out the procedures of the transcanal endoscopic approach without difficulty. The surgeon did not have to switch to conventional 2D endoscopic surgery to complete the surgeries. Additionally, there was no mortality, perioperative complications nor notable postoperative complications. The patients stayed in the neurosurgery intensive care unit 1 day postoperatively for observation and then were transferred to their original ward. The patients were discharged 5 days later.

There were three assisting doctors, one neurosurgeon, 1 ENT doctor, 2 anesthesiologists, 2 interns and 3 nurses participating in the operation. Questionnaires were completed by these 12 participants after the surgery. Three main questions regarding 3D image system for endoscopic ear surgery were asked in response to our previous study[2]. All participants agreed that the 3D imaging system enabled them to perceive stereoscopic vision and provided fair depth perception without experiencing visual fatigue or discomfort when observing the 3D images.

This system provided 3D vision. The depth perception offered superior management of the complicated surgical anatomy. In addition, there was no time delay and no visual fatigue noted by the surgeon. The endoscope has the benefit of visualizing the complex anatomy of the ear and lateral skull base around the tumor. The sharp image and stereoscopic vision offered by the computer-assisted system also provided visual depth perception, which is vital to the operation.

FIGURE AND TABLE LEGENDS:

Figure 1: Endoscopic image of the transcanal transpromontorial surgery for the left side vestibular schwannoma. (**A**) Conventional 2-dimensional (2D) endoscopic image. (**B**) A 3D image obtained from the computer-based processing system. The vestibular schwannoma (black arrow) of case one patient was exposed after drilling the basal, middle, and apical turn of the cochlea.

Table 1: Patients demographic characteristics, preoperative and postoperative results.

DISCUSSION:

Endoscopic ear surgery has become more popular. However, the main limitation is the lack of stereoscopic vision when compared to a microscopic surgery. The use of a 3D endoscope may be difficult in transcanal ear surgery because of the limited space in the external ear canal. In this study, we applied a 3D computer-based processing system with a conventional 2D endoscope in the transcanal transpromontorial approach for vestibular schwannoma resection and evaluated its clinical feasibility for lateral skull base surgery. Both patients underwent resection of their vestibular schwannomas with the transcanal transpromontorial approach. There were no intraoperative or postoperative complications noted. All the surgical procedures were carried out without difficulty.

This computer-based processing system produces 3D video images from conventional 2D endoscopy images. The advantage of this 3D imaging system is that it can be combined with any conventional 2D endoscope to perform various transcanal ear procedures. In addition, this 3D imaging system provided stereoscopic vision and better depth perception, especially for the complicated and delicate surgical anatomy. In addition, no time delay and no visual fatigue were noted by the surgeon.

Transcanal endoscopic transpromontorial approaches for vestibular schwannoma resection have been published for patients with small vestibular schwannomas with nonserviceable preoperative hearing[1,8,11-13]. This approach through the natural surgical corridor (EAC) is a minimally invasive procedure with low morbidity when compared with other traditional approaches for vestibular schwannoma removal. However, this approach destroys the cochlea, resulting in hearing loss and loss of the chance for cochlear implantation for hearing reconstruction.

As far as simple tympanoplasty, this 3D system may provide a few benefits, but the cost of the 3D imaging system is very high. However, the 3D imaging system is beneficial in performing complicated and meticulous procedures, such as lateral skull base surgery.

The advantage of endoscopic surgery includes seeing around the corner of the target, which can help preserve more tissue and prevent tissue injury, as 3D images offer stereoscopic images that make precise operations. Combining the microscope and endoscope is promising for the transcanal transpromontory resection of vestibular schwannomas. However, there are disadvantages of this hybrid method. First, the surgeon must be familiar with performing both the microscopic and endoscopic techniques. Second, the equipment is expensive. The hybrid technique for the transcanal transpromontory resection of vestibular schwannomas needs more practice and experience with the complicated anatomy, especially from different viewpoints. The anatomy related to the traditional craniotomy and transcanal transpromontorial approaches is different. The limitation of this approach is the tumor size must be less than 2 cm and be of Koos grade I or II[11].

In conclusion, our preliminary results indicate that the proposed computer-based 3D imaging system provides superior depth perception compared to the 2D endoscope. Transcanal endoscopic transpromontory approach is a feasible method for resection of small vestibular schwannoma.

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DISCLOSURES:

The authors have nothing to disclose.

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Figure 1A

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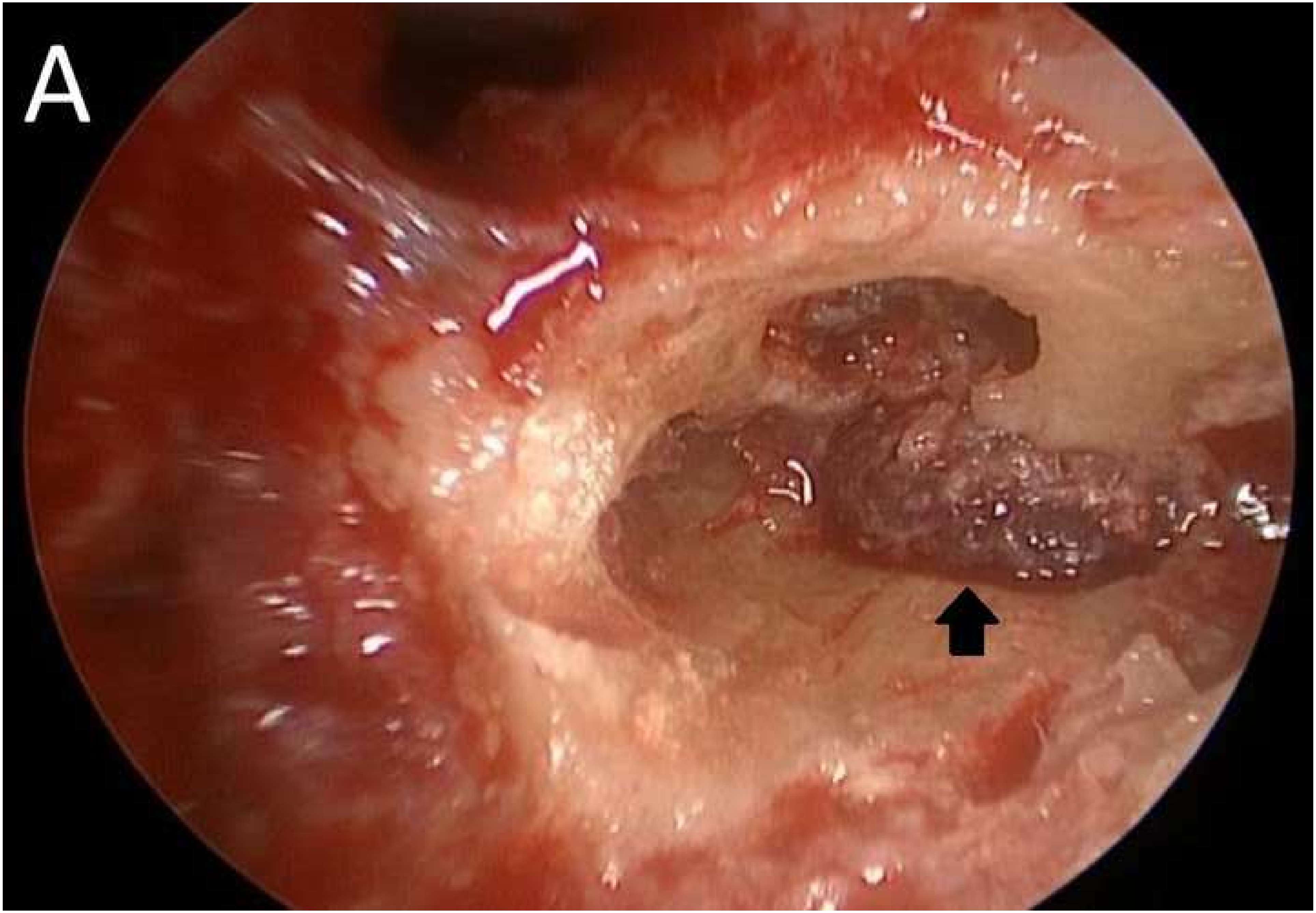

Figure 1B

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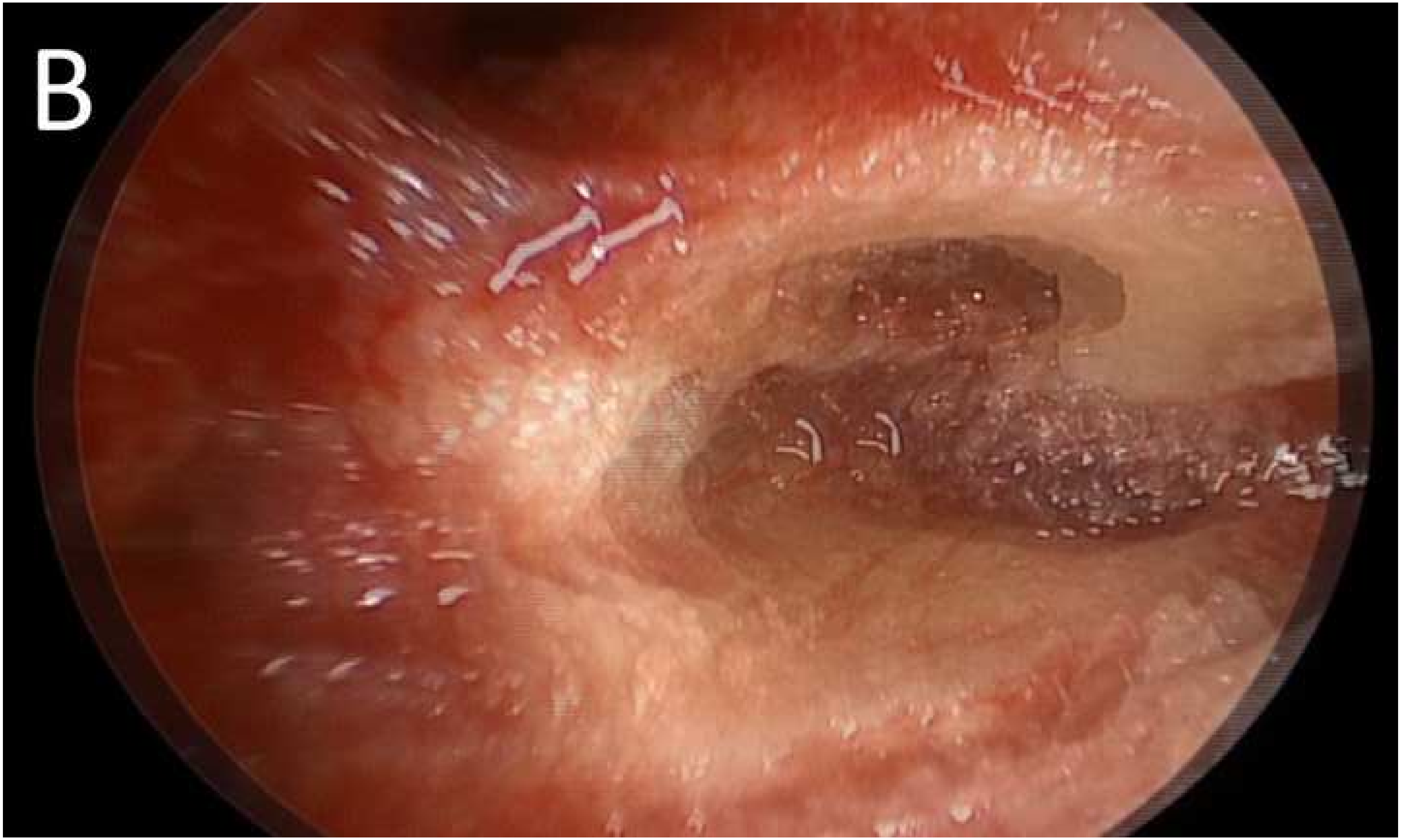

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Patient	Age (years)	Gender	Lesion side	Facial Function (HB grade)		Hearing status (dB)	
				preoperative	postoperative	preoperative	postoperative
1	35	Male	Left	V	II	>110	>110
2	73	Female	Right	I	I	95	>110

Name of Material/Equipment	Company	Catalog Number
2D endoscope HOPKINS Straight Forward Telescope 0, with 3, 2.7,1.9 mm diameter	Karl Storz, Germany	7220AA, 7220BA, 7220FA, 7229AA 1232A
3D medical LCD monitor LMD-2451 MT	Sony, Japan	22220055-3 9524 N 22201020-1xx
computer-based 3D imaging system	Shinko Optical, Japan	HD-3D-A
Piezosurgery instrument	Mectron, Carasco/Genova, Italy	MP3-a30

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CORRESPONDING AUTHOR

Name: Li-Chun, Hsieh

Department: Otolaryngology, Head and neck Surgery

Institution: Mackay Memorial Hospital

Title: Computer-based three-dimensional image system for endoscopic transcanal transpromontorial approach for vestibular schwannoma

Signature: Li-Chun, Hsieh

Date: 2019- March. 30

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Editorial comments:

Changes to be made by the Author(s):

- *1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues. The JoVE editor will not copy-edit your manuscript and any errors in the submitted revision may be present in the published version.*

Reply: Thanks. The article had sent for English editing already.

- *2. Please rephrase the Long Abstract to more clearly state the goal of the protocol*

Reply: Thanks for your suggestion. We had rephrase and shorten the abstract.

- *3. Please ensure for in-text formatting, corresponding reference numbers should appear as numbered superscripts after the appropriate statement(s).*

Reply: Thanks for your suggestion. We had checked the signed references carefully.

- *4. Please reword lines 47-51, 80-82, 153-15 as it matches with the previously published literature.*

Reply: Thanks for your suggestion. We had reword or deleted these lines. Please see the page 3 lines 78-79, and page 5 lines 168-170.

- *5. Please ensure that the Introduction includes all of the following with citations:*
  a) A clear statement of the overall goal of this method
  b) The rationale behind the development and/or use of this technique
  c) The advantages over alternative techniques with applicable references to previous studies
  d) A description of the context of the technique in the wider body of literature
  e) Information to help readers to determine whether the method is appropriate for their application

Reply: We had revised the introduction to state clearly the goal and advantages of this method.

- *6. Please add more details to your protocol steps. Please ensure you answer the "how" question, i.e., how is the step performed?*

Reply: Thanks for your suggestions. We had described more about our protocol steps.

- *7. 1.3: How do you locate the facial nerve using the facial monitor. Please include all button clicks, the knob turns, etc.*

Reply: 1.3 Use electrophysiologic facial nerve monitor (NIM 2.0 nerve monitoring system from Medtronic) to assist the surgeon in facial nerve location and dissection.

1.3.1 Use the detector probe to touch the suspected facial nerve or tissue to make sure the operating direction is correct.
1.3.2 Set a current to 1 A. If the monitor alarms, stop the procedure. Then, decrease the current to 0.5 A and 0.2 A to ensure that the facial nerve will not be damaged. Then, restart the surgical procedure.

- *8. 2.1: How is this done- using syringe? Please include the size of the needle and syringe? Also, do you need to provide local anesthesia after general anesthesia is already provided.*

Reply: 2.1. Using a 3 ml syringe with a 21 G needle, provide local anesthesia by subcutaneously injecting the anesthetic (2% lidocaine with 1:100,000 epinephrine) radially to the external auditory meatus.

- *9. 2: How is the incision performed? How big is the incision? Do you sterilize the area prior to incision? How is the elevation performed?*

Reply: We had described the steps involved in canalplasty more detail. Please see the page 4 lines 123-136.

- *10. 3: Please include all the steps involved in canaloplasty. How do you bring the microscope in the picture? At what step of the protocol do you use silicone sheet or cotton ball, etc.*

Reply: We had described the steps involved in canalplasty more detail. Please see the page 4 lines138-151 and page 5 lines152-155.

- *11. 5: Please include how is this done?*

Reply: We had described how this surgical procedure was done in detail. Please see the page 5 lines 182-189 and page 6 lines 190-209.

- *12. There is a 10-page limit for the Protocol, but there is a 2.75-page limit for filmable content. Please highlight 2.75 pages or less of the Protocol (including headings and spacing) that identifies the essential steps of the protocol for the video, i.e., the steps that should be visualized to tell the most cohesive story of the Protocol. JoVE videographer will come to your place and film the protocol.*

Reply: We follow your recommendation to meet the criteria of the journal.

- *13. For the representative result section, please include a table for the cases being described to show the pre and post-operative details.*

Reply: We had added a table about the pre and post-operative details of these two cases.

- *14. Please do not embed any figure in the manuscript. Please upload all figures separately to your editorial manager account.*

Reply: We had deleted the figures in the manuscript and we uploaded all the figures already.

- *15. As we are a methods journal, please revise the Discussion to explicitly cover the following in detail in 3-6 paragraphs with citations:*
  a) Critical steps within the protocol
  b) Any modifications and troubleshooting of the technique
  c) Any limitations of the technique
  d) The significance with respect to existing methods
  e) Any future applications of the technique

Reply: We had added the paragraph about the advantages and limitations of this techniques. Please see the page 8 lines 277-288.

“ The advantage of endoscopic surgery includes seeing around the corner of the target, which can help preserve more tissue and prevent tissue injury, as 3D images offer stereoscopic images that make precise operation. Combining the microscope and endoscope is promising for the transcanal transpromontory resection of vestibular schwannomas. However, there are disadvantages of this hybrid method. First, the surgeon must be familiar with performing both the microscopic and endoscopic techniques. Second, the equipment is expensive. The hybrid technique for the transcanal transpromontory resection of vestibular schwannomas needs more practice and experience with the complicated anatomy, especially from different viewpoints. The anatomy related to the tranditional craniotomy and transcanal transpromontorial approaches is different. The limitation of this approach is the tumor size must be less than 2 cm and be of Koos grade I or II. “

- *16. Please combine the figure panels of the individually uploaded figure.*

Reply: Thanks for your remind.

- *17. Please revise the table of the essential supplies, reagents, and equipment. The table should include the name, company, and catalog number of all relevant materials in separate columns.*

Reply: We had revised the table of essential equipment.

Reviewer #1:

Manuscript Summary:

This paper described a computer-based three-dimensional image system for endoscopic transcanal transpromontorial approach for vestibular schwannoma.

Major Concerns:

- *If the authors could compare the 3D effect between this computer-based technique with 2 lens 3D methods, the readers would have a better impression.*

Reply: Thanks for your suggestion. We had published an article about the comparison of 2D and 3D endoscopic ear surgeries in 18 patients in 2018 (reference 2 , Chen CK, Hsieh LC, Hsu TH. Novel three-dimensional image system for endoscopic ear surgery. European Archives of Otorhinolaryngology.275, 2933-2939, 2018). Because case numbers of vestibular schwannoma (VS) receiving transcanal endoscopic resection are limited, it is difficult in comparing the results of 2D and 3D endoscopy applying in transcanal transpromtomtary resection. Wish in the future, we can share the results of 2D and 3D endoscopic resection of VS if the case numbers are enough.

- *Minor Concerns:*

  The authors could describe the principle of the technique in more detail.

Reply: Thanks for your suggestion. We had rephrased the abstract and introduction and described the protocol in more detail.

Reviewer #2:

Manuscript Summary:

This is a good paper, which is concisely written. There are some questions unanswered.

Major Concerns:

- *1. Using 2D images to produce 3D images should cause delays, and rather than just stating "no time-delay and no visual fatigue was complained" (in discussions), more objective measures would be preferable; such as the processing time caused 50 milliseconds and did not cause time-delay complaints to the surgeons.*

Reply: Thanks for your suggestion. We had published an article about the comparison of 2D and 3D endoscopic ear surgeries in 18 patients in 2018 (reference 2, Chen CK, Hsieh LC, Hsu TH. Novel three-dimensional image system for endoscopic ear surgery. European Archives of Otorhinolaryngology.275, 2933-2939, 2018). There was no differences of the operation time in both 2D and 3D endoscopic ear surgeries (tympanoplasty and mastoidecomy). According to the results of questionnaires by 35 observers and one surgeon, most of them agreed that this 3D imaging system enabled them to perceive stereoscopic vision , provide superior depth perception. Furthermore, most of them reported no time delay, no visual fatigue or discomfort when observing the 3D images.

This study, the main goal is to describe how we do the surgery of transcanal transpromontary resection of vestibular schwannoma with 3D imaging system. Because the case numbers of vestibular schwannoma (VS) receiving transcanal transpromontary resection are limited, it is difficult in comparing the results of 2D and 3D endoscopy applying in transcanal transpromtomtary resection.

- *2. In supplementary figures, you mention the image input as 60 frames/sec. How about the output? Does it decrease to somewhat lower framerates per second? If possible, please specify it (Looking at the design, I presume the framerate should be decreased, but it is not mentioned.). In addition, according to figure and table legends, the viewing angle seems decreased. How much penalty does it have in regard to viewing angles?*

Reply: According to Durrani and Preminger's study, they reported the output is 120 Hz (60Hz for each eye) [1]. Principles of our method are used to separate images from both eyes. Observers can sense the different image angles captured by both eyes. Different images between right and left eyes generate gaps at locations, which may cause binocular parallax. If the gap between the retinal

images in both eyes is small, the human cerebrum is capable of perceiving depth in front of and behind the object being viewed, depending on the size and direction of the gap [2].

- *3. The manuscript just utilizes this new system, but it would be better to explain the basic algorithm for polymorphing 3D images out of 2D images. Did the system utilize different image processing on odd and even frames for left and right and use that to construct 3D images in real-time?*

Reply: Principles of the 3D video system

The 3D video system is based primarily on the following fundamental principles. First, the exclusive endoscope with two image guides connected to the exclusive video camera captures individual left and right images at slightly different angles (binocular parallax). Next, the system converts the images to 60–120 Hz images, and the left and right images are alternately displayed in sequence on a single display monitor. Rather than standard 3D endoscopy technology, our method utilized a conventional endoscope and then processed the 2D images with a specialized processor to create a composite binocular view in real-time, then display it on a 3D monitor or head-mounted display to achieve stereoscopy. The human brain unconsciously senses the difference in angles of the images captured by the right and left eyes. The brain then fuses the images seen at the different angles and interprets them as stereoscopic images [2].

- *Minor Concerns:*
  How does this synthesized 3D videos/images compare to the binocular endoscopic system in terms of image quality and depth perception? Does it provide equivalent depth perception? If not, does the software have some capabilities to calibrate the perceived depth perception?

Reply:

According to Yoshida et al.'s report, a typical 3D endoscopy imaging relies on convergence and binocular disparity, utilizing the twin left and right images obtained from two optical axes to achieve a 3D image. Through the progress of several technologies, 3D imaging obtained with this approach is natural and high quality. Rather than standard 3D endoscopy technology, our method utilized a conventional endoscope and then processed the 2D images with a specialized processor to create a composite binocular view in real-time, then display it on a 3D monitor or head-mounted display to achieve stereoscopy [3]. Kawaida et al. said that the surgeons nearly always perceive stereoendoscopic images that are close to reality. The images were slightly darker than ordinary video images. However, if a strong xenon light source is used, the darker images do not hinder the actual use of the images [2].

Birkett et al. documented this 2d transformed 3d method originally provided only a fixed-distance image shift regardless of the depth of the object in the image, the operating principle was different from that of the true binocular parallax created by binocular vision. Thus, surgeons would be unlikely to perceive any sense of depth perception [4].

But an experienced surgeon develops compensatory mechanisms, relying on tactile feedback, scope movements, and anatomical knowledge [5]. Some authors reported from both otorhinolaryngologists and neurosurgeons suggest that 3D technology improves task speed and efficiency [6,7].

Reference

[1] Durrani, A. F., & Preminger, G. M. (1995). Three-dimensional video imaging for endoscopic surgery. Computers in biology and medicine, 25(2), 237-247.

[2] Kawaida, M., Fukuda, H., & Kohno, N. (2002). New visualization technique with a three-dimensional video-assisted stereoendoscopic system: application of the BVHIS display method during endolaryngeal surgery. Journal of Voice, 16(1), 105-116.

[3] Yoshida, S., Kihara, K., Fukuyo, T., Ishioka, J., Saito, K., & Fujii, Y. (2015). Novel three-dimensional image system for transurethral surgery. International Journal of Urology, 22(7), 714-715.

[4] Birkett, D. H., Josephs, L. G., & Este-McDonald, J. S. O. (1994). A new 3-D laparoscope in gastrointestinal surgery. Surgical Endoscopy, 8(12), 1448-1451.

[5] Roth, J., Singh, A., Nyquist, G., Fraser, J. F., Bernardo, A., Anand, V. K., & Schwartz, T. H. (2009). Three-dimensional and 2-dimensional endoscopic exposure of midline cranial base targets using expanded endonasal and transcranial approaches. Neurosurgery, 65(6), 1116-1130.

[6] Gardner, P. A., Kassam, A. B., Thomas, A., Snyderman, C. H., Carrau, R. L., Mintz, A. H., & Prevedello, D. M. (2008). Endoscopic endonasal resection of anterior cranial base meningiomas. Neurosurgery, 63(1), 36-54.

[7] Oostra, A., van Furth, W., & Georgalas, C. (2012). Extended endoscopic endonasal skull base surgery: from the sella to the anterior and posterior cranial fossa. ANZ journal of surgery, 82(3), 122-130.

Reviewer #3:

Manuscript Summary:

The manuscript presents an interesting application of a computer-based three-dimensional image system used for endoscopic transcanal transpromontorial surgical resection of vestiublar schwannoma.

- *Major Concerns:*
  It is very difficult to follow the new approach. Please provide an image of the operative set-up. Please show images of the 3D imaging system, the 3D monitor and stereoscopic glasses. This is necessary for understanding how this works in clinical reality.

Reply: Thanks for your suggestion. We will provide the operative set-up video of this 3D imaging system.

- *Please show images of both cases and indicate the findings. Non-ENT surgeons are not familiar of endoscopic images of the middle and inner ear. Figure legend 1 should keep the wording vestibular schwannoma and not acoustic neuroma.*

Reply: We had revised the figure legend as vestibular schwannoma.

Reviewer #4:

Manuscript Summary:

Description of computerized assisted endoscopic surgery of the ear (acoustic neuroma removal by a trans-canalar approach.

- *Major Concerns:*

  No information on the neurosurgical difficulties or tips for removal of the disease, even if this method is described as a good one for that purpose

Reply: After exposure of the tumor, a neurosurgeon removed the tumor piece by piece to avoid damage the facial nerve. Hold the endoscope by one hand, and remove the tumor by the other hand. Sometimes, using both hands are good to do. Most of time, a NS surgeon do the surgery using both hands under microscope. The endoscope was used to see around the vessels and nerves.

- *Minor Concerns:*

  Please give more details on the size and exact location of the acoustic neuromas of the 2 cases. What is the references for the classification in stade I or II?

Reply: We added table 1 to list the characteristics of these 2 cases. We also added the reference about Koos grading of vestibular schwannoma.

Reviewer #5:
JoVE60069R2

Description:
This is a second revision for an invited methods article- JoVE produced video, titled "Computer-based three-dimensional image system for endoscopic transcanal transpromontorial approach for vestibular schwannoma".

The major take-home message (per the authors) is that combining the 2D endoscope with a 3D processing system and 3D visualization allows for better depth perception during transcanal vestibular schwannoma removal/ lateral skull base surgery.
During 2 surgical procedures in patients with intracochlear vestibular schwannoma and non-servicable hearing, the authors used a 3mm endoscope with the 2D and 3D imaging software in parallel. The surgeons wore 3D glasses and did not encounter any peri-or postoperative complications.

- *Major comments:*
  This study has multiple weaknesses, most importantly, no convincing imaging/ video/ data was shown that proves that the 3D approach was superior to 2D. No systematic approach was described, and only 2 surgical cases were performed (but not demonstrated on video). Major limitations (such as potential time delay from processing as well as visual fatigue) were not scientifically assessed and discussed. A 2D monitor was used in parallel to 3D monitor, and it is undistinguishable which monitor the surgeon ultimately focused on during surgery. No convincing improvement for cochlear dissection was presented with 3D technology. Lastly, the study is lacking in grammar and style and will require a professional editing service.

  In conclusion, this study does not provide a critical review/ assessment that would indicate a superior performance of 3D versus current 2D technology for endoscopic ear surgery.

Reply: The aim of this study is to provide a new concept using the 3D imaging system to assist the transcanal transpromontary resection of vestibular schowaanoma, which is also a new surgical procedure different from traditional craniotomy. For a rising interest about endoscopic technique in lateral skull base surgeries, more and more surgeons may be adopted transcanal transpromontary approach to treat the lesion. The endoscope had its benefit to see the details

around the target and 3D images to help surgeons to get stereoscopic images. Computer-based imaging system not only provides 3D images but also can be applied for any diameter of endoscopes. Indeed, we cannot provide comparisons of 2D and 3D system in limited two cases, which is the limitation of this study. In fact, the need and possibility to adopt the transcanal transpromontary approach technique to resect the vestibular schwannoma is new and rare because the candidates must meet the criteria of near total hearing loss or profound hearing impairment and small tumor within internal auditory canal like our two cases. For larger vestibular schwannoma cases, the present choice is radiation therapy, but only surgical resection can provide the possibility to remove the tumor completely.

Questionnaires were completed by these 12 participants after the surgery. Three main questions regarding 3D image system for endoscopic ear surgery were asked to response our previous study. All of them agree the system can 3D imaging system enabled them to perceive stereoscopic vision, provide fair depth perception and without experienced visual fatigue or discomfort when observing the 3D images.

Video

-Slide design "Challenges"- Words are separated/ broken up on slide

Ans: We will revise it later.

-The introduction is too long on video (~7 min) and mostly focused on binocular/ monocular cues and differences and not on the actual improvement during surgery

Ans: We will revise the introduction later.

-Spelling mistakes on the slides

Ans: We will revise it later.

-"set up" slide only has a photo without description- conceptually would work better if the information provided on the "Intervention" slide was provided on set up slide

Ans: We can provide a setup video for JOVE video. WE need JoVE professional editing service for video.

-Why are canalplasty images identical and pulled vertically?

Ans: We will revise it later.

-Only 2 images are shown comparing 2D and 3D intraoperatively directly

Ans: As the present material shown, we just aim to depict the new technique and new approach method to resect the small vestibular schwannoma in patients complicated with profound hearing loss.

-Would be much more convincing if actual video was shown in 2D versus 3D from surgery

Ans: We provide the video of 2D about the operation first, and if needed we will provide 3D video later.

-Canalplasty is not a crucial step during intracochlear schwannoma surgery- quality of imaging should be compared during intracochlear resection

Ans: We try to show the video of tumor resection through transcanal intracochlear approach.

-Picture of postoperative wound is irrelevant for this manuscript

Ans: We can delete this slide.

Specific comments:

-Please use professional editing service for video and manuscript

Ans: We will need the professional Video team to help us editing service for video. We had performed this manuscript for English edition.

-Please provide references for lines 69, 90

Ans: We had added the references for lines 67 and 87 in revised manuscript.

-Line 93: several different endoscopes are described for use in otology, but are missing from list of instruments, video and partly in description of surgery

Ans: We described the different size of endoscopes in list of instruments and description of surgery.

-Line 137: Canalplasty was performed with microscope, but images were shown on video with endoscope. Would recommend only showing video and pictures of endoscopic parts of surgery

Ans: We had rewrite and offer more details about the canalplasty. In the brief, we start the canalplasty under the endoscope and then under the microscope to enlarge the canal. Finally, we use the endoscope to make sure all the epithelium was removed.

-Line 145: How can the authors control which monitor is the surgeon focusing on if both are showing surgery?

Ans: The 2D and 3D monitors are both in front of the operative table. With goggle, the surgeon and assistors can obtain 3D images. Without goggle, we can watch 2D monitor.

-Line 154: How was time delay, sharpness and color measured/ compared?

Ans: There was no time delay perceived by the surgeon and observers as we had identified in our previous study. In these limited two rare cases, it is practically impossible to have significant statistical data to support the idea repeatedly as our previous study shown.

-Line 161: Commonly accepted settings for endoscopes are 50% or lower for ear surgery

Ans: Thanks for reviewer's remind, we set 30% light for the endoscope.

-Line 166: Surgical procedure: At which critical point was the 3D technology superior to 2D?

Ans: We use the endoscope to check any hidden area where the microscope cannot see directly, and then start where want to go . The critical points included no epithelium retained in the middle ear cavity, facial nerve, E tube in the middle ear, vessels and nerves around the tumor.

-Line 187: Surgical cases: Case descriptions are inconsistent- state stages and laterality for both cases. How large were tumors and where was exact location in regards to promontory?

Ans: We added table 1 to describe the detail of these two cases.

-Line 213-215: How was time delay and visual fatigue measured? How many surgeons tested the system?

Ans: There were three assistor doctors, 1 nerosurgeon, 1 ENT doctor, 2 anesthesiologists, 2 interns and 3 nurses participating the operation. Questionnaires were completed after the surgery. To say briefly, responses to questionnaires regarding 3D image system for ensdoscopic ear surgery, three main questions were asked as our previous study. All of them agree the system can 3D imaging system enabled them to perceive stereoscopic vision, provide fair depth perception and without experienced visual fatigue or discomfort when observing the 3D images.

-Line 248-251: Relevance for 3D? In any case, this procedure would be intracochlear and therefore not for hearing preservation.

Ans: Yes. The present two cases were vestibular schwannoma combined with profound hearing loss.

-Line 252-255: The authors do not demonstrate why the 3D technology was superior to 2D.

Ans: In our limited cases, we cannot get statistical significance to explain 3D technology was superior to 2D. Questionnaires were done by 12 participants. All of them agree the system can 3D imaging system enabled them to perceive stereoscopic vision, provide fair depth perception and without experienced visual fatigue or discomfort when observing the 3D images.

-How did it improve surgery/ OR time?

Ans: This 3D imaging system improve the whole surgical procedure because it offer more details about tissue around the target. Doctors can gain more confidence from the images and make precise decision within our experience.