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3D exoscopic surgery of lateral skull base

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Abstract

Purpose The aim of the study is to assess whether the 3D exoscopic surgery technique could be used in lateral skull base surgery and if it could ultimately replace the microscope in the future.

Methods This is a retrospective study in which were included 24 patients affected by lateral skull base pathologies, who underwent surgery using the 3D exoscope or the operative microscope at the Department of Otolaryngology—Head and Neck Surgery at the University Hospital of Verona. The exoscope and microscope groups each included 12 cases. The feasibility of all the surgical steps solely using the 3D exoscope was evaluated. The exoscope group and microscope group were compared taking into account the following factors: time of the surgery, facial and hearing functions outcomes, as well as the intraoperative and postoperative complications.

Results No intraoperative complication occurred during all the procedures. Postoperatively, only one minor complication emerged. The average operative time was 289 in the exoscope group and 313 min in the microscope one. No significant statistical differences were identified between the two groups ($p > 0.05$). The facial and hearing function outcomes were fully comparable.

Conclusion Our experience demonstrated that the exclusive use of the 3D exoscope, as that of the traditional microscope during lateral skull base surgery, is feasible for all open approaches. The use of the 3D exoscopic technique is very promising for future lateral skull base surgeries.

Keywords Lateral skull base · Exoscope · Exoscope 3D · Microscope · Translabyrinthine · Subtotal petrosectomy · Vestibular schwannoma · Petrous apex surgery · Cholesteatoma

Introduction

Lateral skull base surgery often needs an open surgical field and a careful, long and scrupulous bone work, that is traditionally performed using the operative microscope. During these approaches, the identification, magnification, and preservation of the anatomical structures, as well as the facial nerve and the internal carotid artery, are necessary during the elaborated surgical dissection in the lateral skull base.

The new introduction of the exoscopy has allowed the magnification of the surgical field and the anatomical structures during the open approaches through a high-resolution camera with an increasing image definition.

The introduction of the 3D exoscope in the surgical process has enabled the surgeon and the assistants to appreciate the complex anatomy of the lateral skull base with precise details.

Due to the technical aspects of the exoscope, it is easy to consider its increasing use as a tool in skull base surgeries or for it even to become a substitute for the traditional microscope to access the lateral skull base.

The use of the exoscopic technique includes the use of a camera and a monitor instead of the microscope. The exoscope has the same features of an endoscopic surgical approach (since the surgeon works looking at the monitor positioned in front of him/her) and of a microscopic surgical technique, because the surgeon has the same bimanual surgical work.

Working with the exoscope as an operative tool may be a difficult surgical device without the adequate microscopic and endoscopic surgical training or background. Moreover, the application of the 3D exoscope may be difficult for the

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surgeon to adapt to in the initial stages, especially in the case of long surgeries.

The present study analyzes the first experience of several skull base surgeries exclusively using the 3D exoscope or combined with the microscope, comparing this case series to the exclusive microscopic technique. The aim of the study is to assess whether the 3D exoscopic surgery technique could be used in this type of surgery and if it could ultimately replace the microscope in the future.

Materials and methods

This is a retrospective study in which we included all the lateral skull base surgical procedures exclusively using the 3D exoscope or combined with the microscope or endoscope, performed by a single senior surgeon (D.M.) at the Department of Otolaryngology—Head and Neck Surgery at the University Hospital of Verona.

All the procedures, in which the 3D exoscope was not used as an operative tool, but only used for teaching or recording surgery, were excluded from the study.

The VITOM 3D exoscope (Karl Storz GmbH, Tuttlingen, Germany) was used as an operative tool in all the procedures. The system consists of a holding arm for VITOM 3D placed in front of the surgical field (at distance 20–50 cm). This is a full HD 3D, 16: 9 modular video system, stereoscopic optics with high-resolution image sensors (4 K) and 8–30 × magnification. The image is shown on a 32-inch 3D monitor using the appropriate passive glasses.

Operating room setup

The 3D 4 K screen was placed in front of the surgeon allowing a direct view during the surgery. The surgeon and the assistants wore 3D glasses or clip-on glasses for those wearing corrective glasses. There is a control unit (IMAGE PILOT), to either regulate the focus, enlarge or shift the field of view. The latter is located next to the surgeon and kept in place by another holding arm. An assistant or the surgeon usually handles the control unit. If the assistant handles the control unit, the surgeon can work focusing only on the surgical procedure.

The surgical scrub nurse is on the opposite side of the operating table to the surgeon in front of a second 2D screen, while the anesthesiologist is at the foot of the operating bed (Fig. 1).

Fig. 1 Operating room setup. The camera is attached to its holding arm and it is positioned on the surgeon's right side. The assistant stands on the right-hand side of the surgeon modifying both the magnification and focus by using the control unit. The 3D monitor is in front of the surgeon and the assistant. The scrub nurse in on the opposite side of the surgeon following the surgery on a 2D video

Surgical step evaluation

The surgical feasibility was evaluated in all the procedures following the next steps:

- Soft-tissue work: dissection of the skin and subcutaneous tissues and creation of muscle-periosteal flap and neck dissection.
- Bone work: exposure of the external auditory canal (enlarged canalplasty during the enlarged transcanal tranpromontorial approach); exposure of the middle ear anatomical structures; drilling of the mastoid (mastoidectomy and subtotal petrosectomy) exposure of the inner ear and internal auditory canal (IAC) (translabyrinthine, transotic, and infratemporal fossa approaches) and exposure of cerebellopontine angle (CPA).
- Pathology dissection.

The feasibility of all the surgical steps using the 3D exoscope (as described above) was evaluated through this method:

a. The surgical step was feasible and the 3D exoscope replaced the microscope entirely.
b. The surgical step has required the use of microscope in some surgical actions.
c. The surgical steps were not feasible using the 3D exoscope and it was necessary to switch to the microscope.

This study group was also compared to a control group, which was composed of the same number of microscopic surgical procedures performed by the same senior surgeon (D.M.). The choice of the control group (microscopic procedures) was carried out by a third author (S.D.G.), which included patients with the same type of surgical approach, pathologies, location and extension to the lateral skull base of the 3D exoscopic group.

Both groups were compared taking into account the following factors: time of the surgery, facial and hearing functions outcomes, as well as the intraoperative and postoperative complications.

The facial function was evaluated using the House and Brackmann scale [1], while the hearing function was assessed using the pure tone average (PTA) of both air and bone conduction thresholds at 500, 1 K, 2 K, 4 K (Hz) frequencies on the treated side.

Results

According to the inclusion criteria, 24 surgical procedures were included in this study. In 12 of these, the 3D exoscope was the exclusive operation tool used or in some occasions combined with the microscope. The endoscope was occasionally used at the end of some operations to eliminate any possible residual pathologies (exoscope group), while the other 12 procedures were exclusively microscopic procedures (microscope group) (Table 1).

Surgery

The 3D exoscopic procedures performed were (Table 2):

- 1 infratemporal approach for jugulotympanic paraganglioma type C.
- 1 enlarged transcanal transpromontorial approach for vestibular schwannoma limited to the IAC.
- 1 translabyrinthine approach for vestibular schwannoma involving the CPA.
- 1 subtotal petrosectomy with total parotidectomy and selective neck dissection (II-III lymph node levels) for external auditory canal squamous cell carcinoma.
- 1 extended middle cranial fossa approach with anterior transpetrosal approach for petrous apex chondrosarcoma.
- 3 subtotal petrosectomy for cholesteatoma; in one out of these three, a subtotal petrosectomy was performed with simultaneous cochlear implantation.
- 1 retrolabyrithine approach for petrous bone cholesteatoma.
- 1 transcochlear approach and facial nerve end-to-end anastomosis for petrous bone cholesteatoma.
- 1 facial nerve decompression via subtotal petrosectomy and cochlear implantation for previous herpes zoster oticus.
- 1 selective vestibular neurectomy through retrolabyrinthine approach for Menière syndrome.

The control case series (microscope group) include similar pathologies and approaches, performed using the operative microscope (Table 3).

In the exoscope group, 9 out of 12 surgical procedures were performed with the exclusive use of 3D exoscope. In two procedures (patient N.1^E, N.2^E), the microscope was used only for the pathology dissection: in one of these cases the microscope was used after the IAC exposure to completely remove the vestibular schwannoma from IAC (patient N.2^E) and in the other case (patient N.1^E) was used to begin the dissection of the jugulotympanic

Table 1 Exoscope and microscope groups

Exoscope group			Microscope group		
Patient no	Age and gender	Pathology	Patient no	Age and gender	Pathology
1^E	79 F	JTP Type C	1^M	41 F	JTP Type C
2^E	53 F	VS	2^M	62 M	VS
3^E	53 F	VS	3^M	58 F	VS
4^E	51 M	EAC SCC	4^M	71 F	EAC SCC
5^E	59 M	CS	5^M	58 M	CS
6^E	34 F	C	6^M	48 F	C
7^E	70 F	C	7^M	67 F	C
8^E	47 F	C	8^M	11 M	C
9^E	77 F	PBC	9^M	51 F	PBC
10^E	72 M	PBC	10^M	71 M	PBC
11^E	64 M	HZO	11^M	25 M	PTFP
12^E	42 M	MS	12^M	54 M	MS

Demographic information

C cholesteatoma, *CS* chondrosarcoma, *EAC SCC* external auditory canal squamous cell carcinoma, *HZO* herpes zoster oticus, *JTP* jugulotympanic paraganglioma, *MS* Menière syndrome, *PBC* petrous bone cholesteatoma, *PTFP* post traumatic facial nerve paresis and hearing loss, *VS* vestibular schwannoma

Table 2 Surgical procedures, outcomes and complications in Exoscope group

Exoscope group								
No	Procedure	Facial function		Hearing (PTA)(dB)		Complications		
		Pre-op	Post-op	Pre-op	Post-op	Intra-op	Post-op	
1E	Infratemporal approach type A	V HB	VI HB	AC = 60 BC = 56	BC = 56.25	None	Right VC paralysis	
2E	Enlarged transcanal transpromontorial approach	I HB	I HB	Anacusis	Anacusis	None	None	
3E	Translabyrinthine approach	I HB	V HB	AC = 49 BC = 44	Anacusis	None	None	
4E	Subtotal petrosectomy with total parotidectomy and selective neck dissection, levels II–III	I HB	II HB	AC = 45 BC = 12.5	BC = 12.5	None	None	
5E	Extended MCF and anterior transpetrosal approach	I HB	I HB	AC = 20 BC = 15	AC = 20 BC = 15	None	None	
6E	Subtotal petrosectomy	I HB	I HB	AC = 33.75 BC = 13.75	BC = 28	None	None	
7E	Subtotal petrosectomy	I HB	I HB	AC = 94 BC = 65	BC = 65	None	None	
8E	Subtotal petrosectomy and simultaneous CI	I HB	I HB	Anacusis	FFT = 48.75	None	None	
9E	Retrolabyrithine approach	I HB	I HB	AC = 71.25 BC = 55	AC = 82.5 BC = 57.5	None	None	
10E	Transcochlear approach and facial nerve end-to-end anastomosis	VI HB	VI HB	AC = 61.5 BC = 30	Anacusis	None	None	
11E	Facial nerve decompression via subtotal petrosectomy and CI	V HB	V HB	Anacusis	FFT = 26.25	None	None	
12E	Selective vestibular neurectomy through retrolabyrinthine approach	I HB	I HB	AC = 31.25 BC = 26.25	AC = 61 BC = 52	None	None	

AC air conduction, *BC* bone conduction, *CI* cochlear implant, *FFT* free field threshold using cochlear implant, *HB* House-Brackmann grade, *MCF* middle cranial fossa, *PTA* pure tone average, *VC* vocal cord

paraganglioma type C (completed with the exoscope). In the case of the petrous apex chondrosarcoma (patient N.5E), we performed a preoperative internal carotid artery occlusion on the same side of the disease, because the internal carotid artery was encased by the tumour. This preoperative procedure allowed for the removal of the intrapetrous internal carotid artery together with the petrous apex. In this case, an endoscopic check of the final surgical cavity was necessary at the end of the exoscopic excision of the tumour. During the endoscopic examination, a residual disease was found and removed under the horizontal segment of the intrapetrous internal carotid artery. We also performed an endoscopic check of the final surgical cavity in patient 5M, at the end of the microscopic dissection of the tumour, and we found and removed a residual disease located in the same hidden area (under the horizontal segment of the internal carotid artery).

The average operative time in the exoscope group was 289 min and 313 min in the microscope group. No statistically significant difference was identified between both groups ($p = 0.61$) (Table 4).

Facial and hearing function

Regarding the facial nerve function, in the exoscope group, three patients had a worsening of the facial nerve function after the operation. In the microscope group, there was a postoperative deterioration of the facial nerve function in two patients (Tables 2, 3).

With reference to the audiology situation, the hearing was preserved in all the procedures, which allowed a postoperative hearing preservation (retrolabyrinthine and middle cranial fossa approach) in both the exoscope and microscope groups (Tables 2, 3).

Complications

During all the procedures no intraoperative complication occurred. In terms of postoperative, no major complications emerged, with only a minor issue in each group. In the exoscope group, a vocal cord paralysis occurred (Table 2). In the microscope group, one patient had a dehiscent of the external auditory canal cul-de-sac suture 2 months after surgery, which was repaired in the operating room (Table 3).

Table 3 Surgical procedures, outcomes and complicationss in Microscope group

Microscope group							
No	Procedure	Facial function		Hearing (PTA) (dB)		Complication	
		Pre-op	Post-op	Pre-op	Post-op	Intra-op	Post-op
1[M]	Infratemporal approach Type A	I HB	I HB	AC = 29 BC = 11	BC = 11	None	None
2[M]	Enlarged transcanal transpromontorial approach	I HB	I HB	Anacusis	Anacusis	None	None
3[M]	Translabyrinthine approach	I HB	I HB	AC = 41.25 BC = 36.25	Anacusis	None	None
4[M]	Subtotal petrosectomy with total parotidectomy and selective neck dissection, levels II-III	I HB	V HB	AC = 52 BC = 48	BC = 48	None	None
5[M]	Extended MCF and anterior transpetrosal approach	I HB	I HB	AC = 17.5 BC = 12.5	AC = 20 BC = 15	None	None
6[M]	Subtotal petrosectomy	I HB	I HB	AC = 88 BC = 35	BC = 35	None	None
7[M]	Subtotal petrosectomy	I HB	I HB	Anacusis	Anacusis	None	ESD repaired in OR
8[M]	Subtotal petrosectomy and CI replacemet	I HB	I HB	FFT = 20	FFT = 48.75	None	None
9[M]	Retrolabyrinthine approach	I HB	I HB	AC = 10 BC = 5	AC = 11.25 BC = 6.25	None	None
10[M]	Transchoclear approach	I HB	IV HB	Anacusis	Anacusis	None	None
11[M]	Facial nerve decompression via subtotal petosectomy	V HB	V HB	Anacusis	Anacusis	None	None
12[M]	Selective vestibular neurectomy through retrolabyrinthine approach	I HB	I HB	AC = 35 BC = 28.75	AC = 58 BC = 45	None	None

AC, air conduction, *BC* bone conduction, *CI* cochlear implant, *ESD* external auditory canal cul-de-sac suture dehiscence, *FFT* free field threshold using cochlear implant, *HB* House-Brackmann grade, *MCF* middle cranial fossa, *OR* operating room, *PTA* pure tone average

Table 4 Comparison Exoscope vs Microscope group

Patient no	Work on soft tissue		Bony work		Anatomical exposure		Pathology dissection		Opertive time (min.)	
	E	M	E	M	E	M	E	M	E	M
1	1	2	1	2	1	2	3	2	373	490
2	1	2	1	2	1	2	3	2	273	243
3	1	2	1	2	1	2	1	2	317	262
4	1	2	1	2	1	2	1	2	465	446
5	1	2	1	2	1	2	4	4	362	352
6	1	2	1	2	1	2	1	2	159	175
7	1	2	1	2	1	2	1	2	235	180
8	1	2	1	2	1	2	1	2	195	150
9	1	2	1	2	1	2	1	2	174	321
10	1	2	1	2	1	2	1	2	349	540
11	1	2	1	2	1	2	1	2	310	346
12	1	2	1	2	1	2	1	2	260	250
									A = 289	A = 313

A average, *E* exoscope group, *M* microscope group, *1* exclusive exoscope use, *2* exclusive microscope use, *3* microscope integration, *4* endoscopic-assisted procedure

Discussion

The 3D exoscope has been recently introduced in daily clinical practice.

The current literature includes some articles with reference to the use of the exoscope in neurosurgery, either as an exclusive instrument or combined with the microscope [2–6].

Only very few studies have been carried out in otology and neurotology [7, 8]. In general, in otolaryngology, the exoscope is used as an external camera to perform instructional videos, but it is not currently used in daily practice as an operative surgical instrument.

Smith and collegues described eleven cases of otologic/neurotologic procedures. In their study, the exoscope was used exclusively in seven procedures for the steps requiring postauricular or transmastoid approaches [8].

Garneau and collegues described six patients undergoing lateral skull base surgery with the use of the exoscope in the vestibular schwannoma resection (four cases) or the repair of a temporal lobe encephalocele (two cases). Both the transmastoid approach (mastoidectomy) and transtemporal craniotomy along with the skull base repair were performed with the operating exoscope [7].

In the literature, there are no studies in which a group of exoscopic procedures is compared to a control group of microscopic procedures performed both by a single surgeon. This comparison is important to understand the real differences between exoscopic and microscopic surgery.

The microscope and endoscope are excellent tools in otoneurosurgery, but as every tool, they have some advantages and disadvantages.

Some of the limitations of the operative microscope is its large frame and fixed cumbersome design. It also constrains the primary surgeon and assistants to fixed positions around the operative field with limited visual angles. Moreover, the operative microscope screens, allowing non-surgeons and trainees to follow the surgical intervention, and the images projected are generally two-dimensional (only the surgeon has a stereoscopic vision).

On the other hand, the endoscopic surgery allows for an ergonomic position of the surgeon with a horizontal gaze and an angled vision ‘behind the corner’. The endoscope has a small depth of field and the surgeon and all the staff look at the same two-dimensional monitor. Therefore, in this surgery, one of the disadvantages is the impossibility to have the three-dimensionality, in any case, easily overcome by moving the endoscope into the surgical field.

Recently, a further operative tool has been introduced in surgery: the exoscope. Initially, despite not providing a three-dimensional vision even for the surgeon, only the 2D exoscope was used during surgical procedures. In this case, the 2D vision was not overcome by the movement of the instrument in the surgical field, as in the endoscopic surgery. For this reason, the 2D exoscope was especially used for video recording and teaching reasons. Subsequently to the 2D exoscope, the 3D exoscope has been introduced, which provides the surgeon and the assistants, who have the same view as the latter, with three-dimensional images.

Furthermore, there are some additional differences between the exoscope and microscope. In terms of surgical training for the fellows and residents, the use of the 3D exoscope allows them to follow the surgery in the same way as the first surgeon because they view the surgery by looking at the same three-dimensional screen.

The 3D exoscope allows to understand the three-dimensionality of the complex anatomy of the lateral skull base that otherwise would not be appreciated with other 2D exoscopic systems.

Furthermore, we found that the anatomical structures are more realistic and that the recognition and differentiation of the different structures are better with the 3D exoscopic view.

The exoscope has a small frame with a large depth of field, which reduces the need to refocus during periods of dissection [4]. Shifting from microscopic to macroscopic vision can be rapidly and easily done without moving the scope or completely losing microscopic vision [2].

Its wide operative fields and focal distances long enough to provide unobstructed operative corridors, enable the surgeon to have a considerable amount of mobility to work with the necessary tools. This differs considerably from the endoscope [2], where the surgical field is limited by the camera.

Regarding ergonomic advantages, the exoscope allows for a position with a horizontal gaze throughout the surgical operation. On the other hand, the horizontal gaze may be also maintained throughout surgery using an operative microscope, however the use of fixed optics limits head and neck movement causing discomfort to the surgeon [3]. It is well known that during long procedures, surgeon fatigue related to suboptimal ergonomic conditions can negatively influence operative performance [9, 10].

The exoscope also presents some disadvantages.

In our opinion, a good regulation of light is necessary because when there is a high intensity light, it can cause homogenization of the colors and anatomical structures in the surgical field.

Some authors noticed that the exoscope’s surgical limitations include low lighting in small surgical corridors and pixellation at high magnification in lateral skull base and mastoid surgery [8].

In fact, due to the low lighting, those surgeries or steps requiring small spaces and narrow surgical corridors are difficult to perform with the exoscopic view (for example the posterior tympanotomy) [8].

It was also described by some authors that during microvascular anastomosis, in the 3D exoscopic visualization, at the highest magnification, the depth perception is inferior to that provided by a standard operative microscope, which impedes the procedure [6].

According to Beez et al. [5] the preparation and image definition were rated equal for the microscope and exoscope. The microscope's field of view, illumination and user-friendliness (use of zoom, focus and change of the visual field position) were considered superior, while the advantages of the exoscope were seen in the ergonomics and in the accessibility of the surgical field.

Furthermore, minimal dizziness, little nausea, fatigue or vertigo are described using 3D vision during surgery [11, 12].

3D images are known for inducing more ocular and systemic fatigue and discomfort, which can be referred to as '3D asthenopia' [13]. Kong et al. compared novices to experienced surgeons by analyzing the execution of tasks using both 2D and 3D. They found that the inexperienced suffered from mild dizziness with the 3D system in the first 2 days, which is overcome as time goes by [12].

Since the exoscope is a quite new operative tool, in our opinion, it requires adequate training in order to learn the simultaneous coordination of the hand together with the images appearing on the monitor. This technique needs previous training on endoscopic and microscopic surgery because the skills deriving from both techniques are necessary to perform surgery using the exoscope.

Based on our experience, we gradually arrived to the conclusion that the exoscope can be used as a surgical instrument in mastoid and traditional lateral skull base surgeries. The 3D exoscope can be used as an operative tool to perform surgical procedures, replacing the microscope. It is excellent for teaching and learning since the surgeon's view is the same as the trainee's and assistants', as in the endoscopic surgery, with the advantage of a three-dimensional and high definition view.

In our study, we analyzed and compared the 3D exoscopic to the microscopic techniques in lateral skull base surgery and we found no differences in terms of timing of surgery, facial and hearing outcomes, as well as intra- and post-operative complications.

We even analysed the different surgical steps using the 3D exoscope on soft tissue, bone work, and tumour dissection. Regarding surgical steps on soft tissue, they are usually performed using the loupe or without the use of optical instruments, so the view of the anatomical structures is much better using the exoscope during soft tissue work. The use of the 3D exoscope during these steps requires some training because the surgeon is used to working without the optical instruments, so initially these surgical steps need more time.

We analysed and even compared the surgical steps on bone work both with the microscope and the 3D exoscope, but we did not find significant differences. One of the differences is that the stereoscopic optic can be rotated by $\pm 90°$, so it is possible to visualize anatomical areas that are not perceptible with the microscope, because it does not have this function. We found that the 3D exoscope could completely replace the microscope during bone work.

Regarding the 3D exoscopic pathology dissection, in our case series, there were 2/12 cases in which we performed a microscopic tumor dissection. These two cases were the first cases in which we worked with the 3D exoscope. Therefore, at the beginning the operator was more comfortable using the microscope for the more delicate dissections (pathology dissection of vestibular schwannoma in an enlarged transcanal approach and jugulotympanic paraganglioma type C in an infratermporal fossa type A). With time we gradually improved and became more experienced in the use of the 3D exoscope eventually solely using this tool even during this step.

Regarding the surgical approach to the petrous apex for chondrosarcoma, in both the exoscope and microscope groups, we found performing an endoscopic-assisted procedure to be necessary. In this complex area both the tools have the same limitation of difficult visualization in the hidden areas (medial to the fundus of IAC, under the horizontal segment of the internal carotid artery). For this reason, we believe that it is necessary to perform an endoscopic check of the surgical field with an angled endoscope in the petrous apex at the end of the exoscopic or microscopic procedures to detect potential residual of pathology, which is located in areas otherwise not visualized.

Based on our experience, the surgical steps on soft tissue, bone and pathology dissection were easily feasible exclusively using the 3D exoscope, since the lateral skull base procedures require a large surgical field without narrow corridors. Obviously, 3D exoscopic surgery requires adequate training.

The exoscope is best suited for approaches with a large surgical field, since it allows an optimal view, rather than for small surgical fields. In fact, in the case of large surgical field approaches the use of the 3D exoscope can replace the microscope. Therefore, the surgeon has to operate looking at the high definition monitor located in front of him/her (this concept is already known in endoscopic surgery).

The 3D exoscope allows the surgery to be performed working with two hands over the surgical field, as in traditional microscopic surgery, simultaneously looking at the monitor as in the endoscopic surgery. This 3D exoscopic technique required the combination of both endoscopic with microscopic backgrounds creating the concept of the exoscopic surgery. Our experience demonstrated that the exclusive use of the 3D exoscope, instead of the traditional microscope during lateral skull base surgery, is feasible for all the procedures with a large surgical field. Therefore, the 3D exoscopic technique is very promising for future procedures in the lateral skull base surgery.

Author contributions All of the authors have read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The present authors have no financial relationship to disclose.

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