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ORIGINAL ARTICLE

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Combined simultaneous endoscopic endonasal and transcranial surgery using high-definition three-dimensional exoscope for malignant tumors of the anterior skull base

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Abstract

Background: Advanced surgical interventions are required to treat malignancies in the anterior skull base (ASB). This study investigates the utility of endoscopic endonasal and transcranial surgery (EETS) using a high-definition three-dimensional exoscope as an alternative to traditional microscopy.

Methods: Six patients with carcinomas of varying histopathologies underwent surgery employing the EETS maneuver, which synchronized three distinct surgical modalities: harvesting of the anterolateral thigh flap, initiation of the transnasal technique, and initiation of the transcranial procedure.

Results: The innovative strategy enabled successful tumor resection and skull base reconstruction without postoperative local neoplastic recurrence, cerebrospinal fluid leakage, or neurological deficits.

Conclusion: The integration of the exoscope and EETS is a novel therapeutic approach for ASB malignancies. This strategy demonstrates the potential of the exoscope in augmenting surgical visualization, enhancing ergonomics, and achieving seamless alignment of multiple surgical interventions. This technique represents a progressive shift in the management of these complex oncological challenges.

Seiichiro Makihara and Yoshihiro Otani contributed equally to this study.

KEYWORDS
anterior skull base malignant tumors, anterolateral thigh flap, endoscopic endonasal and transcranial surgery, ORBEYE, skull base reconstruction

1 | INTRODUCTION

Tumors located in the anterior skull base (ASB) and paranasal sinuses are rare, accounting for 1% of all cancerous growths and 3%–5% of neoplasms within the head and neck region.[1] There is a paucity of empirically supported information regarding treatment strategies due to the rarity, asymptomatic local progression, and substantial variability of these tumors. The confluence of these characteristics complicates therapeutic approaches for affected individuals.[2] The anterior craniofacial resection technique, which is a surgical intervention targeting tumors located in the ASB, was first introduced by Ketcham et al. in the 1960s.[3] Subsequent adaptations of this technique have been recognized as conventional treatment strategies for malignant tumors located in the ASB and paranasal sinuses.[2] The use of nasal endoscopy for ASB procedures was introduced in the early 21st century, and it has been utilized in more complex scenarios involving the spread of malignancies of the nasal sinus into the ASB.[4,5] Endoscopic endonasal skull base surgery for the removal of malignant tumors of the ASB is a minimally invasive approach that enables quicker recovery, better cosmetic outcomes, and treatment efficacy comparable with those of the more invasive external incisional methods used in craniofacial surgery.[6–9]

The endoscopic endonasal approach is suitable for the resection of ASB malignancies that do not involve critical areas, such as the anterior wall of the frontal sinus, nasal bone, skin, orbital contents, or intracranial regions (including dural involvement over the lateral aspect of the orbit and the brain parenchyma).[10] The suitability of utilizing endoscopic transnasal resection for malignancies extending to these areas has been debated in the scientific community, and it must be acknowledged that external surgical procedures, such as bifrontal craniotomy and the transfacial approach, become imperative when ASB malignancies surpass the predefined anatomical limits.

The use of simultaneous endoscopic endonasal and transcranial surgeries (EETS) was first described for the resection of pituitary lesions.[11] Several benefits of this approach have been reported. First, comprehensive tumor excision can be achieved from multiple perspectives during a single surgical procedure. Since two surgeons can concurrently access the tumor from the cranial and nasal aspects, the excision can be effectively completed within a restricted timeframe. Second, surgeons can receive guidance from their counterparts on the opposite side regarding the adjacent anatomical structures. Lastly, one surgeon can facilitate tumor excision by exerting pressure to displace the tumor from the opposing side.

Several studies have described the use of combined EETS for the removal of ASB malignancies.[5,12,13] The transcranial route predominantly involves the use of a microscope. However, performing the transcranial procedure with the microscope and the endonasal method with an endoscope concurrently is inherently challenging for otolaryngologists and neurosurgeons given the substantial size of the surgical microscope placed directly over the operative site. Moreover, the successive performance of transcranial and nasal methods extends the overall surgical duration.[14]

This study describes an effective integration of EETS using a high-definition three-dimensional exoscope (HD-3D Exoscope), which can serve as an alternative to traditional microscopy for the treatment of malignant tumors located in the ASB.

2 | MATERIALS AND METHODS

2.1 | Patients

Six consecutive patients diagnosed with malignant tumors of the ASB at the Okayama University Hospital were retrospectively analyzed. These patients underwent EETS aided by an HD-3D exoscope between June 2022 and June 2023. Computed tomography (CT) and magnetic resonance imaging (MRI) of the paranasal sinus were performed to determine the extent of tumor invasion and examine the anatomy of the skull base. Preoperative three-dimensional (3D) models were utilized as described previously.[15] The standard protocol for preoperative assessment of metastasis in anterior skull base (ASB) malignancies at our institution includes positron emission tomography-computed tomography (PET-CT) imaging. This comprehensive approach is employed to evaluate cervical lymph node metastasis and potential distant metastasis. However, whole-body metastatic imaging using contrast-enhanced CT scanning can be considered in select cases where specific patient-related factors, such as financial considerations or other constraints, necessitate an alternative approach. Data regarding patient demographics; surgical metrics, including the type of surgical approach, skull base reconstruction technique, blood loss, duration of surgery, and surgical margins; and postoperative prognosis were collected. The postoperative status of the margin was classified as microscopically positive or clear. Margins of <1 mm were considered positive. The histopathological records were retrospectively analyzed. The primary objective of each surgical intervention was complete tumor removal. This study was approved by the Ethics Committee of Okayama University Hospital (approval number: 2010-026), and an opt-out approach was used to obtain consent from the participants.

2.2 | Therapeutic strategies for the resection of ASB malignancies

Patients with tumors located in the ASB that were amenable to en bloc resection were eligible to undergo combined simultaneous EETS. Another critical factor influencing the choice of surgery was the anatomical boundaries of the tumor. Tumors that invaded the anterior wall of the frontal sinus, nasal bone, skin, and orbital components, as well as tumors that exhibited encroachments (such as dural invasion over the lateral aspect of the orbit or involvement of brain tissue), surpass the limits for an isolated endonasal approach.[10] Combined simultaneous EETS with or without the addition of external surgical procedures, such as a transfacial approach, was performed to resect these extensive malignancies adequately. Similarly, tumors that densely occupied the nasal cavity, which impeded their removal through the endoscopic endonasal method, were considered eligible. However, combined simultaneous EETS was contraindicated in patients with distant metastases and tumor invasion into the sphenoid sinus, cavernous sinus, clivus, internal carotid artery, and sigmoid sinus.[16] Postoperative radiation and adjuvant chemotherapy were recommended based on the histological characteristics of the tumor and status of the margins.

2.3 | Surgical techniques

The patients underwent combined simultaneous EETS with an additional external incision made in the facial area, as needed. The transcranial approach was performed using an exoscope, the Olympus ORBEYE (Olympus, Tokyo, Japan), whereas the endoscopic endonasal approach was performed using a 4K endoscopic camera system. Figure 1A illustrates the positioning of the surgical team and equipment in the operating theater. The endoscopic endonasal technique was performed by otolaryngologists in conjunction with neurosurgeons, and the procedure was initiated by making coronal skin incisions (Figure 1B,C). Subsequently, a two-layer flap was reflected from the anterior region of the scalp while preserving the vascularized pericranial flap for skull base reconstruction. The anterolateral thigh (ALT) flap was reflected as an adipofascial flap if a subcutaneous extension of the tumor into the forehead region was observed or if the patient had previously undergone craniotomy, which made the pericranial flap unusable. Bifrontal craniotomy and cranialization of the frontal sinus were performed. As depicted in Figure 2A, the position of the monitor of the exoscope was changed from directly above the patient's feet to the bottom left, which facilitated three concurrent surgical actions: reflection of the ALT flap by the plastic surgeons, initiation of the endoscopic transnasal approach by the otolaryngologists, and initiation of the transcranial approach by the neurosurgeons. The progress of each method was displayed concurrently on the monitors, which included two-dimensional submonitors, for collaborative viewing by all surgeons. Figure 2B,C shows an intraoperative photograph where three surgeons simultaneously perform transcranial and transnasal surgery for anterior skull base malignancies without mutual hindrance, highlighting the integrated surgical teamwork within the operating theater. Tumor resection was performed using approaches that offered optimum maneuverability and an unobstructed visual field. Surgical incisions were made on the skull base using a navigation system according to a predetermined plan. In addition, the light emitted from the tip of the transnasal endoscope was used to illuminate the anticipated resection line on the skull base, which facilitated tumor resection via the transcranial approach. Neurosurgeons performed primary dural sealing using the temporal fascia or fascia lata to guard against cerebrospinal fluid (CSF) contamination stemming from the paranasal sinuses after tumor extraction. A pericranial flap was used to seal the anterior cranial base from the intracranial aspect. An ALT flap was used as an adipofascial flap for the same purpose in cases where the pericranial flap could not be used. A nasoseptal or superior lateral anterior pedicle flap was secured with fibrin glue. Polyglycolic acid sheets (Neoveil. Gunze Co., Ltd., Tokyo, Japan) were used to shield the anterior cranial base from the nasal interior in cases where the pedicled mucosal flap was absent due to tumor resection.

3 | RESULTS

The study cohort comprised four male and two female patients (Table 1). The average age of the patients at the

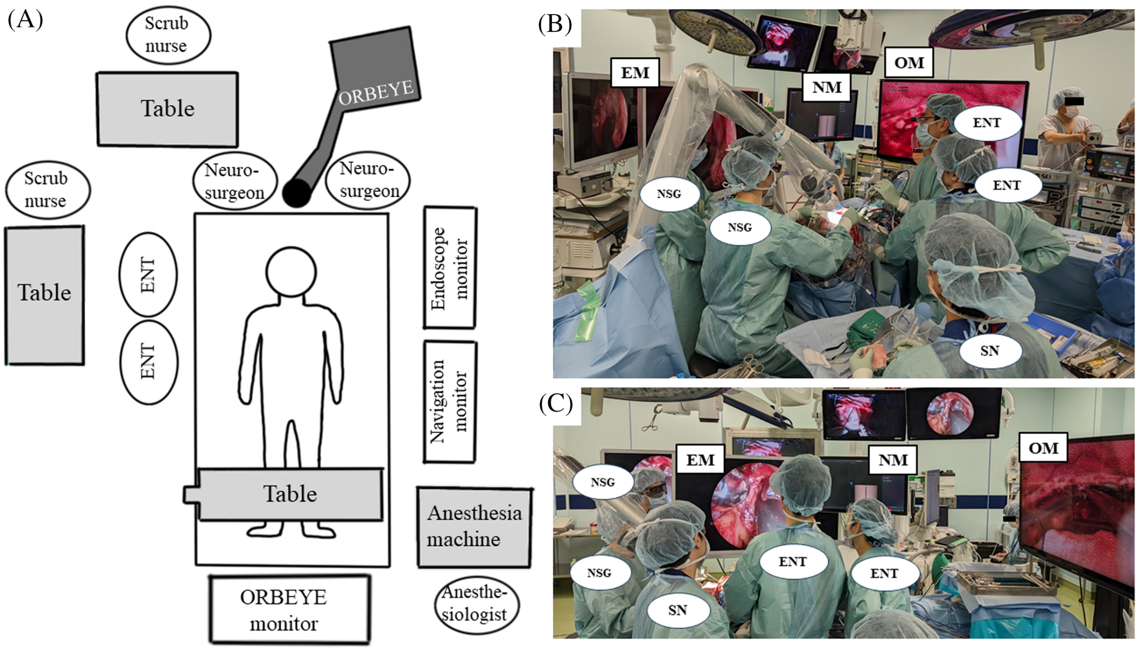

FIGURE 1 (A) Conceptual representation detailing the positioning of the surgical team and equipment within the operating theater during the concurrent performance of two distinct surgical procedures, that is, the endoscopic transnasal approach by the otolaryngologists and the transcranial approach by the neurosurgeons. (B, C) Intraoperative photographs showing two surgeons simultaneously performing transcranial and transnasal surgeries for anterior skull base malignancies. The surgeons performed the surgery without mutual hindrance. ENT, otolaryngologist; EM, endoscope monitor; NM, navigation monitor; NSG, neurosurgeon; OM, ORBEYE monitor; SN, scrub nurse. [Color figure can be viewed at wileyonlinelibrary.com]

time of surgical intervention, represented as mean ± standard deviation (SD), was 55.2 ± 17.4 years. Among the six patients, two patients (33.3%) had undergone treatment prior to surgery. Histopathological examination revealed squamous cell carcinoma in two patients, metastatic renal cell carcinoma manifesting as clear cell carcinoma in one patient, neuroendocrine carcinoma in one patient, non-intestinal adenocarcinoma in one patient, and adenoid cystic carcinoma in one patient. The anatomical origin of the tumor was the ethmoid sinus in three patients, the nasal cavity in two patients, and the frontal bone in one patient. The T stage of the primary tumor was T3 in one patient, T4a in two patients, T4b in two patients, and metastatic renal cell carcinoma in one patient. Preoperative evaluation for cervical lymph node and distant metastasis was conducted using PET-CT imaging in the majority of patients. Nevertheless, in two cases (Patients 1 and 4), contrast-enhanced CT scanning from the skull base to the pelvis was employed as an alternative assessment method due to patient-related factors, primarily including considerations related to the cost of the examination. Despite these deviations from our standard protocol, the evaluations were thorough and cervical lymph node metastasis was not observed in any of the patients during the initial evaluation. Furthermore, distant metastasis was observed in only one patient with metastatic renal cell carcinoma. All the patients underwent bifrontal craniotomy and the transnasal approach. A lateral rhinotomy incision was made in one patient, and a modified midfacial degloving procedure was performed via the transfacial approach in one patient. Skull base reconstruction was performed via the composite approach using primary dural closure combined with the fascia, pericranial flap, and pedicled nasal mucosal flaps in three patients. Pedicled nasal mucosal flaps could not be raised in one patient. Another method that combined primary dural closure with the fascia, ALT flap, and pedicled nasal mucosal flaps was used in one patient. The mean (±SD) duration of surgery and tumor excision was 757 ± 160.3 min and 504.7 ± 118.1 min, respectively. The mean volume of intraoperative blood loss was 440.8 ± 216.3 mL. One patient presented with a pulmonary embolism and subsequently underwent anticoagulant management, showing favorable recovery. Postoperative CSF leakage, neurological deficits, surgical site infections, postsurgical sepsis, or perioperative fatalities were not observed in any of the patients. Histological evaluations established clear margins in all but one case. Two patients received postsurgical radiation, and two patients received postoperative chemoradiation. The radiation dose was reduced in one patient postoperatively. The mean (±SD) duration of stay

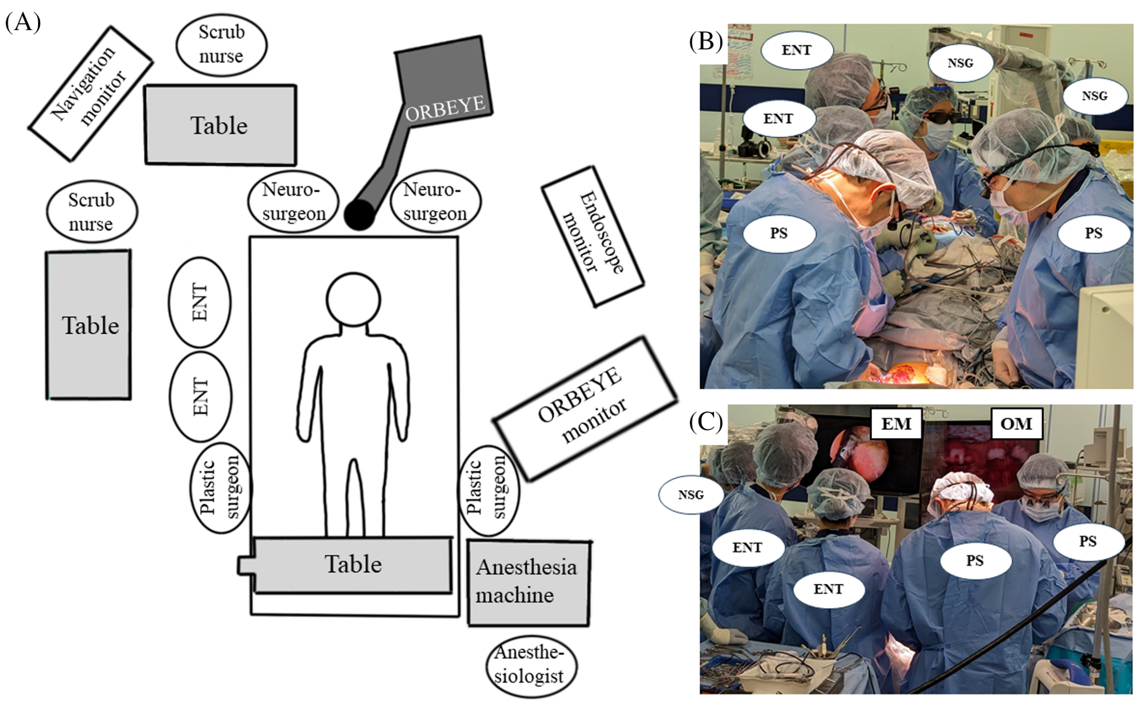

FIGURE 2 (A) Conceptual representation detailing the positioning of the surgical team, including plastic surgeons, and equipment within the operating theater during the concurrent performance of three distinct surgical procedures: reflection of the anterolateral thigh flap by the plastic surgeons, the endoscopic transnasal approach by the otolaryngologists, and the transcranial approach by the neurosurgeons. (B, C) Intraoperative photograph showing three surgeons simultaneously performing transcranial and transnasal surgery for anterior skull base malignancies. The surgeons performed the surgery without mutual hindrance. ENT, otolaryngologist; EM, endoscope monitor; NSG, neurosurgeon; OM, ORBEYE monitor; PS, plastic surgeon. [Color figure can be viewed at wileyonlinelibrary.com]

in the intensive care unit and otolaryngology admissions was 4.5 ± 1.0 days and 23.0 ± 8.4 days, respectively. The mean (±SD) duration of follow-up was 6.5 ± 4.5 months. Local neoplastic recurrence was not observed in any of the cases. One patient (Patient 1) presented with metastatic renal cell carcinoma in the femoral region and underwent radiotherapeutic intervention.

A representative case (Patient 1) wherein combined surgery was performed by three specialists is presented below. A 68-year-old man with clear cell carcinoma (metastatic renal cell cancer) and a neoplasm primarily rooted in the frontal bone underwent combined simultaneous EETS (Figure 3A,B). Comprehensive radiographic imaging confirmed the absence of neoplastic growth except for the frontal bone lesion. The surgical procedure was commenced via an endoscopic endonasal approach by otolaryngologists, and coronal skin incisions were made by neurosurgeons concurrently (Video S1, Supporting Information). The plastic surgeons harvested the ALT flap concurrently given the subcutaneous extension of the tumor into the forehead region (Figure 2A–C). An otolaryngologist excised the inferior portion of the tumor via the coronal skin incision on the nasal bone to ensure adequate margins (Figure 3C). Incisions at the ASB were primarily made via a transcranial approach using an exoscope with the aid of a transnasal endoscope (Figure 3D,E). Skull base reconstruction was performed via primary dural closure with the fascia lata, an ALT flap, and a nasoseptal flap. Clear margins were confirmed via histopathological examination. The patient was followed up for 13 months without evidence of local neoplastic recurrence (Figure 3F). Femoral metastasis from renal cell carcinoma was identified after 12 months, which required radiotherapy.

4 | DISCUSSION

This study contributes to the growing body of research on the treatment of malignant ASB tumors using combined simultaneous EETS and HD-3D exoscope. In addition, the innovative relocation of the monitor of the exoscope from directly above the patient's feet to the lower left side enabled three distinct surgical procedures to be performed concurrently: harvesting of the ALT flap by the plastic surgeons, initiation of the endoscopic transnasal approach by the otolaryngologists, and initiation of the transcranial approach by the neurosurgeons.

TABLE 1 Clinical data of the six patients who underwent combined simultaneous endoscopic endonasal and transcranial surgery.

Patient	Age	Sex	Tumor site	T stage (ES)	Histology	Surgical approach	Skull base reconstruction	OP time (min)		Blood loss (mL)	Surgical margin	Postoperative complication	Adjuvant therapy	Local recurrence	FU (months)
								Total	TR						
1	68	M	Frontal bone		CCC	BFC + TNA	PDC w/FL, ALT, NS	756	433	170	Negative	None	None	None	13
2	63	F	Ethmoid sinus	T4b (brain)	NC	BFC + TNA	PDC w/TF, PC, NS	720	528	690	Positive	None	CRT	None	11
3	65	M	Ethmoid sinus	T4a (frontal sinus)	SCC	BFC + TNA	PDC w/FL, ALT	1029	679	480	Negative	PE	PR	None	6
4	43	M	Nasal cavity	T4a (MEA)	SCC	BFC + TNA + TFA (LR)	PDC w/TF, PC	809	583	270	Negative	None	CRT	None	3.5
5	25	M	Ethmoid sinus	T4b (dura)	NID	BFC + TNA	PDC w/TF, PC, NS, SLAP	683	460	685	Negative	None	RT	None	3.5
6	67	F	Nasal cavity	T3 (CP)	ACC	BFC + TNA + TFA (MMD)	PDC w/TF, PC, SLAP	545	345	350	Negative	None	RT	None	2

Abbreviations: ACC, adenoid cystic carcinoma; ALT, anterolateral thigh flap; BFC, bifrontal craniotomy; CCC, clear cell carcinoma (metastatic renal cell cancer); CP, cribriform plate; CRT, chemoradiation; ES, extended site; FL, fascia lata; FU, follow-up; LR, lateral rhinotomy; MEA, minimal extension to anterior cranial fossa; MMD, modified midfacial degloving; NC, neuroendocrine carcinoma; NID, non-intestinal type adenocarcinoma; NS, nasoseptal flap; OP, operation; PC, pericranial flap; PDC, primary dural closure; PE, pulmonary embolism; PR, patient refusal; RT, radiation; SCC, squamous cell carcinoma; SLAP, superior lateral anterior pedicle flap; TF, temporal fascia; TFA, transfacial approach; TNA, transnasal approach; TR, tumor removal.

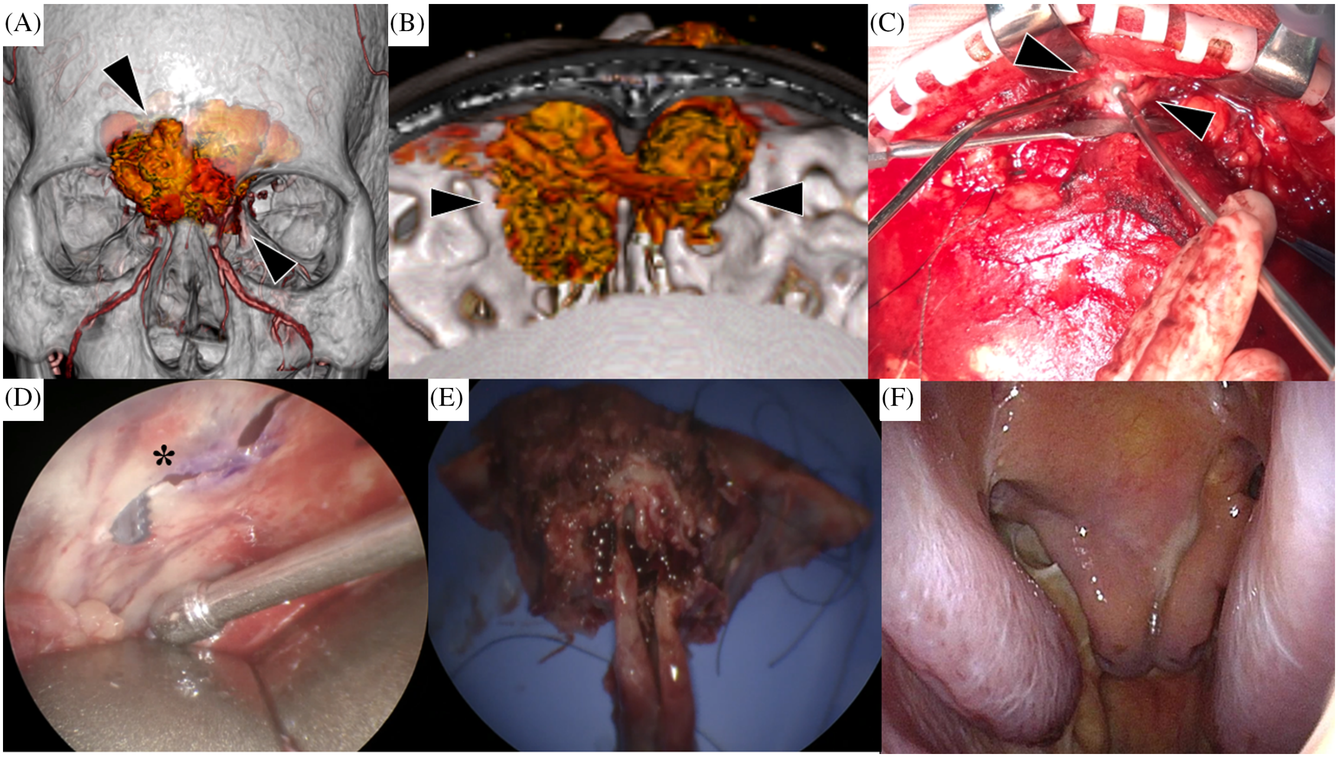

FIGURE 3 (A, B) Preoperative three-dimensional computed tomography images of Patient 1 showing clear cell carcinoma (metastatic renal cell cancer). The tumor is located in the frontal bone, as indicated by the black arrowheads. (C) The inferior portion of the tumor was excised by an otolaryngologist via a coronal skin incision on the nasal bone (black arrowheads) after ensuring the presence of adequate margins. (D) An incision made in the left orbital roof via the transcranial approach using an exoscope with the assistance of an endoscope. *: left orbital roof. (E) Successful en bloc resection of the tumor. (F) Postoperative photograph of the intranasal region. Local tumor recurrence was not observed within the nasal cavity. Nasal crusting was non-existent. [Color figure can be viewed at wileyonlinelibrary.com]

Exoscopes such as ORBEYE, VITOM (Karl Storz GmbH, Tuttlingen, Germany), and KINEVO (Carl Zeiss Meditec AG, Jena, Germany) have emerged as alternatives to conventional microscopes. VITOM-3D and ORBEYE have been used at our institution since 2018 and 2022, respectively. ORBEYE delivers ultrahigh-definition 4K images in 3D, and its depth of field and visual range surpass those of standard operative microscopes.[17] Furthermore, it has demonstrated several advantages, particularly when combined with simultaneous EETS.[14,16,17] First, the use of a compact exoscope, as opposed to a conventional microscope, creates a space above the surgical site, facilitating the simultaneous insertion of an endoscope within the same operative field. This ensured that the parallel surgical procedures were uninterrupted. Second, observing the expansive 55-inch ORBEYE monitor and the endoscope display enables real-time exchange of information between neurosurgeons and otolaryngologists, serving as an instrumental teaching tool for students. However, a 2D submonitor was positioned atop the main display for convenience since otolaryngologists typically avoid the intraoperative use of 3D glasses for ORBEYE. Third, it enabled neurosurgeons to adopt a more ergonomic position while performing microsurgeries using an exoscope. Traditional microscopes require considerable tilting of the visual axis when targeting lesions located in the ASB, which compels neurosurgeons to assume uncomfortable positions. In contrast, an exoscope supports efficient microsurgical tasks from any visual angle while ensuring the surgeon's comfort. Several challenges are associated with the use of an exoscope, including the potential for visual fatigue, the initial learning phase, and financial implications.[14,17] Achieving a comfortable stereoscopic perspective with 3D glasses may be initially challenging, leading to physical discomfort for surgeons that manifests as headaches, visual tension, and other related symptoms.[14]

A previous study has described the use of simultaneous EETS using VITOM-3D.[16] The primary limitations of VITOM-3D include limited illumination and pixelation during elevated magnification in constricted surgical areas.[18,19] However, the supplementary integration of an endoscope enhances visualization, offering a comprehensive and improved perspective of constricted surgical areas. This can be attributed to its tip-based illumination and compatibility with several angled optical instruments. Nevertheless, there remains limited evidence regarding the effectiveness and practicality of ORBEYE, given its recent introduction.

The potential for exoscopes to replace traditional microscopes remains controversial.[17] Notably, although a microscope was available as a contingency, it was not used in lieu of ORBEYE. Similarly, an extra endoscope was not used by the neurosurgeons for the intracranial approaches. This preference might stem from performance variations between ORBEYE and VITOM-3D, the manner in which the surgical field was established, and individual surgical techniques.

As described previously,[14] neurosurgeons can perform simultaneous EETS by observing a 55-inch ORBEYE display positioned directly over the patient's feet, even with a 55-inch endoscope screen. The strategic repositioning of the ORBEYE monitor from directly above the patient's feet to the bottom left facilitated the simultaneous execution of three separate surgical interventions: harvesting of the ALT flap by plastic surgeons, initiation of the endoscopic transnasal approach by otolaryngologists, and initiation of the transcranial approach by neurosurgeons. A standard-sized endoscope screen is favored in such scenarios as a 55-inch display occupies excessive space in the surgical suite.

The skull base reconstruction technique predominantly used in our study was the multilayered double flap reconstruction technique, which encompasses three distinct layers: the inaugural layer comprising the fascia used for primary dural closure, the pericranial flap, and the third layer comprising pedicled nasal mucosal flaps.[13] Vascularized flaps are favored over non-vascularized flaps to address the defects in the ASB, especially for patients who have undergone chemotherapy and irradiation.[20] The ALT flap can be used as an appropriate substitute in cases where the use of a pericranial flap is contraindicated or impractical. Tomio et al. used an absorbable felt comprising polyglycolic acid (Neoveil) to enhance the efficacy of primary dural closure.[13] In cases wherein lesion resection resulted in the loss of the pedicled mucosal flap, Neoveil was introduced as the third protective layer against potential threats to the ASB from within the nose. Notably, spinal fluid leakage was not noted in any of the patients, including those who received postoperative radiotherapy or chemotherapy.

A major limitation of this study is its single-center framework and the absence of measurable outcome metrics. Moreover, only a limited number of cases were included, and the duration of postoperative monitoring was brief. However, our hospital handles a large number of cases and implements a longer duration of postoperative monitoring; therefore, we aim to acquire more comprehensive knowledge regarding the enduring efficacy of combined simultaneous EETS for malignant tumors located in the ASB. Lastly, the tumor recurrence rate and adverse surgical events warrant further consideration.

5 | CONCLUSION

This investigation delves into the therapeutic efficacy of integrating EETS for malignant tumors located in the ASB, augmented by the advanced ORBEYE, which is a 3D exoscope. ORBEYE has revolutionized surgical visualization, thereby enabling surgeons to perform simultaneous procedures while maintaining an ergonomic posture. The multilayered double-flap technique has proven to be pivotal for skull base reconstruction. Large-scale, multicenter studies are warranted for further elucidation and validation.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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