Brain and Spine 2 (2022) 100891

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

Eyebrow incision with a crescent-shaped orbital rim craniotomy for microscopic and endoscopic transorbital approach to the anterior and middle cranial fossa: A cadaveric study and case presentation

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ARTICLE INFO

Keywords:
Orbital rim craniotomy
Anterior skull base
Middle skull base
Transorbital approach
Eyebrow incision

1. Introduction

Endoscopic transorbital approaches (ETOA) through an eyelid incision have recently been introduced to the neurosurgeon's armamentarium, providing minimally invasive access to multiple regions of the skull base for a variety of pathologies (Ramakrishna et al., 2016; Dallan et al., 2018; Locatelli et al., 2016; Gerges et al., 2019; Vural et al., 2021).

The microscopic transpalpebral approach with an eyelid incision combined with a keyhole craniotomy was initially introduced in neurosurgery for intracranial pathologies, such as aneurysms or skull base lesions, as an alternative to eyebrow incision (Raza et al., 2010; Abdel Aziz et al., 2011; Owusu Boahene et al., 2010; Xie et al., 2014; Andaluz et al., 2008). However, this eyelid incision was overwhelmed by the eyebrow incision and keyhole concept, with either a subfrontal or an orbito-pterional craniotomy, which had been extremely effective with excellent cosmetic outcomes and limited orbital swelling (Cai et al., 2019; Lan et al., 2021; Mori et al., 2018; Youngerman et al., 2021).

Meanwhile, in 2007, Moe et al. described an ETOA for the repair of cerebrospinal fluid (CSF) fistula and orbital fractures (Moe et al., 2010). Following the development of endoscopic endonasal approaches (EEA), ETOA recently gained attention as a valuable alternative to EEA for more lateral skull base lesions (Dallan et al., 2018; Vural et al., 2021; Di Somma et al., 2018a; Ferrari et al., 2016; Lee et al., 2019), with the advantage of a reduced risk of approach-related morbidity and CSF leakage (Vural et al., 2021). Numerous additions have been described, including lateral orbitotomy, to extend the area of exposure and push the limits of these approaches, at the crossroad between ophthalmology, otorhinolaryngology, and neurosurgery specialties (De Rosa et al., 2019; Di Somma et al., 2018b; Matsuo et al., 2016; Noiphithak et al., 2019).

However, the superior eyelid incision and transorbital approach remain an unfamiliar territory for most neurosurgeons, requiring specific ophthalmologic skills with the fear of unsatisfactory cosmetic results and prolonged periorbital swelling compared to the well-established eyebrow incision or classic scalp incisions (Dallan et al., 2015, 2018; Vural et al.,

Abbreviations: Endoscopic transorbital approach, ETOA; Endoscopic endonasal approach, EEA; Computed tomography, CT; Orbito-temporal periosteal fold, OTPF; Trigeminal nerve, V1; Maxillary nerve, V2; Mandibular nerve, V3; Foramen rotundum, FR; Foramen ovale, FO; Foramen spinosum, FS; Cerebrospinal fluid, CSF; Inferior orbital fissure, IOF; Entry-point, EP; Optic strut, OS; Maxillary strut, MS.

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https://doi.org/10.1016/j.bas.2022.100891
Received 14 February 2022; Received in revised form 6 April 2022; Accepted 20 April 2022
Available online 28 April 2022

2021). Owing to the narrow corridor, visualization is also limited to the use of an endoscope and requires significant experience with the endoscopic technique (Vural et al., 2021). Finally, retraction and compression of orbital structures necessary to create an intra orbital working corridor, carry a risk of additional visual morbidity (Vural et al., 2021; Balakrishnan and Moe, 2011).

Based on a cadaveric study, we propose a new technique that amalgamates the advantages of the established concepts of ETOA and keyhole surgery. It involves an eyebrow incision and crescent-shaped superolateral orbital rim craniotomy, providing a more direct line of sight with reduced retraction on the orbital contents, and allowing the use of both the microscope and endoscope.

2. Material and methods

Seven formalin-fixed cadaveric heads injected with colored neoprene latex (14 sides) were used. Anatomical dissections were performed with the use of microscope (Leica microsystems GmbH), endoscope (4K camera Karl Storz GmbH). For the endoscopic part, 18 cm long 4-mm-diameter 0°, 30°, 45° endoscopes were used. Bone resection was performed with a high-speed drill (Midas Rex Legend Stylus, Medtronic). Intra-operative images were recorded and stored with the Karl Storz Aida system. High resolution computed tomography (CT) was performed to obtain the measurements of distances and angles as described below. Measurements of distances and angles between entry points and targets (described below) were obtained with high resolution computed tomography (CT) performed before and after C-shaped craniotomy and dissection.

For documentation and confirmation of anatomical structures as well as defined landmarks, neuro-navigation was used (Stealth Station S7, Medtronic).

Owner of cadavers as well as the patient of the case presentation consented to the publication of their images. The study received approval from our institution institutional review board.

2.1. Anatomical dissection

The specimen is fixed in a Mayfield head holder in a slightly rotated (around 10° toward the contralateral side) and extended position. The dissection starts with the microscope. A 2.5 cm skin incision is made within the eyebrow, lateral to the supraorbital groove (Fig. 1 and A; Fig. 1 and B). After the orbicularis muscle is incised along its fibers, the periosteum is cut and the supraorbital rim, superior temporal line, and frontozygomatic suture are exposed (Fig. 1 and C). The supraorbital groove and nerve are identified medially. The periorbita is elevated from the superior and lateral wall of the orbit, while taking care not to damage the supraorbital nerve medially. Then, the superolateral orbital rim from the frontozygomatic suture to the point lateral to the supra-orbital foramen is removed using a pediatric craniotome. This crescent-shaped piece of orbital rim measures approximately 2 cm in width (Fig. 1 and D). The periorbita is further elevated from the orbital roof until the orbitotemporal periosteal fold (OTPF) is identified (Fig. 2 and A). By elevating the periorbita from along the inferior part of the lateral wall of the orbit, the lateral aspect of the inferior orbital fissure (IOF) is reached (Fig. 2 and B). The cross section of bone exposed with the removal of the orbital rim (Fig. 1 and D) is further drilled with a 3-mm diamond burr, in various directions to gain additional working space, respecting the outer cortical margin of the craniotomy. By drilling the orbital roof laterally and the greater sphenoid wing, the deep periostealsurface of the temporalis muscle is exposed (Fig. 2 and C). The greater sphenoid wing is then drilled more medially to expose the temporal fossa dura below the level of the OTPF (Fig. 2 and C; Fig. 2 and D). In the angle formed by the superior and lateral wall, the lesser sphenoid ridge is drilled to expose the sulcus between temporal and frontal dura (Fig. 2 and D). More medially above the OTPF, the base of the anterior clinoid process is drilled (Fig. 2 and E). The endoscope is then brought into the surgical field to increase visualization.

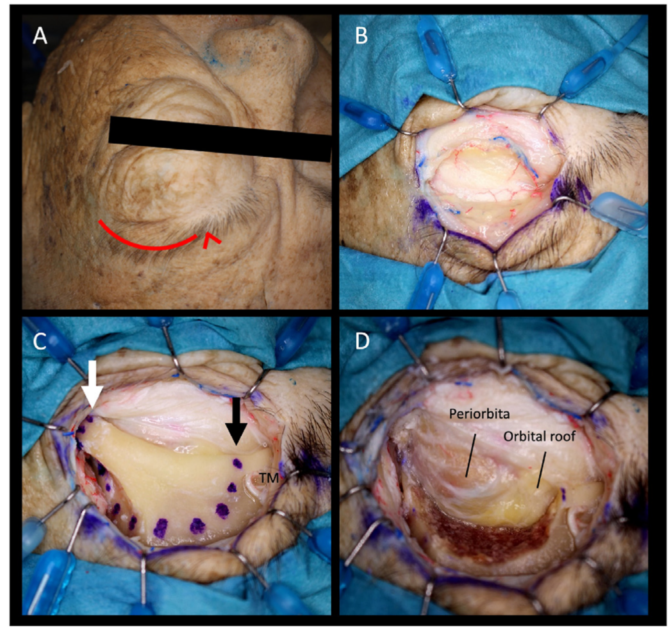

Fig. 1. Dissection illustrating the exocranial steps of the approach (left side)
1A: 4-cm skin incision within the eyebrow is performed.
1B: Skin, subcutaneous tissue, and orbicularis oculi muscle are incised.
1C The superolateral orbital rim, the supraorbital foramen and nerve (black arrow), the frontozygomatic suture (white arrow) are exposed. The temporalis muscle is elevated. The dotted lines indicate the limits of the crescent-shaped orbital rim craniotomy. TM: temporalis muscle
1D View after the craniotomy indicating the bone section that will be further drilled.

The OTPF between the periorbita and temporal fossa dura is sharply divided (Fig. 2 and F) and the temporal fossa dura forming the outer layer of the lateral wall of the cavernous sinus is elevated from the cavernous sinus, and this interdural space is expanded (Fig. 3 and A). The temporal dura is then retracted, enabling visualization of the first division of the trigeminal nerve (V1), the second division (V2) within the foramen rotundum (FR), and the third division (V3) within the foramen ovale (FO), as well as the Gasserian ganglion, and the middle meningeal artery within the foramen spinosum (FS) (Fig. 3 and B; Fig. 3 and C).

After identification of the superior aspect of the anterior clinoid process and the roof of the optic canal (Fig. 4 and A), an extradural anterior clinoidectomy is performed, followed by unroofing of the optic canal (Fig. 4 and B). The final exposure after completion of the craniotomy is illustrated in Fig. 5.

2.2. Measurements of distances and angles between entry points and targets

Entry-point 1 (EP1) was defined as the point located along the orbital rim at the midpoint between the two extremities of the crescent-shaped bone flap, before the craniotomy. Entry-point 2 (EP2) was defined as a point located along the outer table at the midpoint between the two extremities of the crescent-shaped craniotomy after the craniotomy (Fig. 6 and A; Fig. 6 and B).

Three targets were defined: anterior aspect of the optic strut (OS), anterior aspect of the maxillary strut (MS), and anterior aspect of FO. High-resolution CT was performed before and after dissections. Pre- and post-dissection measurements were performed on CT images using the Carestream® software. The distance between EP1 and EP2 and the three targets, as well as the angles between the lines connecting the OS, MS, and FO, with EP1 and EP2 were measured in millimeters (mm) and degrees for distances and angles, respectively.

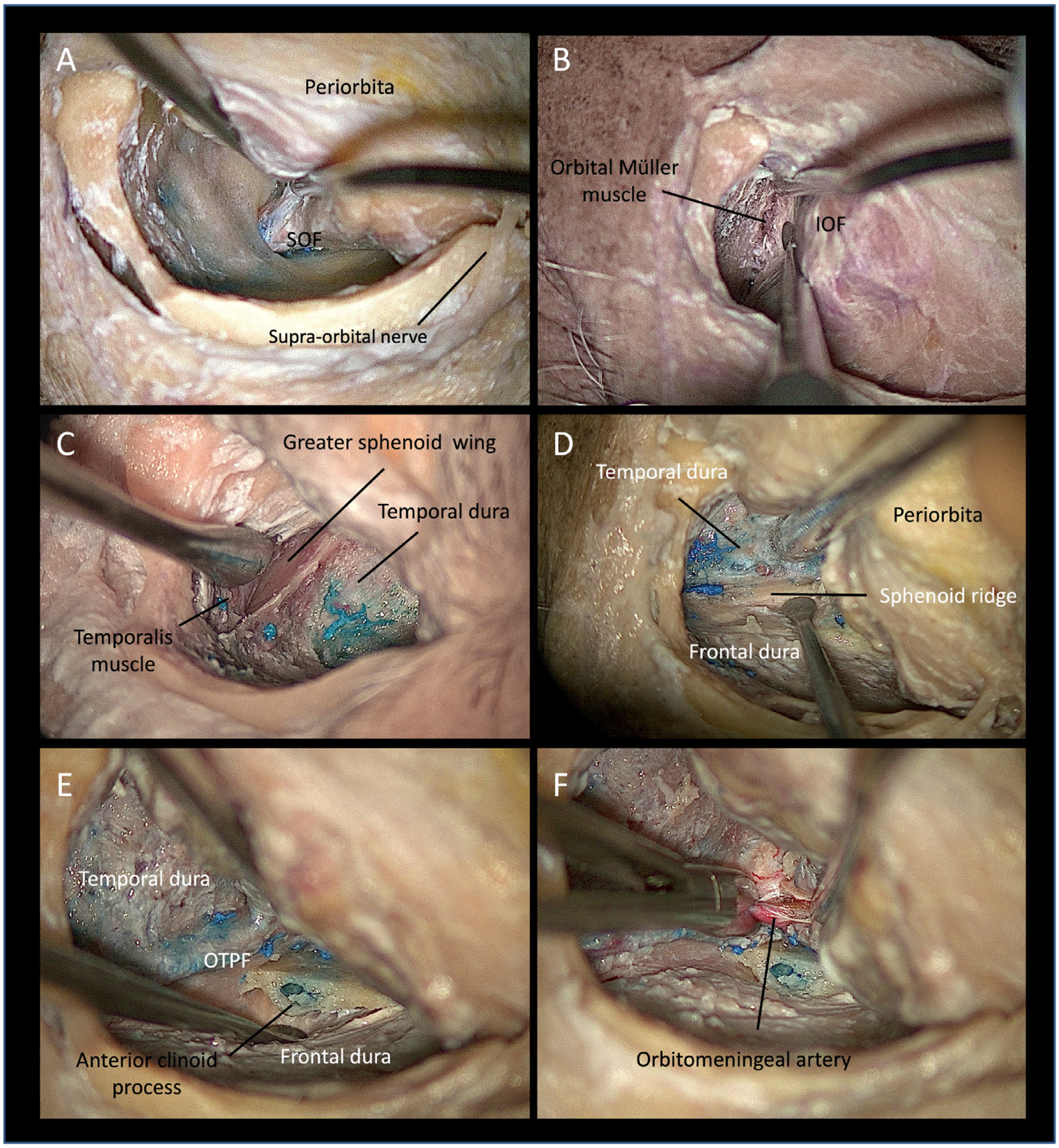

Fig. 2. Dissection illustrating the intra orbital steps of the approach (left side)
2A: The periorbita is elevated until the lateral aspect of the superior orbital fissure (SOF) and orbito-temporal periosteal fold (OTPF) come into view.
2B: The elevation periorbita continues along the inferior part of the lateral wall of the orbit, until the lateral aspect of the inferior orbital fissure (IOF) is reached. The orbital Müller muscle that spans the IOF is visualized.
2C: The temporal fossa dura is exposed medially below the level of the OTPF by drilling the greater sphenoid wing medially. Laterally, the lateral aspect of the greater sphenoid wing and the deep periosteal surface of the temporalis muscle are exposed.
2D. In the angle formed by the superior and lateral wall, the lesser sphenoid ridge is exposed separating the frontal to the temporal dura.
2E: The base of the anterior clinoid process and the roof of the optic canal are exposed above the OTPF.
2F: The OTPF between the periorbita and temporal fossa dura is sharply divided and the orbitomeningeal artery is sectioned.
SOF: superior orbital fissure; IOF: inferior orbital fissure; OTPF: orbito-temporal periosteal fold.

3. Results

3.1. Distances and angles from EP to targets

The mean distances from EP1 to OS, MS, and FO were 52.6 ± 1.6 (49.7–55.3), 53.4 ± 1.9 (50.8–57.2), and 62.9 ± 3.8 (56.2–70.1) mm, respectively. Following the crescent-shaped orbital rim craniotomy, distances from EP2 to OS, MS, and FO were 49.5 ± 3.6 (41.7–53.2), 50.9 ± 2.9 (44.3–53.4), and 60.1 ± 4.7 (49.8–66.1) mm, respectively. The angles between the two lines of view before and after orbital rim craniotomy, EP1-FO-EP2, EP1-OS-EP2, and EP1-MS-EP2 were 10.6 ± 0.8 (9.2–11.5), 8.9 ± 1.2 (8.08–11.2), and 7.7 ± 0.4 (6.8–7.98) degrees, respectively (Table 1).

3.2. Case presentation

A 38-year-old woman presented with a slight proptosis. CT scanner and MRI revealed an extra-axial, hyperostotic tumor, suspected to be a spheno-orbital meningioma (Fig. 7 and A; Fig. 7 and B). Observation was initially decided. After 1-year, the tumor grew significantly with worsening of periorbital pain and exophthalmia. There was no history of progestin intake. Ophthalmological examination was normal. An eyebrow incision (Fig. 8 and A) with a crescent-shaped orbital rim craniotomy was performed (Video 1). The eyebrow incision and the entire surgery were performed under the microscope without the need of an endoscope. The endoscope was used at the end to explore the surgical cavity. The small craniotomy was reattached to the skull with miniplates and screws.

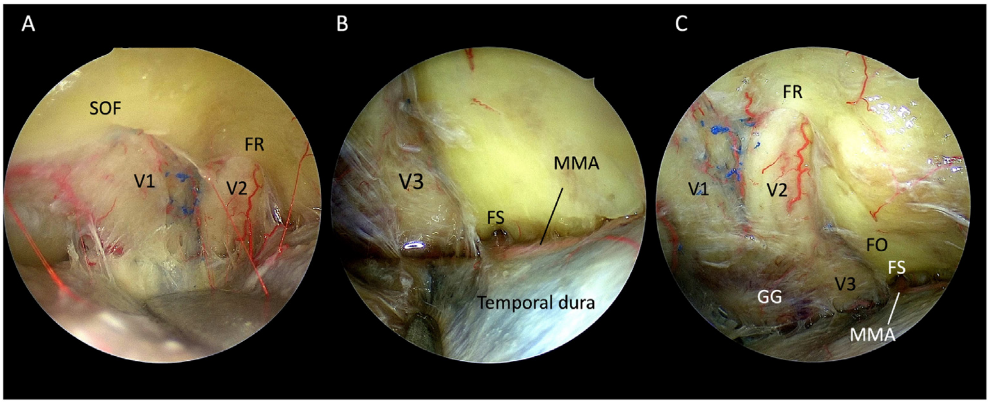

Fig. 3. Endoscopic exposure of the temporal fossa floor (30° endoscope, left side).
3A: Interdural middle cranial fossa peeling exposing V1, V2, superior orbital fissure, and foramen rotundum.
3B: Exposure of V3, foramen ovale, foramen spinosum and middle meningeal artery.
3C: Complete exposure of the cavernous sinus and the foramen spinosum.
V1: trigeminal nerve; V2: maxillary nerve; V3: mandibular nerve; SOF: superior orbital fissure; FR: foramen rotundum; FO: foramen ovale; FS: foramen spinosum; GG: Gasserian ganglion.

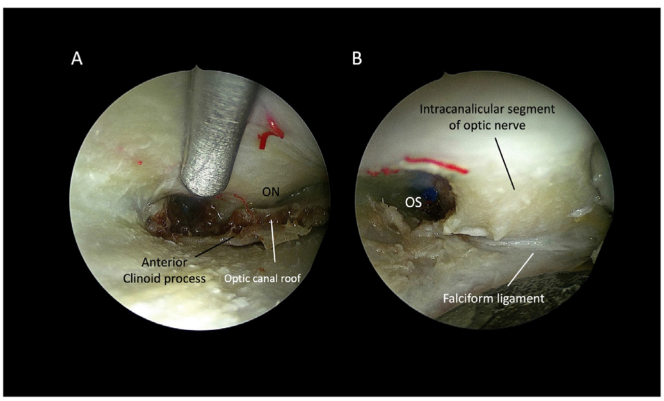

Fig. 4. Endoscopic unroofing of the optic nerve and extradural anterior clinoidectomy (30° endoscope, left side).
4A: Above the OTPF, the lesser wing of the sphenoid and the base of the anterior clinoid process are drilled.
4B: Unroofing of the optic canal and extradural anterior clinoidectomy. The optic strut (OS) was pneumatized in this specimen.
ON: optic nerve; OS: optic strut.

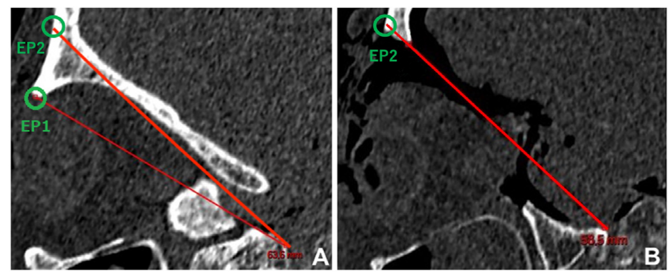

Fig. 6. Computed tomography images illustrating the entry point 1 (EP1) and entry point 2 (EP2) before (6A) and after (6B) the crescent-shaped craniotomy. EP1 was defined as the point located along the orbital rim at the midpoint between the two extremities of the crescent-shaped bone flap, before the craniotomy. EP2 was defined as a point located along the outer table at the midpoint between the two extremities of the crescent-shaped craniotomy, after the craniotomy.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.bas.2022.100891

The patient's postoperative course was uneventful, without postoperative morbidity. CT and MRI confirmed the complete resection (Fig. 7 and C). The suture was removed on postoperative day 6, and the

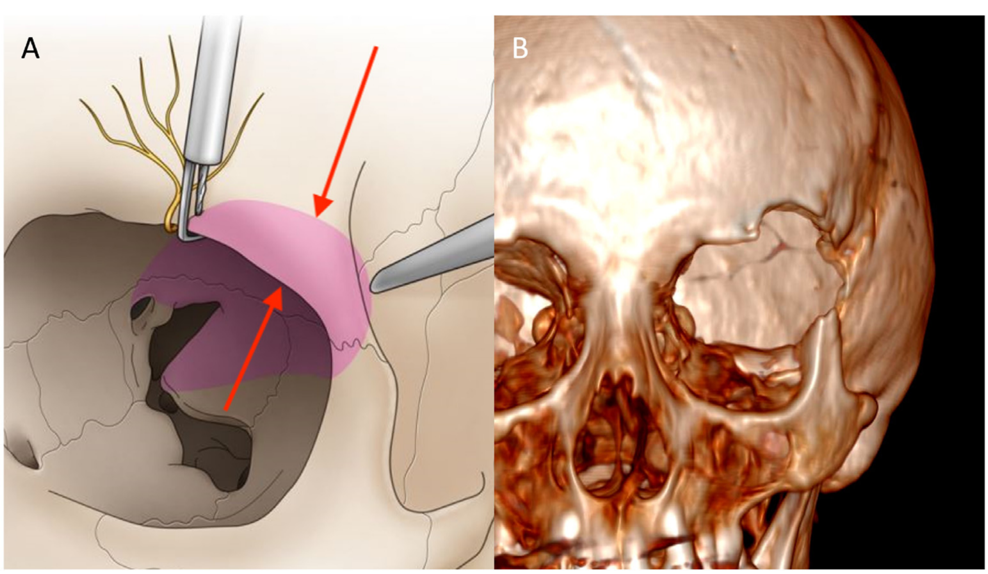

Fig. 5. Final view of the modified ETOA exposure
5A: Schematic illustration of the orbital rim craniotomy via our modified ETOA approach.
5B: Computed tomography three-dimensional rendering after completed dissection.

Table 1
Results of measurements between EP1 and EP2 and targets.

Distances	Pre-craniotomy mean ± SD (mm)	Range (mm)	Post-craniotomy mean ± SD (mm)	Range (mm)	Angles	Angles mean ± SD	Range (degree)
EP to OS	52.6 ± 1.6	49.7–55.3	49.5 ± 3.6	41.7–53.2	EP to OS	10.6 ± 0.8	9.2–11.5
EP to MS	53.4 ± 1.9	50.8–57.2	50.9 ± 2.9	44.3–53.4	EP to FR	8.9 ± 1.2	8.08–11.2
EP to FO	62.9 ± 3.8	56.2–70.1	60.1 ± 4.7	49.8–66.1	EP to FO	7.7 ± 0.4	6.8–7.9

Abbreviations: EP: entry point; OS: optic strut; FR: foramen rotundum; FO: foramen ovale.

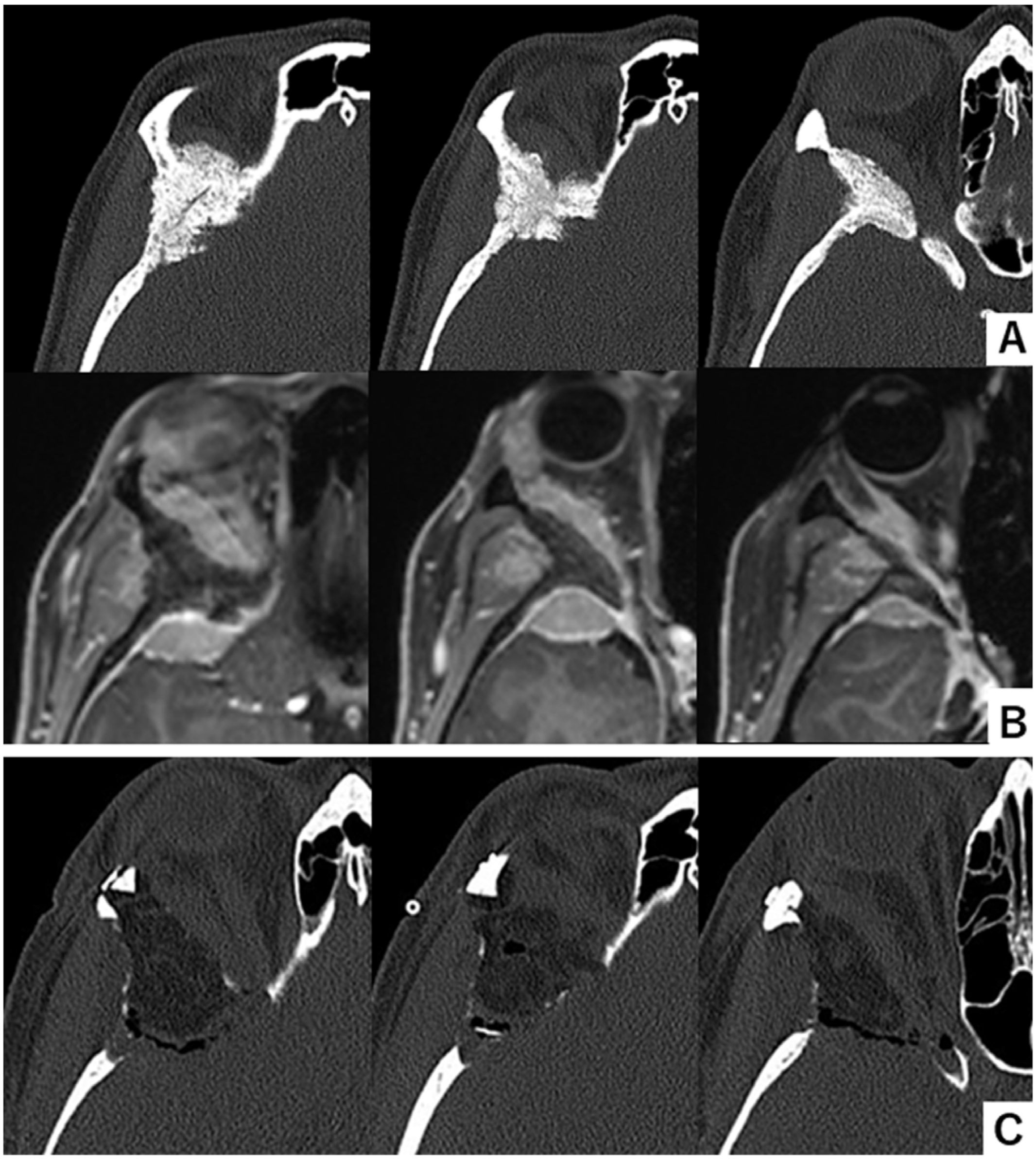

Fig. 7. Case illustration
7A: Preoperative computed tomography images (bone window) showing the hyperostosis caused by the spheno-orbital meningioma, involving the greater sphenoid wing, lesser sphenoid wing, anterior clinoid process, and superior wall of the orbit as well as the temporal squama.
7B: Preoperative gadolinium-enhanced magnetic resonance imaging (MRI) showing the spheno-orbital meningioma extending from the supraorbital wall to the lateral orbital wall as well as the periorbita. The temporal pole dura, temporalis muscle were also infiltrated. Compression of the orbit caused proptosis of the globe.
7C: Postoperative computed tomography images demonstrating gross total removal of both the meningioma and the hyperostosis.

patient was discharged in perfect clinical condition with a hardly visible scar and regression of proptosis (Fig. 8 and B).

4. Discussion

Our study suggests that the proposed crescent-shaped orbital rim craniotomy may provide an effective access to lesions of the sphenoid wing, the anterior and middle cranial fossae. This simple modification of the technique via an eyebrow incision amalgamates the advantages of the ETOA and keyhole surgery, enhances surgical freedom and minimizes the manipulation and distortion of the orbital contents.

In the nascent stages of modern neurosurgery, anterolateral skull base

Fig. 8. Cosmetic eye-brow incision
8A: Outline of the surgical incision and landmarks.
8B: Cosmetic results on postoperative day 5.

lesions were approached through large craniotomies such as fronto-temporal, orbitozygomatic approach (Aziz et al., 2002) or subtemporal approach (Seifert and Dietz, 1992). These transcranial approaches are time-consuming and associated with a significant morbidity and post-operative discomfort due to the extensive soft tissue dissection (Boari et al., 2018; Tomio et al., 2021). With the evolution of microscopes, endoscopes, surgical instruments, and the introduction of navigation, intraoperative targeting of lesions improved, and smaller skin incisions and craniotomies, so-called minimally invasive approaches, have become possible and are now widely used (Reisch and Perneczky, 2005; Dzhindzhikhadze et al., 2018; Reisch et al., 2013, 2015; Yamahata et al., 2014).

The first description of a superior eyelid approach in neurosurgery was provided in 2000 by Fukushima et al. (Ohjimi et al., 2000) for orbital fractures and orbital hemangiomas. The transpalpebral approach using an incision in a natural eyelid crease, compared with the supraorbital eyebrow mini-craniotomy approach, eliminates the risk of injuring the facial nerve branches, preserves sensory innervation of the forehead, and allows removal of the orbital rim and frontal bone as a mono-bloc flap (Raza et al., 2010). Abdel Aziz et al. (Abdel Aziz et al., 2011) reported their experience with the use of a microscopic transpalpebral eyelid incision and orbitofrontal craniotomy with various lesions such as aneurysms and meningiomas. They concluded that the transpalpebral approach allows preservation of the orbicularis muscle, and prevents facial nerve branches injury with excellent cosmetic outcome (Abdel Aziz et al., 2011).

Despite the promising results of the microscopic transpalpebral approach, its use by neurosurgeons for intracranial pathology remained confidential, limited to few neurosurgical teams.

During the last 20 years, the use of EEA has considerably grown, changing the surgical strategies for midline central skull base lesions. More recently, experienced teams with endonasal approaches have applied endoscopy to the transorbital corridor through an eyelid incision, to overcome the limitations of the EEA to more lateral skull base lesions (Vural et al., 2021; Balakrishnan and Moe, 2011; Di Somma et al., 2018b; Dallan et al., 2015; Park et al., 2020a). Further addition extended the limits of this ETOA (Di Somma et al., 2018b; Noiphithak et al., 2019; De Rosa et al., 2019). Lateral orbitotomy through a lateral canthal incision (Altay et al., 2012; Abou-Al-Shaar et al., 2020; Chabot et al., 2017), a purely conjunctival incision (Moe et al., 2010; Bly et al., 2014; Raza et al., 2013) or a superior eyelid incision (Di Somma et al., 2018a; Kong et al., 2019; Park et al., 2020b), either using a microscope or the endoscope, have been described to provide a more lateral angle of view to the middle fossa and cavernous sinus and an increase exposure to the inferior orbital wall toward the infratemporal fossa. Until now, indications for ETOA have mostly been limited to meningiomas of the middle and anterior skull base and trigeminal nerve schwannomas (Dallan et al., 2018; Vural et al., 2021; Park et al., 2020a; Di Somma et al., 2021). Numerous reports have described extensions of ETOA to other skull base regions such as the petrous apex, inferior orbital fissure, infratemporal fossa, etc (Vural et al., 2021; Moe et al., 2010; Topczewski et al., 2020).

However, most neurosurgeons remain unfamiliar and reluctant to ETOA and eyelid incisions. It requires specific training, specific instrumentation, and collaborations between specialties such as ophthalmology. In addition, eyelid incisions carry a risk of eyelid oedema, keratitis, pseudomeningocele, and permanent cosmetic complications (Vural et al., 2021; Balakrishnan and Moe, 2011).

On the other hand, keyhole approaches through an eyebrow incision has been shown to be extremely effective in removing tumors of the anterior skull base, as well as vascular lesions (Reisch and Perneczky, 2005; Youngerman et al., 2021; Cai et al., 2019; Robinow et al., 2021; Aldea and Gaillard, 2019), with excellent aesthetic outcomes and limited immediate post-operative discomfort caused by periorbital swelling. This technique is now mastered by many neurosurgeons, does not require any specific ophthalmologic skills, and theoretically offers a better cosmetic result compared to the eyelid incision as the wound is hidden by the eyebrow.

Our technique combining an eyebrow incision with a crescent-shaped orbital rim craniotomy was proposed as a simple, safe, and effective addition to the transorbital approach for lesions involving the sphenoid wing, anterior and middle cranial fossae, and orbit. The surgical corridor is widened by the removal of the orbital rim lip that covers the antero-superior aspect of the orbit. Compared to the conventional ETOA, this approach seems to be more effective in term of surgical freedom and maneuverability, as documented by additional angle of exposure and shortened working distance, with a minimized orbital compression. Our approach also gives a more direct trajectory to the roof of the orbit allowing easy access to anterior skull base lesions. This approach is an amalgamation of the established concepts of ETOA and keyhole approach and can be used with both microscope and endoscope.

However, further experience is needed to evaluate the advantages and disadvantages of our proposed approach, especially regarding long-term cosmetic outcome and potential limitations of exposure and resulting tumor recurrence.

5. Conclusion

The crescent-shaped orbital rim craniotomy provides an effective surgical access to the anterior and middle cranial fossae. When compared to the conventional ETOA, it increases the surgical freedom and maneuverability with a reduced compression of orbital contents, allowing the use of both endoscope and microscope. Furthermore, this technique may provide a more favorable cosmetic result when compared to eyelid incisions.

Ethical approval

Owner of cadavers as well as the patient of the case presentation consented to the publication of their images.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authorship statement

The conception and design of the study, or acquisition of data, or analysis and interpretation of data: FM, TP, BC, CM, SF. Drafting the article or revising it critically for important intellectual content: FM, TP, SF. Final approval of the version to be submitted: RA, CN, LG, BD, EM.

All the co-authors critically revised the article and gave a substantial contribution in the improvement of the content of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

None.

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