1 Mini-pterional: How "Mini" is too Mini and the Next Generation of Keyholes

Walter C. Jean, Franco Rubino, Ivo Peto, and Kunal Vakharia

Summary
Minimally invasive neurosurgery (MINS) was introduced with the goal of reducing surgical trauma through small, keyhole openings, which minimize skin incision, soft tissue damage, and craniotomy size. Pioneered by Axel Perneczky, MINS focuses on reducing iatrogenic injury while maximizing surgical efficiency. Over time, keyhole techniques have demonstrated their effectiveness and safety in treating a range of intracranial conditions, including tumors and vascular pathologies. Despite its advantages, the concept faces criticism due to concerns about safety, surgical visibility, and potential risks associated with limited exposure. However, studies have shown that MINS offers advantages such a shorter recovery times, reduced hospital stays, and lower narcotic use, providing tangible benefits for patients.

MINS is particularly effective for deep-seated targets, where the small corridor widens with depth, making keyhole approaches feasible. However, these techniques require precise planning, and small openings must be strategically placed to avoid compromising safety. As the technique evolves, even complex procedures, such as petrosectomies or transcallosal approaches, have been successfully adapted into minimally invasive formats. Technology plays a key role in MINS, with advances such as virtual reality (VR), augmented reality (AR), and endoscopes improving surgical precision and visualization. Although MINS may initially seem costly, its potential to shorten recovery times and reduce health care costs could justify the investment. The future of MINS lies in continued technological advancement and broader applications, potentially revolutionizing neurosurgery.

Keywords: keyhole approach, mini-pterional, first-generation approaches, minimal invasive neurosurgery, endoscopy, exoscopy, hospital stay, postoperative complications

The concept of MINS was promulgated with the principal tenet that small or "keyhole" openings with its "limited exposure[,] reduces skin incision, soft tissue trauma, and craniotomy size of standard microsurgical approaches to a necessary minimum."[1] In one of his treatises on keyhole surgery, Axel Perneczky wrote, "the fundamental philosophy…[is] operating with a minimum of iatrogenic traumatization and achieving a maximum efficiency in neurosurgical therapy."[2] Since that writing, the second half of the "efficiency" of minimally invasive techniques has been widely proven.[3,4,5,6,7,8] Because of this, keyhole approaches have been repeatedly shown to be effective and safe for a wide variety of intracranial oncologic[2,3,4,6,7,8,9,10,11] and vascular pathologies.[1,5] Even large tumors can be approached through keyholes,[6,12] and as one would expect, believers of the keyhole concept continue to grow.

For disciples of Perneczky's principles, the link between small openings and shorter recovery and, ultimately, a happier patient is widely assumed.[13] However, if surgical success and complications are similar between MINS and standard technique, most of the existing comparative data only support "noninferiority" of the two techniques. And therein lies the "Achilles' heel" of MINS techniques, as detractors complain, in worldwide conferences and editorials of many neurosurgical journals, "why would anyone intentionally operate through tiny openings, limit the exposure, and compromise the safety and efficiency of complex brain surgery?" In theory, of course, small openings and the reduction of iatrogenic trauma lead to easier recovery and a happier patient. However, until there are data to support these assumptions, the naysayers will continue to believe that MINS is but to satisfy the surgeon's ego, a way to show off dexterity, finesse, and his/her own bravery at the expense of patient safety and operational speed.

Data from our own group have changed this. In a matched cohort study with head-to-head comparison of classic versus minimally invasive procedures, emphasizing on testing apples-to-apples and oranges-to-oranges, operative time, length of hospital stay, and narcotic consumption were all in favor of the minimally invasive cohort.[14] To be sure, many conditions must be satisfied for these superior results to be realized. First, keyholes must

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be utilized for the appropriate indications, and for MINS, these are usually deep-seated targets. This is because the corridor widens as it deepens, and so counterintuitively, with shallow targets, the corridors may be too narrow. And because the openings are small, only by placing them at the perfect anatomic point would minimally invasive surgery be successful. Placed anywhere but the perfect location and one may have to revert to a larger opening to gain the necessary exposure. And, finally, small though it must be to qualify as a "keyhole," if overdone in its miniaturization, surgical freedom may be restricted and safety compromised. However, as long as the minimally invasive techniques satisfy the "Goldilocks principle," i.e., not too big, not too small, but just right, then there can be benefits that are tangible to the patient.

Since Perneczky's original idea and the advent of the minimally invasive concept, the "first-generation" keyholes such as the mini-pterional[15] and supraorbital keyhole through a transciliary or transpalpebral incision have been well established in the repertoire of many neurosurgeons. The goal of this collection of chapters and videos is to highlight the technical details for maximally efficient and effective execution of these approaches and, through the videos, such as the one that accompanies this chapter on the mini-pterional opening, demonstrate step-by-step performance of the operations (**Video 1.1**). What the collection reveals is that keyhole openings have reached at least its "second generation." In fact, just by glancing at the table of contents, one might initially be surprised to find that a transcallosal approach, or even a petrosectomy, can be included in a minimally invasive collection. What this indicates, however, is by shortening the incision, minimizing soft tissue trauma, and reducing the bone removal as much as possible, *any* craniotomy may have a minimally invasive version. And following that logic, keyholes should not be conceptualized as separate, individually named entities with a strict size threshold. Instead, "minimally invasiveness" must be considered a principle, and it should be liberally considered and judiciously applied. Of course, some applications, such as the mini-pterional, have become commonplace, but with unique targets that calls for it, some "out-of-the-box" utilization can lead to "one-off" operations.[16]

There will always be clinical scenarios that call for large openings, if not for the characteristics of the lesion, then perhaps for the timing or circumstances of the clinical presentation. However, for the appropriate surgical target, with the right equipment, and having the opportunity to precisely and diligently plan the anatomically precise opening, as long as every step of the approach is done with conscious and strict adherence to minimizing iatrogenic traumatization, then the minimally invasive principle may be achievable for many operations. The fact that this requires or creates a border between minimally invasive and "standard" approaches that is blurry and challenging to define may be something that neurosurgeons will simply have to tolerate or even suffer. However, whether a minimally invasive approach is used often or only once, as long as the principle is applied properly, the patient benefit will justify whatever the surgeon might suffer.

As the keyhole concept evolves, the utilization will undoubtedly broaden. For example, one might argue that a contralateral transfalcine approach fulfills the criteria of "minimally invasive" simply by utilizing the most direct trajectory to target and eliminating cortical retraction, especially with gravity-assisted brain mobilization to dissect the falx. And when advanced intraoperative image guidance is added, so that a small, keyhole opening can reliably avoid the bridging veins while accessing the precise point to traverse the falx, that would be "icing on the cake." Faced with the idea that there are limitless applications of the minimally invasive concept, the editors have chosen to focus on the mainstream applications for this collection. However, we acknowledge that with imaginative extension of the principles, the next generation of MINS, such as aneurysm clipping through the orbit, might become the mainstream in the near future.[17,18] Perhaps, we will use the second edition of the collection for the third- or fourth-generation keyholes!

Finally, there is the topic of equipment and technology. Because of the requisite anatomic precision, high-quality and multimodality preoperative imaging studies are absolutely required for the minimally invasive concept. Beyond cross-sectional imaging, the senior author was only able to join the minimally invasive camp during a mid-career pivot because of the availability of mixed reality technology. VR not only was useful for three-dimensional, 360-degree anatomic inspection, but also afforded the opportunity to trial various approaches. The selection of the proper

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keyhole after VR surgical rehearsal—when openings of various sizes and positions can be simulated, reset, and modified—provided the necessary confidence that small openings can safely lead to the target and achievement of the surgical goal. For intraoperative guidance and taking the place of pointer-monitored-based navigation, AR added to the minimally invasive evolution. Marker and guideposts that are placed during VR rehearsal can be projected with AR, “ghosted” onto the surgical scene via a navigation-tracked AR-capable microscope.[19] The ability to put the markers in and take them away on demand, without needing to turn to another monitor or place a probe onto the field, adds to the surgeon’s focus for both guidance to the target and away from antitargets, the neurovascular structures that must be protected.

For illumination and visualization, the endoscope is almost synonymous with keyhole surgery. Because the superficial bone opening is small, it blocks the penetration of illumination from any source that is above the craniotomy. Bringing the light directly to the edge of the deep-seated target makes perfect sense. However, with the progressive availability of the exoscope, another step in the evolution is happening. Although the light source is still above the keyhole, the spread and penetration of the exoscope’s illumination may be better than standard microscopy.[20] Add to that the fact that the endoscope takes up space in the surgical corridor, the “second-generation” minimally invasive cranial surgeon may be well served by being indiscriminate to illumination and visualization and use all the available tools flexibly and interchangeably. In the future, as technology evolves to the point where illumination and visualization can be easily decoupled—through innovations such as lit-dissectors or endoscopes so thin they can be integrated into a suction device—our current concepts of microscopy, endoscopy, and exoscopy will be completely disrupted. We eagerly await these advancements in the next generation of surgical visualization tools.

With all these pieces of equipment, not to mention single-shafted scissors, bipolars, and aneurysm clip appliers designed specifically for keyhole surgery, minimally invasive cranial surgery might sound like an expensive endeavor feasible only in the hospitals for the rich. However, if the patients’ benefit in shorter hospital stay and reduced narcotic needs can be extrapolated to earlier return to work, then the societal gains may well justify the expensive tools that it requires. As technologies continue to advance, hopefully the cost will drop, and the improvement in both technology and technique will drive MINS in many generations to come.

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Part I

Approach Involving the Orbit

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2 Endoscopic Supraorbital Approach

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Summary

The endoscope-assisted supraorbital approach (EASOA) is a minimally invasive technique used for accessing the anterior and middle fossa to treat skull base pathologies, particularly olfactory groove meningiomas. This approach offers a tailored, focused corridor for tumor resection, minimizing soft tissue disruption and promoting faster recovery compared with traditional bifrontal or pterional craniotomies. The EASOA is particularly beneficial for extra-axial tumors such as olfactory groove, tuberculum, planum, and clinoidal meningiomas, as well as intra-axial tumors or vascular lesions such as aneurysms.

In a typical case, the patient undergoes a keyhole craniotomy via an incision made near the eyebrow, with a careful dissection to avoid damaging key structures such as the supraorbital nerve and facial nerve. Using angled endoscopes allows for better visualization and resection of hard-to-reach areas, such as the cribriform plate and anterior middle fossa. This approach also provides the possibility of preserving olfaction, which is important in patients with preserved olfactory function.

The operative setup involves careful positioning and meticulous dissection, with the use of fat grafts to prevent cerebrospinal fluid leaks when the frontal sinus is violated. Key risks include frontalis palsy and skin tearing, but these can be minimized with proper incision placement and retraction techniques.

In conclusion, the eyebrow EASOA offers a minimally invasive, effective solution for skull base tumors, providing excellent tumor resection with reduced morbidity and the potential for olfaction preservation.

Keywords: supraorbital approach, eyebrow incision, anterior fossa, olfactory groove meningioma, endoscope, supraorbital nerve

2.1 Introduction

Approaches to the anterior and middle fossa have traditionally been through a bifrontal or pterional craniotomy or one of their numerous variations. These approaches involve significant tissue dissection and wide exposure of the cortex while providing excellent visualization of the frontotemporal skull base. Although certain pathologies may necessitate such conventional approaches, many can be addressed through a more focused and tailored surgical corridor such as the eyebrow supraorbital approach (SOA) via an eyebrow incision and keyhole craniotomy. Early criticisms of the SOA largely centered around the exposure limiting and the working angles too challenging to overcome safely. However, as this chapter will discuss, with careful patient selection and meticulous exposure and dissection, a wide array of skull base pathologies can be addressed using this more minimally invasive approach with a similar, if not improved, safety profile. Utilizing angled endoscopes and instruments unlocks further potential of the SOA, targeting difficult-to-reach corners of the anterior and middle fossa.

2.2 Common Disease Indications for the Technique/Approach, Area of Exposure

The eyebrow SOA is classically described for extra-axial skull-based tumors of the anterior and middle fossa. These include olfactory groove, tuberculum, planum, or clinoidal meningiomas. In patients with olfactory groove meningiomas with preserved olfaction, the SOA is particularly powerful as it provides the ability to preserve the contralateral olfactory nerve and potentially preserve or improve olfaction. Planum and tuberculum sellae meningiomas are natural targets for a posterior extension of the SOA, although with some different considerations. Significant sellar extension below the planum or a more acute angle of the tuberculum would make the SOA more difficult, although the use of angled endoscopes can overcome these challenges. We also favor an endonasal approach over the SOA when there is involvement in one or both optic canals, as we can decompress the optic nerve earlier and more effectively from an endonasal approach. Finally, clinoidal meningiomas with a significant portion above the lesser wing of sphenoid can also be

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addressed through an SOA, but those with significant middle fossa extension may be better approached through a keyhole pterional craniotomy. The indications of the SOA, however, are not limited to extra-axial pathologies, as it can be similarly used for intra-axial tumors or vascular lesions including aneurysms or cavernomas.

2.3 Pertinent Anatomy

The eyebrow SOA is a unilateral subfrontal approach utilizing the frontal portion of a frontotemporal craniotomy. Although the trajectory is similar to the frontotemporal craniotomy, there are some notable differences to consider. The frontotemporal branch of the facial nerve is a consideration given the course is parallel to the eyebrow incision. Furthermore, the supraorbital nerve along the medial aspect of the incision should be carefully identified, dissected out, and preserved. The craniotomy involves a keyhole burr hole at the pterion and an exposure flush with the frontal skull base. Frontal and sphenoidal osteotomies are necessary for adequate visualization. Once fully exposed, the anterior skull base from contralateral anterior clinoid to the entire ipsilateral lesser wing of sphenoid can be exposed. Further exposure can be achieved either using angled endoscopes or with dissection through the cisterns to reach the posterior circulation and brainstem, although with much more significant restriction in maneuverability (▶ Fig. 2.1).

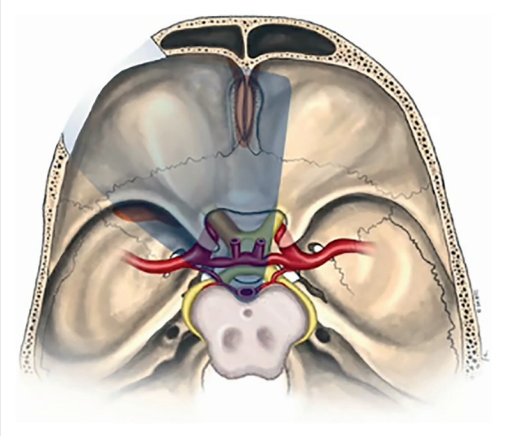

Fig. 2.1 SOA exposure. The shaded areas depict the areas reachable via the SOA. The entire anterior skull base from contralateral anterior clinoid to the entire ipsilateral lesser wing of sphenoid is included. To reach the posterior circulation, brainstem, and the anterior portion of the ipsilateral middle fossa, angled endoscopes would be required. (Copyright of Pacific Neuroscience Institute Foundation.)

2.4 Brief Description of the Case in the Video (Video 2.1)

This patient is a 62-year-old woman with a 4-year history of hyposmia (that was presumed to be due to COVID-19 infection) and headaches who presented with transient acute blurry vision in her right eye. She was found to have a 3.3 × 3.3 × 3.2 cm frontal extra-axial dural-based enhancing mass that was consistent with an olfactory groove meningioma. There is additional evidence of peritumoral edema along the left frontal lobe and complete effacement of the left olfactory tract. The patient was noted to have a type 2 cribriform plate per the Keros classification system. The Brief Smell Identification Test revealed asymmetric diminished olfaction with a score of 4 (out of 12) on the left and 7 on the right.

2.5 Approach Selection

Broadly speaking, the potential surgical approaches for this patient can be grouped into a conventional, keyhole, or an endonasal approach. A traditional approach involving a large bifrontal or pterional craniotomy, with or without orbitotomy, would provide excellent visualization and access to the tumor. However, in our practice, these approaches are rarely employed given the large amount of soft tissue trauma and morbidity involved. Simply put, the same surgical goals can be achieved through a keyhole craniotomy. These larger conventional approaches can be associated with increased postoperative pain, longer recovery times, and wound-healing issues.

An endonasal approach has the advantage of approaching the tumor and its dural attachment directly. This allows for early devascularization as well as minimal to no brain manipulation. In addition, it provides direct access to the origins of the tumor within the cribriform plate, which, given the depth of this patient's cribriform plate, would be a challenging area to reach from a lateral approach. While this approach would have an elevated risk of cerebrospinal fluid (CSF) leak,

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these can be mitigated with meticulous closure, reconstruction with a vascularized nasal septal flap, and perioperative placement of a lumbar drain. However, the nature of the approach necessitates the complete sacrifice of olfaction with the disruption of the olfactory nerves from the olfactory bulbs.

The eyebrow SOA is a minimally invasive approach that allows for potential olfaction preservation while minimizing soft tissue disruption for enhanced postoperative recovery. The unilateral frontal approach often requires sacrifice of the ipsilateral olfactory tract; however, with careful dissection, the contralateral olfactory tract can be anatomically preserved. The patient's somewhat deep olfactory groove is a consideration as discussed earlier given the lateral approach; however, this is mitigated by the use of an angled endoscope as well as angled instruments that allow for visualization and resection in this skull base valley. Finally, while the patient's laterally pneumatized frontal sinus is also a consideration, it is similarly not a contraindication as preoperative planning for an intraoperative abdominal fat graft harvest can mitigate the concern for a postoperative CSF leak.

Given the patient's moderately preserved olfaction on the right, we elected to proceed with a left SOA with the goal of gross total tumor resection and preservation of the right olfactory tract.

2.6 Operative Setup

- **Position:** The patient was placed in supine position with slight reverse Trendelenburg. The head is placed in slight extension and 15 to 20 degrees of contralateral head rotation to position the malar eminence at the most prominent point.
- **Incision:** The incision is within the eyebrow about 0.5 cm medial to the supraorbital notch and about 1 cm lateral to the superior temporal line.
- **Bone Opening:** From a burr hole just inferolateral to the superior temporal line, the craniotome is directed superiorly around 2 cm before curving medially. The medial extent of the craniotomy is the supraorbital nerve (▶ Fig. 2.2).
- **Durotomy:** The dura was then opened in a curvilinear fashion following the superior edge of the craniotomy and flapped inferiorly.

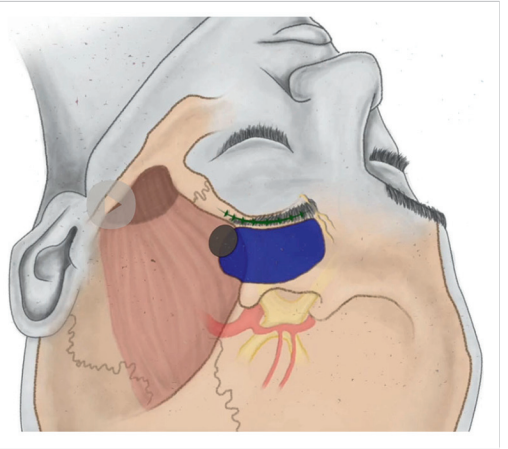

Fig. 2.2 Incision and keyhole opening of the SOA. The incision is within the eyebrow ~0.5 cm medial to the supraorbital notch and ~1 cm lateral to the superior temporal line. The dark brown circle represents the burr hole, placed inferolateral to the superior temporal line. From the burr hole, the bone cut is extends superiorly (~2 cm) before curving medially. The medial extent of the craniotomy is the supraorbital nerve. (Copyright of Pacific Neuroscience Institute Foundation.)

2.7 Key Steps of the Procedure

- **Exposure:** Maximizing brain relaxation prior to incision is a critical step in the SOA. The degree of head rotation depends on the location of the pathology—for more midline or contralateral tumors, more head rotation is required. The patient was also given mannitol (0.5 g/kg) to facilitate further brain relaxation.
- **Incision:** The above-described incision was infiltrated with epinephrine-infused local anesthetic. The incision was made through the skin and subcutaneous fat in the direction of the hair follicles. Hemostasis of any arterial bleeding was achieved using pinpoint bipolar cautery; care was taken to avoid excessive coagulation to avoid damage to hair follicles. The dissection was carried deeper until the supraorbital nerve and its course was identified. The nerve was kept intact and carefully mobilized medially. Using a scalpel, an "L"-shaped incision was made in the pericranium and temporalis fascia to the bone first along the orbit from just lateral to the

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superior temporal line to just lateral to the supraorbital nerve, then from the supraorbital notch superiorly around 2 cm, paralleling the supraorbital nerve. The pericranial and temporalis muscle flap was then elevated superiorly in a subperiosteal fashion and retracted using fishhooks, exposing the frontal bone and keyhole.

- **Craniotomy:** A high-speed drill was then used to make a burr hole just lateral to the superior temporal line. Aiming posteriorly and superiorly avoids unintentional violation of the orbit. After stripping the dura, the craniotome was used to turn the bone flap. It is critical to maximize the height (superior–inferior) of the craniotomy by directing the craniotome superiorly, from the lateral aspect of the burr hole, approximately 2 cm before curving medially. The medial extent of the craniotomy is limited by the supraorbital nerve. Finally, the inferior cut was made as low along the anterior fossa as possible with the angle of the drill aimed as inferiorly toward the orbit as allowed by the thickness of the bone.
  Once the bone has been elevated, the bone edges were carefully examined for exposed frontal sinus air cells, which were temporarily occluded with betadine-soaked Gelfoam. The inner table of the frontal bone was drilled while maintaining the outer table allowing for a more tangential approach toward the skull base and minimizing the craniotomy defect. The dura was then elevated off the anterior skull base to expose its bony ridges, which were carefully flattened. This proves to be a critical step as these prominences, even those that appear minor, can be a significant obstruction in visualization during the intradural approach.
- **Dissection/Resection:** Under the operating microscope, the frontal lobe was then elevated and followed posteriorly toward the lesser wing of sphenoid. Subarachnoid cisterns (opticocarotid, prechiasmatic, or carotid-oculomotor) were opened generously to allow for the egress of CSF and brain relaxation. If the pathology obstructs the access to these cisterns, the tumor can first be debulked to provide the working corridor. The ipsilateral olfactory tract was sacrificed to facilitate tumor debulking and mobilization. The contralateral olfactory tract was first identified proximally and further exposed with more tumor removal. The anterior falx was coagulated and incised to free the contralateral portion of the tumor.
  When the majority of the tumor had been removed, invasion into difficult-to-visualize areas was then inspected using the 30- and 45-degree endoscopes. Such areas can include the cribriform plate, the anterior aspect of the middle fossa over the sphenoid wing, along the tuberculum and sella, and the proximal optic canals. As the endoscope sits deep within the surgical field, possibly beyond more superficial critical structures, it is crucial to introduce instruments under direct visualization of the endoscope prior to bringing the endoscope to its final position for dissection. To maximize dexterity in dissection of the tumor, it is useful to have the endoscope held either by an assistant or a pneumatic endoscope holder—the former of which has the added benefit of dynamic adjustment of depth and angle of view.
- **Closure:** Upon completion of tumor resection and adequate hemostasis, a watertight dural closure was attempted and a collagen dural substitute was overlayed. As the frontal sinus air cells were violated, the betadine-soaked Gelfoam was removed and replaced with an abdominal fat graft. The bone flap was plated and replaced in the superior-most portion of the defect. The inferior gap was then filled, but not overfilled, with bone cement. The fascia of the temporalis muscle is then approximated followed by superficial layers in a multilayer fashion. Skin glue is avoided. A gentle compressive wrap was then placed for 24 hours.

2.8 Pertinent Risks and Keys to Their Avoidance

Much of the complication profile for the SOA is comparable, although generally with lower rates, with its traditional counterparts including hematoma, stroke, wound infection, and CSF leak.

Frontalis Palsy: Complications that require special consideration with the SOA are frontalis nerve palsy, forehead hypesthesia, and skin tearing. While rates of transient frontalis nerve palsy and forehead hypesthesia are relatively high (21.7% and 17.8%, in our series) likely owing to

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retraction injury, permanent deficits are relatively rare (4% and 0%). To minimize permanent facial palsy, it is critical to contour the incision along the orbit laterally. The frontalis branches of the facial nerve run superiorly posterior to the frontal process of the zygoma, and by not allowing the incision drift posteriorly, these branches should be preserved. Similarly, careful dissection and identification of the supraorbital nerve is critical in its preservation. Finally, as there is typically significant tension on the skin from fishhook retraction to maximize the area for craniotomy, it is important to periodically adjust the location of retraction as well as reduce the tension throughout the case to minimize risk of skin necrosis or tears.

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