Optic Nerve Decompression through a Supraorbital Approach

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Abstract

Objective We propose a stepwise decompression of the optic nerve (ON) through a supraorbital minicraniotomy and describe the surgical anatomy of the ON as seen through this approach. We also discuss the clinical applications of this approach.

Methods Supraorbital approaches were performed on 10 preserved cadaveric heads (20 sides). First, 3.5-cm skin incisions were made along the supraciliary arch from the medial third of the orbit and extended laterally. A 2 × 3-cm bone flap was fashioned and extradural dissections were completed. A 180-degree unroofing of the ON was achieved, and the length and width of the proximal and distal portions of the optic canal (OC) were measured.

Results The supraorbital minicraniotomy allowed for identification of the anterior clinoid process and other surgical landmarks and adequate drilling of the roof of the OC with a comfortable working angle. A 25-degree contralateral head rotation facilitated visualization of the ON.

Conclusion The supraorbital approach is a minimally invasive and cosmetically favorable alternative to more extended approaches with longer operative times used for the management of ON decompression in posttraumatic or compressive optic neuropathy from skull base pathologies extending into the OC. The relative ease of this approach provides a relatively short learning curve for developing neurosurgeons.

Keywords

- ▶ minimally invasive
- ▶ optic nerve
- ▶ decompression
- ▶ optic neuropathy
- ▶ supraorbital approach

Introduction

Several pathologies, both extracranial (orbital) and intracranial, including primary neural tumors invading the optic canal (OC) (tuberculum sellae or sphenoid wing meningiomas, optic pathway gliomas), secondary lesions (mucocele, paranasal orbital-sinus neoplasms), inflammatory pseudotumors, fibrous or bony dysplasias, and Graves orbitopathy

can all cause optic neuropathy.^{1–3} The visual system is also affected in ~ 2% of cases of closed head trauma, specifically trauma to the fronto-orbital region.⁴ Compression of the optic nerve (ON) leading to visual deficits may occur either because of a fracture of the bony canal or because of intraneural contusion and hemorrhage, secondary vasospasm and venous occlusion, edema and compartment syndrome, and/or necrosis.⁵

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Fig. 1 Supraorbital minicraniotomy. A 2×3 -cm bone flap (blue dashes) was fashioned as basal as possible and flush with the floor of the anterior cranial fossa.

Surgical decompression is indicated in all cases of direct or indirect injury to the intracanalicular portion of the ON that is fixed within the OC.^{6–8} Numerous extracranial (transorbital, lateral orbit wall decompression, transcaruncular or transethmoidal medial orbit wall decompression, inferomedial transantral-transethmoidal, transsphenoidal) and intracranial (pterional, fronto-orbital, fronto-orbitozygomatic) approaches have been proposed for the management of ON decompression.^{3,9–11}

Decompression of 50% of the ON circumference has been reported to result in a favorable outcome.^{11–14} Most of the

surgical approaches just cited achieve this along the lateral or medial walls of the OC. A supraorbital approach would provide 180 degrees, or 50%, exposure of the superolateral and superomedial walls of the OC, and it is an increasingly popular, fast, and minimally invasive surgical alternative.^{11,15,16} There is currently a lack of data on the intracranial surgical anatomy seen through this approach.^{2,8,11,17,18} We propose a stepwise decompression of the ON through a supraorbital minicraniotomy and describe the surgical anatomy of the ON as seen through this operative window.

Methods

Supraorbital Approach and Optic Nerve Decompression

Supraorbital craniotomies and ON decompression were performed on 10 preserved cadaver heads (20 sides) injected with colored latex (red for arteries, blue for veins) using a neurosurgical operative microscope (OPMI Neuro/NC 4 System, Carl Zeiss Meditec AG; Jena, Germany) and high-speed drills (Anspach eMax 2 Plus, DePuy Synthes Power Tools; Palm Beach Gardens, Florida, United States).

Three-point fixation was achieved using a Mayfield head holder, and the heads were positioned with 20 degrees of extension and the vertex pointed slightly downward with 25 degrees of rotation toward the contralateral side to facilitate retraction of the frontal lobe (**Fig. 1**).¹⁶

Skin Incision

A 3.5-cm skin incision was made along the supraciliary arch, lateral to the supraorbital foramen, and extended laterally until the zygomaticofrontal suture (**Fig. 2A**). The orbicularis oculi muscle was exposed, and the skin incision was continued down to the periosteum following the superior fibers of the orbicularis oculi and pushing the myoperiosteal layer to the orbital margin. This incision technique helped avoid

Fig. 2 Left supraorbital minicraniotomy. (A) A 3.5-cm skin incision was made along the supraciliary arch, lateral to the supraorbital foramen, extending laterally until the zygomaticofrontal suture. (B) A burr hole was placed posterior to the anterior end of the temporal line, just superior to the frontozygomatic suture. (C) A 2×3 -cm bone flap was fashioned flush with the anterior fossa floor. (D) The inner edge of the orbital rim and bony irregularities on the roof of the orbit were drilled down.

injury to the frontalis branches of the facial nerve and facilitated postoperative reconstruction.¹⁷ The anterior margin of the temporal muscle was retracted laterally and posteriorly, and the orbicular muscle was retracted downward to expose the anterior temporal line.

Minicraniotomy

A burr hole was placed posterior to the anterior end of the temporal line, just above the frontozygomatic suture, and a 2 × 3-cm bone flap was fashioned as basal as possible and flush with the floor of the anterior cranial fossa (►Fig. 2B, 2C). The inner edge of the orbital rim and any bony irregularities on the roof of the orbit toward the ON were drilled down using a diamond burr to widen the surgical corridor and to increase the available working angle (►Fig. 2D).

Dural Elevation

The frontobasal dura layer was carefully dissected and detached from the inner edge of the frontal bone, orbital roof, anterior ethmoidal bone, and lesser wing of the sphenoid. Dural elevation was continued posteriorly until the optic foramen was encountered at the edge of the posterior aspect of the lesser wing of the sphenoid. Immediately lateral to the OC, the dura was elevated to uncover the base and tip of the anterior clinoid process. The entrance of the dura into the OC, the base of the anterior clinoid process, and the posterior edge of the planum sphenoidale were all identified extradurally (►Fig. 3A).

Exposure and Unroofing of the Optic Canal

After localization of the OC, the direction of the OC was identified, and two troughs were drilled on each side of the OC. The lateral trough was placed at the base of the anterior clinoid process, which served as an anatomical landmark for the lateral aspect of the OC. The dura entering the OC was stretched using a suction tip to help facilitate identification of the medial edge of the OC. A second trough was then fashioned on the medial side, parallel to the direction of the OC. The roof of the OC was then carefully thinned between the two troughs.

Drilling of the roof began at the thickest portion (orbital side) of the OC, and a thin shell of bone was left in place to protect the ON. The remainder of the roof was drilled in a posterior to anterior direction using a 2- to 3-mm diamond burr until only a thin shell of bone remained. Copious and continuous irrigation revealed, through the transparent bony rim, the underlying white ON. After unroofing of the OC, the falciform ligament was opened parallel to the ON. The remaining thin shell of bone was then carefully fractured using a blunt dissector, and the optic sheath was exposed (►Fig. 3B, 3C).

Optic Nerve Decompression

The ON was decompressed by incising the optic sheath and opening the periorbital. Because of the relationship between the ophthalmic artery (OA) and ON, the optic sheath was incised at the superomedial aspect of the OC. The optic sheath was opened, and the annulus of Zinn was exposed and incised between the lateral and superior rectus muscles (►Fig. 4).

Fig. 3 Left optic nerve decompression. (A) The frontobasal dura was detached, and the orbital roof was thinned. (B) The edge of the optic canal was identified, two troughs were drilled on each side of the optic canal, and the remaining shell of bone was carefully fractured using a blunt dissector. (C) The optic sheath was exposed.

The periorbital was incised immediately lateral to CN IV to spare the medial extra-annular structures: the lacrimal nerve, frontal nerve, and superior ophthalmic vein.

The distance between the inner edge of the craniotomy and the optic foramen, the length of the bone roof of the OC, the diameter of OC at its intracranial and extracranial orifices, and the available working angles were measured in every approach. The optimal angle of head inclination for exposure of the superior aspect of the OC was also determined.

Results

Surgical decompression of the ON was successfully performed through supraorbital craniotomies in all specimens, and the key surgical steps were identified. Mechanical and thermal injuries are not uncommon during unroofing and decompression of the ON. A thorough knowledge of the ON anatomy and a detailed understanding of its vascular supply are necessary to avoid intraoperative injury to the nerve.

Fig. 4 Decompressed left optic nerve. (A, C) Two-dimensional (2D) and (B, D) three-dimensional (3D) views of the decompressed optic nerve (ON). (E) 2D and (F) 3D view of the decompressed ON and its relationship with the intraorbital ophthalmic artery.

Optic Nerve Segmentation

For the purposes of this study, the ON was divided into four segments: intracranial (~ 10 mm), intracanalicular (~ 10 mm), intraorbital (25–30 mm), and intraocular (1 mm).⁹

After leaving the optic chiasm, the intracranial ON travels through the subarachnoid space and into the pia mater before entering the OC, which forms a prominence in the upper part of the sphenoid sinus directly in front of the sella turcica and along the medial aspect of the anterior clinoid process. The intracranial segment is surrounded by the optic sheath and maintains a close relationship with the surrounding meningeal architecture. Prior to entering the OC, the intracranial segment is covered by the falciform ligament for several millimeters. The distal dural ring, which surrounds the internal carotid artery (ICA), courses medially and obliquely over the artery and stretches from the interclinoid ligament to the lateral and superior aspects of the optic sheath. This segment then courses anteriorly, caudally, and laterally toward the orbit.

The intracanalicular segment enters the OC with the OA and is surrounded by arachnoid as well as the optic sheath.

The intraorbital segment passes through the medial part of the annulus of Zinn and under the elevator and superior rectus muscles. After exiting the OC, the optic sheath blends smoothly into the periorbita. The subarachnoid space surrounding the intracranial segment is continuous with the subarachnoid space around the intracanalicular and intraorbital segments. The intraorbital segment decreases in diameter by ~ 1 mm (~ 4.0–3.0 mm) just behind the globe.¹⁹

The intraocular segment continues in the optic papilla and, at the optic disk, decreases in diameter to 1.5 to 2.0 mm.¹⁹

Vascular Supply

The heat generated by the surgical drill poses the risk of thermal injury to the vessels supplying the ON. A thorough understanding of the course of the feeding vessels helped determine a safe location and direction for drilling. The OA is the main vascular supply of the ON. We carefully studied the vascular anatomy of the ON in our specimens.

The OA arose from the supraclinoid segment of the ICA, distal to the upper carotid-dural ring, along the medial half of its anterior wall. It originated underneath the anterior clinoid process from either the intradural (17 cases) or extradural (3 cases) portion of the ICA. It first ran medially and then coursed laterally on the upper surface of the optic strut below the intracranial ON just before entering the OC. In its anterior course, the ON pierced the optic sheath at the upper surface of the optic strut and exited the OC outside of the optic sheath. It then coursed along the inferolateral side of the ON and optic sheath to the orbital apex. Previous studies found the OA inferomedial or inferior to the ON at the intracranial orifice of the OC, between the two dural layers inferior to the ON within the OC, and inferolateral to the ON at the intraorbital opening (►Fig. 5).^{10,20,21} The central retinal artery and vein coursed in the middle of the nerve from a point ~ 3 mm behind the globe after exiting from the ON to the papilla. The central retinal artery originated from the OA that traveled in the subarachnoid space from its origin at the intracranial ICA. The superior

Fig. 5 Relationship between the optic nerve (ON) and ophthalmic artery (OA) within the optic canal (OC). At the intraorbital opening (A) the OA is inferolateral to the ON. Within the optic canal (B) the OA is inferior to the ON, and at the intracranial orifice (C), the OA is inferomedial or inferior to the ON. The OC changes in width and thickness along its course. L, lateral side; M, medial.

orbital vein was joined in the orbit by the central retinal vein that penetrated the dura. The intraocular segment received its major blood supply from the short posterior ciliary arteries. Understanding this relationship between the ON and the OA was essential for performing a safe decompression.

Optic Canal

A clear understanding of the shape, size, and boundaries of the OC helped identify the optimal unroofing technique. The OC was separated from the superior orbital fissure by the optic strut; it consisted of a floor, a roof, and a lateral and a medial wall. The anterior root of the lesser wing of the sphenoid formed the roof of the OC. The OC was funnel shaped with a wider cranial orifice and a narrower orbital opening. The cranial opening of the OC was oval shaped with its mediolateral diameter wider than its superoinferior diameter.

Intraoperative Measurements

After performing the intracanalicular decompression of the ON, the mean length of the OC was found to be 11.2 ± 1.1 mm (range: 9–13 mm), the mean width of the proximal portion to be 7.3 ± 1.1 mm (range: 6–9 mm), and

the mean width of the distal portion to be 6.2 ± 0.8 mm (range: 5–8 mm). The mean distance between the inner edge of the craniotomy and the OC was 61.7 ± 1.1 mm (range: 60–63 mm) (► **Table 1**).

Discussion

Numerous intracranial and extracranial surgical approaches have been proposed for intracanalicular decompression of the ON. Minimally invasive surgery has gained wide popularity due to its improved cosmetic outcomes and generally reduced operative times. For such reasons, approaches to the ON, including the endoscopic transsphenoidal and the keyhole supraorbital approach, have been developed.

The supraorbital approach, introduced in 1908 by Krause for the management of pituitary tumors, was later expanded to include removal of the supraorbital ridge and part of the orbital roof to enhance surgical exposure.^{22,23} This approach has been proposed for the treatment of ON decompression in cases of compressive optic neuropathy due to anterior and middle skull base tumors as well as for the treatment of visual loss due to osteoporosis, bacterial abscesses, aspergillosis, Wegener granulomatosis, and sarcoidosis.^{18,24–29}

Table 1 Intraoperative measurements

No. of specimen, side	Craniotomy edge to OC, mm	OC length, mm	OC proximal width, mm	OC distal width, mm
Specimen 1				
Right	61	10	8	6
Left	61	11	7	6
Specimen 2				
Right	63	12	9	5
Left	62	10	9	6
Specimen 3				
Right	60	9	8	7
Left	60	10	8	7
Specimen 4				
Right	61	12	6	6
Left	61	12	6	6
Specimen 5				
Right	60	11	7	5
Left	60	12	7	6
Specimen 6				
Right	62	10	8	6
Left	62	10	7	7
Specimen 7				
Right	63	11	9	8
Left	63	11	8	7
Specimen 8				
Right	62	12	6	5
Left	62	13	6	5
Specimen 9				
Right	63	13	7	6
Left	63	12	8	6
Specimen 10				
Right	62	12	6	6
Left	63	11	6	7
Mean	61.7	11.2	7.3	6.2

Abbreviation: OC, optic canal.

A recent study by Chen et al reported on a series of seven patients who underwent supraorbital keyhole ON decompression and dural repair.¹¹ All seven patients had skull base fractures, and of those, five patients had visual loss associated with cerebrospinal fluid (CSF) leaks. Following surgery, the CSF leakage ceased in all five cases, and recovery of vision occurred in four patients with previously severe or complete ON deficits.

The supraorbital approach minimizes exposure and dissection of normal anatomy and has the potential to reduce operative morbidity and intraoperative time. This minimally invasive approach may also reduce postoperative recovery time while providing the patient with a satisfying cosmetic

result. Although miniaturization of the approach reduces trauma to soft tissue and bone, it does not necessarily reduce trauma to the cortex or reduce the risk of neurologic complications. Thus meticulous microsurgical technique is crucial for a good functional outcome.

Because of the limited exposure provided by the supraorbital minicraniotomy, and the angle of ON exposure it provides, proper positioning of the patient is of primary importance. Optimal head positioning resulted in a 20-degree extension, with the vertex oriented slightly downward and 25 degrees of rotation to the contralateral side (► Fig. 1). In our specimens, this position facilitated frontal lobe retraction and improved exposure of the superior and medial aspects of

the OC. The minicraniotomy must be fashioned as basal as possible and flush with the floor of the anterior cranial fossa to compensate for the minimal frontal lobe retraction afforded by this small bone opening (►Fig. 2D).

As in most skull base approaches, bone resection minimizes brain retraction. Thus reducing the thickness of the orbital roof with a diamond drill minimized the need for frontal lobe retraction, expanded the surgical corridor to the planum sphenoidale, and created a better working angle to the OC. Knowledge of the location and course of the OC was paramount for effectively minimizing bone resection. We studied and measured the course of the OC in all our specimens. The direction of the OC was defined by a line passing from a point ~13 mm medial to the frontozygomatic suture to the OC. After the OC was localized, and the direction of the OC identified, two troughs were drilled on each side of the OC. The roof was then carefully thinned between the two troughs. Thinning of the narrowest and thickest distal parts of the OC proved to be essential in this study for achieving optimal decompression of the most constrained portion of the ON.⁹

A diamond burr was preferred over a cutting burr for unroofing of the OC. Although diamond burrs are more delicate on underlying structures, they tend to produce more heat from friction. Constant irrigation with 0.9% saline solution was applied while drilling to enable a clear view of the underlying structures and to avoid thermal injury to the ON.^{11,30} Because of the complex anatomy, it is safer to start drilling at the thickest portion of the OC and to leave in place a thin shell of bone to cover and protect the ON. Copious and continuous irrigation revealed, through the transparent bony rim, the underlying whitish ON. The remainder of the roof was drilled with a 2- to 3-mm diamond burr, and the last thin shell of bone was carefully fractured using a blunt dissector to expose the optic sheath (►Fig. 3B).

There remains debate about whether the optic sheath should be incised in posttraumatic compartment syndrome. Detractors of sheath incision doubt its efficacy and report higher risks of CSF leak and injury to the OA. In our opinion, OC decompression and sheath incision may have the same benefits on the ON as expansive duraplasty after decompressive craniectomy for traumatic brain injury on brain parenchyma. Therefore we advocate opening of the optic sheath, especially in cases of traumatic neuropathy, even with the risk of injury to the ON and OA. Understanding the anatomy of the OA is important to minimize the risk of thermal injury and, more importantly, to locate the artery accurately while incising the optic sheath.

In all specimens the OA was observed running between the parietal and visceral dural layers within the OC, inferomedial or inferior to the ON at the OC, inferior to the ON within the OC, and inferolateral to the ON at the anterior end of the OC (►Fig. 5). Although the OA has a range of anatomical variations, it rarely runs along the superomedial aspect of the ON within the OC, and this orientation was not observed in any specimens. Because of this relationship between the OA and ON, the superomedial aspect of the OC was identified as the optimal location for incising the optic sheath.

Sharp microdissection of the arachnoid plane helped preserve blood supply to the ON; coagulation must be avoided near the ON. No attempt should be made to coagulate the optic sheath because the intracanalicular segment of the ON receives its blood supply from an overlying pial plexus and from small branches of the OA within the OC.³¹

The annulus of Zinn was found to be strongly attached to the ON, and thus opening of the annulus should be reserved for cases in which inflammation of the soft tissue might contribute to the compression. When opening the annulus, the periorbita was incised immediately lateral to CN IV and spared the medial extra-annular structures (lacrimal, frontal, and superior ophthalmic vein). To avoid injury to the superior ophthalmic vein, we incised the annulus of Zinn between the lateral and superior rectus muscles.¹⁴

Advantages and Limits of the Supraorbital Approach

Exposure of half the circumference of the ON and opening of the entire length of the OC is generally considered necessary for successful decompression of the ON.^{11–14} The supraorbital approach facilitates a 180-degree decompression by providing a working angle that allows for removal of the roof and the superior portion of the medial and lateral walls of the OC (►Fig. 3A).

The supraorbital approach provides a decreased risk of morbidity, compared with more extensive approaches, and the supraorbital corridor provides a relatively easy approach to the ON. Some evidence suggests this procedure has resulted in shorter hospital stays when compared with more traditional surgical approaches.¹¹

Good cosmetic results can be achieved from a 3.5-cm supraciliary skin incision with careful dissection of the orbicularis oculi muscle and facial nerve when compared with wider fronto-orbito or fronto-orbitozygomatic craniotomies, or with skin incisions for medial wall decompressions in the transethmoidal approach.^{9,17,18}

Unlike the fronto-orbito or fronto-orbitozygomatic approach, the supraorbital approach facilitates decreased risk of injury to the facial nerve, superficial temporal artery, and periorbital structures, a risk that is higher in extracranial transorbital approaches.^{9,32} The risk of damaging the periorbital structures, supraorbital nerve, and/or trochlear attachment of the superior oblique muscle are also less of a factor in the supraorbital approach.³³

This surgical corridor is wide enough (3–3.5 cm) to biopsy circumscribed tumors of the orbit. When dealing with skull base meningiomas with OC extension, it is possible to decompress the nerve early in the procedure because the OC is encountered in the initial steps of the surgery before the tumor bulk. Early decompression can minimize the risk of intraoperative injury to the ON and OA during manipulation of the tumor.³⁴ However, posterior exposure may still be limited in cases of deep lesions in the orbital apex.²

Despite the increased surgical distance to the ON compared with the pterional approach (6–13 mm), the supraorbital route provides straightforward and more conservative access to the OC. In the pterional approach for ON decompression, total extradural anterior clinoidectomies have been

proposed,¹⁴ whereas only partial resection of the base of anterior clinoid process was required here. Additional surgical space was achieved by draining CSF through a spinal needle.

Due to the limited size of the craniotomy, this approach is limited in cases of traumatic optic neuropathy where cortical edema from traumatic injury may prevent sufficient brain retraction, identification of the OC, and/or adequate control of the neurovasculature.¹¹ In previous series of patients undergoing supraorbital ON decompression, anterior clinoidectomies had to be performed on five patients to provide adequate exposure of the OC.¹¹

Furthermore, the difficulty of exposing the optic strut is a potential limitation that could result in injury to the supraclinoid internal carotid artery and hinder oculomotor nerve recovery in cases of orbital apex fractures.¹⁴ The risk of injury to the ICA or the optic chiasm is reduced by the surgical trajectory and by early identification of anatomical landmarks that help the surgeon avoid critical neurovascular structures while drilling. The supraorbital approach also negates the risks of injury to the anterior and posterior ethmoidal arteries and/or enophthalmos from opening of the ethmoid air cells that are present in the transthemoidal approach.^{3,4,8} However, medial wall approaches, including the transthemoidal and endonasal transsphenoidal, carry a reduced risk of injury the OA as it courses with the ON in the inferolateral portion of the OC.⁵

Conclusion

The supraorbital approach is a valid, minimally invasive, and relatively fast alternative to more extended approaches for 180-degree ON decompression in cases of posttraumatic ON injury and compressive optic neuropathy due to intraorbital skull base pathologies. Adequate patient positioning provides good surgical exposure that minimizes the need for frontal lobe and olfactory nerve retraction. The extradural bone work and dissection, preservation of part of the anterior clinoid process, and the associated reduced risk of damage to the periorbital structures, supraciliary nerve, facial nerve branches, and/or the superficial temporary artery facilitated by this approach may provide better functional and cosmetic results than more extended approaches.

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