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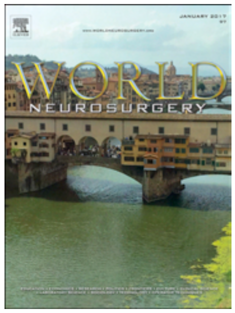

Technical Description of Minimally Invasive Extradural Anterior Clinoidectomy and Optic Nerve Decompression. Study of Feasibility and Proof of Concept

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Technical Description of Minimally Invasive Extradural Anterior Clinoidectomy and Optic Nerve Decompression. Study of Feasibility and Proof of Concept.

ABSTRACT

Background: Several pathologies that involve the optic canal or its contained structures may cause visual impairment. Several techniques have been developed to decompress the optic nerve.

Object: To describe minimally invasive extradural anterior clinoidectomy (MiniEx) for optic nerve decompression, detail its surgical anatomy, present clinical cases and established a proof of concept.

Method: Anatomical dissections have been performed in cadaver heads to illustrate the surgical anatomy and to depict stepwisesy the MiniEx approach. In addition, we have applied these surgical concepts to decompress the optic nerve in six clinical cases.

Result: MiniEx approach allowed the extradural anterior clinoidectomy and a nearly 270-degree optic nerve decompression using the no-drill technique. In the MiniEx approach the size of skin incision, dissection of the temporal muscle and craniotomy were smaller and provided the same extent of exposure of the optic nerve, anterior clinoid process and superior orbital fissure as that usually provided by standard techniques. All patients that underwent operation with this technique had improved visual status.

Conclusion: The MiniEx approach is an excellent alternative to traditional approaches for extradural anterior clinoidectomy and optic nerve decompression. It may be used as a part of more complex surgery or as a single surgical procedure.

Key words: Keyhole approach; Minimally invasive neurosurgery; Pterional approach; Optic nerve; Optic canal; Extradural anterior clinoidectomy.

INTRODUCTION

Several pathologies that involve the optic canal or its contents may cause orbitopathy with consequent visual impairment. [1,2] Fronto-orbital trauma (either due to a fracture of the optic canal or intraneural contusion, vasospasm, necrosis or edema), intracranial tumors (meningiomas of the tuberculum sellae or of the sphenoid bone and optic nerve gliomas), secondary lesions (mucocele, paranasal orbit-sinusal neoplasms), fibrous or bony dysplasia, inflammatory pseudo-tumors, Graves orbitopathy or vascular lesions (carotid-ophthalmic aneurysms) are the most common diseases that may compress the optic nerve. [3-5] Numerous publications have shown that early decompression of the canalicular segment of the optic nerve improves visual outcomes. [6-14]

Minimally invasive craniotomies have increasingly become popular alternative for traditional craniotomies in many surgical scenarios (e.g. vascular and skull base procedures). Compared with traditional techniques they present several advantages. Various minimally invasive techniques to decompress the optic nerve have been recently described. However, some of them include only experimental studies with no associated clinical application, other papers describe endoscopic assistance or include techniques that require intradural procedures [47-55]

Extradural optic nerve decompression through a “keyhole” approach may provide satisfactory decompression of the optic nerve. In this paper, we propose extradural optic nerve decompression technique through a minimally invasive approach as a modification of the method previously described by Dolenc. [1-2]

METHODS

The MiniEx and PT approaches for optic nerve decompression were performed using an operative microscope under magnifications of X4 to X25 on four formalin-fixed cadaveric heads. The arteries were perfused with red and the veins with blue silicone. Another two specimens and two dry skulls were dissected to show the anatomic relationships among the optic nerve and its canal, the anterior clinoid process, cavernous sinus and superior orbital fissure. Measurements of the size and area of the bone flaps were performed with a caliper to avoid measurement errors.

In addition, the technique of extradural anterior clinoidectomy approach with a MiniEx has been used to decompress the optic nerve in six clinical cases. The surgical outcomes of these cases, including visual and neurological morbidities, were analyzed in this study. (Video1)

RESULTS

Bone relationships

The optic canal is located at the orbital apex. It is bounded by the body of the sphenoid bone medially, the lesser wing of the sphenoid bone superiorly and the medial surface of the anterior clinoid process and optic strut laterally and the upper surface optic strut and the adjacent part of the body of the sphenoid bone below (Fig. 1). The optic canal is directed backward and medially and has an oval shape in the vertical axis.[15]

The anterior clinoid process is a projection of bone that directs posteriorly from the medial end of the lesser wing of the sphenoid bone in the anterior part of the roof of the cavernous sinus. In a superior view, it has a triangular shape with its base located ventrally and its tip posteriorly (Fig. 1A, 1B, and 1C). [16,17]

The base of the anterior clinoid process has one lateral and two medial sites of attachment. Laterally, the base is attached to the lesser wing of the sphenoid bone overlying the superior orbital fissure. Medially, the base is attached through two roots: the anterior root extends medially from the base of the anterior clinoid process to the body of the sphenoid bone to form the roof of the optic canal, and the posterior root, called the optic strut, extends medially below the optic nerve to the sphenoid body to form the floor of the optic canal (Fig. 1C).

The superior surface of the optic strut forms the floor of the optic canal and its inferior surface forms the medial part of the roof of the superior orbital fissure and anterior portion of the roof of the cavernous sinus (Fig. 1D). The outer layer of the anterior clinoid process is composed of dense cortical bone with an interior of the cancellous bone. It may contain venous channels or maybe pneumatized and include air cells that communicate with the sphenoid sinus through the optic strut. Postoperative CSF leaks may occur if the sphenoid sinus is opened after, especially in the intradural anterior clinoidectomy or when the dura is opened after extradural anterior clinoidectomy.[10-20]

Dural relationships

The dura that covers the superior surface of the anterior clinoid process continues medially to form the lateral part of the distal dural ring surrounding the internal carotid artery. This dura is continuous laterally with the dura that covers the superior surface of the lesser wing of the sphenoid bone. Medially, it extends below the optic nerve to include the superior surface of the optic strut and forms the anterior part of the distal dural ring. From here the dura extends medially and posteriorly to cover the upper part of the carotid sulcus and from the medial portion of the upper ring. Anteriorly, the dura of the superior surface of the anterior clinoid process covers the anterior root of the lesser wing and attaches to the posterior edge of the planum sphenoidale (Fig. 2). The clinoid segment of the internal carotid artery is located between the proximal and distal dural rings (Fig. 2C and 3F).

The tip of the anterior clinoid process is the site of attachment of the anteromedial tip of the tentorial edge and the anterior petroclinoid and interclinoid dural folds (Fig. 2). Another dural fold, the falciform ligament, extends from the base of the clinoid across the roof of the optic canal to the planum sphenoidale (Fig. 1A and 1B).[21]

Meningo-periorbital band

The meningo-periorbital band, located at the lateral edge of the superior orbital fissure, tethers the frontotemporal basal dura to the periorbita. It blocks the elevation of the temporal dura from the lateral wall of the cavernous sinus (Fig. 3C, 4G and 4H).

At the middle cranial fossa, the dura has two layers: periosteal and meningeal. The periosteal dura covers the bone and the meningeal dura faces the brain and covers the temporal lobe. At the superior orbital fissure, the periosteal dura exits the intracranial space and is continuous with the periorbita, whereas the meningeal layer continues intracranially. The periosteal dura joining the periorbital at the edge of the superior orbital fissure forms a strong dural band at the lateral side of the fissure that blocks elevation of the meningeal dura at this site. It is located at the outboard end of the superior orbital fissure and contains the orbitomeningeal artery and vein.[10,22-26]

Neural relationships

Optic nerve

The optic nerve is divided into four parts: intraocular, intraorbital, intracanalicular, and intracranial. The dural sheath around the optic nerve blends smoothly into the periorbita at the anterior end of the optic canal. After passing through the optic canal, which forms a prominence in the upper part of the sphenoid sinus immediately in front of the sella turcica and along the medial aspect of the anterior clinoid process, the intracranial portion of the nerve is directed posteriorly, superiorly and medially toward the optic chiasm (Fig. 2). The ophthalmic artery enters the orbit on the lateral side of the nerve and passes above the nerve to reach the medial sides of the orbit (Fig. 2A).

Oculomotor, trochlear, abducens and ophthalmic nerves

The oculomotor, trochlear, abducens, and ophthalmic nerves course in the inner part of the lateral wall of the cavernous sinus (Fig. 2A). The abducens courses medial to the ophthalmic nerve and is adherent to the lateral surface of the intracavernous carotid medially and the medial surface of the ophthalmic nerve and the inner part of the lateral sinus wall laterally (Fig. 2C).

The oculomotor nerve pierces the roof of the cavernous sinus near the center of the oculomotor triangle (Fig. 2A and 2B), and the trochlear nerve enters the dura at the posterolateral edge of the triangle (Fig. 2A). Both nerves are situated medial to and slightly beneath the level of the free edge of the tentorium at their point of entry.

The trochlear nerve enters the roof of the sinus posterolateral to the oculomotor nerve and courses below the oculomotor nerve in the posterior part of the lateral wall of the sinus. From there, the trochlear nerve passes medially between the oculomotor nerve and dura lining the lower margin of the anterior clinoid and optic strut to reach the medial part of the orbit and the superior oblique muscle (Fig. 2A, 3E, 3F, 4I, and 4J).

The ophthalmic nerve is the smallest of the three trigeminal divisions. It is inclined upward as it passes forward near the medial surface of the dura, forming the lower part of the lateral wall of the cavernous sinus, to reach the superior orbital fissure (Fig. 2A, 3E, 3F, 4I and 4J).

The superior petrosal sinus passes above the posterior root of the trigeminal root to form the upper margin of the ostium of Meckel's cave (Fig. 2A), which communicates with the subarachnoid space in the posterior fossa. The cave extends forward around the posterior trigeminal root to the midportion of the ganglion.

The abducens nerve pierces the dura forming the lower part of the posterior wall of the cavernous sinus at the upper border of the petrous apex and enters a dural canal, referred to as Dorello's canal, where it passes below the petrosphenoid ligament (Gruber's ligament). The nerve bends laterally around the proximal portion of the intracavernous carotid and gently ascends as it passes forward inside the cavernous sinus medial to the ophthalmic nerve, on the lateral side of the internal carotid artery, and below and medial to the nasociliary nerve (Fig. 2A and 2C).[20]

Arterial relationships

The cavernous segment (C3) of the internal carotid artery enters the cavernous sinus by passing medial to the petrolingual ligament and ends at the distal dural ring.[19] Through its course, the cavernous segment of the internal carotid artery is divided into the posterior ascending segment, posterior curve, horizontal segment, anterior curve, and anterior ascending segment (Fig. 2C).[20]

The segment of the internal carotid artery included between the proximal and distal dural rings is called the clinoid segment and can be exposed by removing the anterior clinoid process (Fig. 2C, 3F and 4J).[20,32] The ophthalmic artery is the first branch of the supra-clinoid segment of the internal carotid artery, arising just distal to the distal dural ring on the superior surface of the internal carotid artery, then coursing forward and laterally to reach the optic canal (Fig. 1A). [20]

Extradural anterior clinoidectomy through MiniEx

Position of the head, skin incision, and muscle dissection

This approach may be implemented as part of a more complicated surgery or as a single surgical procedure. The position of the head, skin incision and muscle dissection may vary. We performed approach as a single procedure through an extended supraciliary incision, as described by Stallard-Wright.[26] It extends from the lateral end of the eyebrow to the orbital rim just lateral to the canthus of the eye, then turns and extends posteriorly (Fig. 4A).[26] At the axial level of the lateral canthus of the eye, the branches of the facial nerve that innervate the orbicularis and frontalis muscles were located at a mean distance of 40.4 mm (range 35.2 - 45.6 mm) above the lateral canthus of the eye.[13] So, the skin incision should not extend more than 40 mm from the lateral canthus to avoid frontal branch injury (Fig. 4A).

After the skin incision and the flap was reflected, the frontalis muscle was reflected superiorly and the orbicularis muscle inferiorly. The periosteum was incised to expose the orbital rim and the anterior and superior attachments of the temporal muscles (Fig. 4B and C).[27] The temporal muscle was detached from the anterior part of the superior temporal line and zygomatic and frontal processes of the frontal and zygomatic bones. Its periosteum underlying the muscle was elevated from the bone, and the muscles were reflected posteriorly and inferiorly (Fig. 4D). Care should be taken to preserve the deep temporal fascia through which the deep temporal vessels and nerves that supply the muscle course to avoid temporal muscle atrophy.[28,29]

Extradural stage

After the bone was exposed, a small craniotomy, 35 mm in diameter, was performed to present the frontal dura superiorly, temporal dura inferiorly and periorbita anteriorly with a Y-shaped osseous configuration separating them (Fig. 4E). We call this area “the bone crossroad.” It is formed anteriorly and superiorly by the orbital roof, anteriorly and inferiorly by the edge of a greater wing of the sphenoid bone, and posteriorly by the lesser wing of the sphenoid bone (Fig. 4E). The decision as to whether to do a craniotomy or craniectomy depends on the pathology.

The frontal and temporal dura was retracted, and the lesser wing and part of the superior and lateral wall of the orbit were drilled to expose the meningo-orbital band, which was divided using curved microscissors and the dura was elevated from the superior and inferior aspects of the anterior clinoid process from the base to the tip (Fig. 4F, 4G and 4H). The periosteal dural layer covering the superior orbital fissure and the anterior part of the lateral wall of the cavernous sinus was elevated to expose the lateral and inferior sides of the anterior clinoid process (Fig. 4I).[30] The procedure continues similarly to the conventional approach. The three osseous attachments of the anterior clinoid process are cut using the no-drill technique using microrongeurs and the optic nerve sheath was opened (Fig. 4J). Care should be taken to avoid injury of the ophthalmic artery. The incision of the optic nerve sheath should extend along its superior aspect. This allows decompression of 270° of the optic nerve.

Clinical series of extradural anterior clinoidectomy through keyhole approach.

Six patients, three female, with an average age of 36.6 years (range: 7 - 57 years) were included in this study. Three patients had meningiomas of the tuberculum sellae, two patients presented fibrous dysplasia and one patient had a tumor in the cavernous sinus. The average surgical time in the six patients was 5.1 hours. The average length of stay in the intensive care unit was 1.4 days (range:1 - 3). Bilateral procedure was performed on three patients. The average diameter of the craniotomy was 26.1 mm (range: 17.5 - 32.1) and the average area was 496 mm2 (range: 349 - 645 mm2). The no-drill technique was used in all cases to remove the anterior clinoid process. Visual acuity was preserved in all six cases as demonstrated by ophthalmologic evaluation. Only one patient developed bitemporal hemianopia following meningioma removal (Table 1).

DISCUSSION

Several diseases have been associated with optic nerve compression, including fronto-orbital trauma (fracture of the optic canal with intraneural contusion or edema), intracranial tumors that involve the optic canal (meningioma of tuberculum sellae or lesser wing of the sphenoid bone or optic nerve gliomas), secondary lesions (mucocele, paranasal orbita-sinusal neoplasms), fibrous or bony overgrowth, inflammatory pseudo-tumors, or vascular pathologies (carotid-ophthalmic aneurysms).[7] Optic canal involvement quite common in tuberculum sellae meningiomas (77.4%) and it correlates well with preoperative visual status.[30]

Most patients will have at least some improvement in vision status after optic nerve decompression for acute or chronic compressive neuropathy.[15,17,31] In cases of tumoral pathologies, optic nerve decompression improves not only the visual outcome but also increases the degree of possible tumor resection.[17] Early optic nerve decompression is essential for enhancing visual recovery, especially in cases of tuberculum sellae and planum sphenoidale meningiomas in which optic nerve decompression has been recommended before tumor removal.[32] Margalit et al.[4] concluded that early decompression of the intracanalicular optic nerve allows identification and separation of the tumor from the nerve and allows removal of the from this area with minimal manipulation of the optic nerve.

Dolenc [1,2,25, 33,34] initially described an anterior clinoidectomy via the extradural space that allows optimal mobilization of the optic nerve and the internal carotid artery in 1985. Anterior clinoidectomy facilitates tumor removal from the parasellar area and cavernous sinus as well as appropriate management of internal carotid aneurysms. [25,33,34] Consequently, some modified methods have been described to accomplish safer and simpler anterior clinoidectomy.

Coscarella et al.[35] published an alternative extradural exposure of the anterior clinoid process aimed at avoiding injury of the oculomotor, lacrimal, frontal and trigeminal nerves and their branches. Instead of exposing the anterior clinoid process from medial to lateral and dividing the meningo-orbital dural fold along the assumed safe path, they elevated the dura from the edge of the lesser wing from lateral to medial, exposed the superior orbital fissure and peeled away the outer layer of the cavernous sinus along the greater wing medial to the foramen rotundum, to reveal the inferolateral surface of the anterior clinoid process. This allowed dural division under full visualization to avoid damaging structures passing through the superior orbital fissure.

Minimally invasive craniotomies have increasingly become popular alternative for traditional craniotomies in many surgical scenarios (e.g. vascular and skull base procedures). Compared with traditional techniques they present several advantages, including less dissection of the temporal muscle, smaller bone flap, protection of neuro-vascular structures of the temporal muscle, preservation of the superficial temporal artery, better aesthetic outcomes, shorter surgical duration, no violation of the paranasal sinus and reduction of the probability of damage to the cortex (Table 2). Various minimally invasive techniques to decompress the optic nerve have been recently described. However, some of them include only experimental studies with no associated clinical application, other papers describe endoscopic assistance or include techniques that require intradural procedures. [47-55]

Abhinav et al.[39] reported an endoscopic endonasal approach for optic canal decompression. They have demonstrated in an anatomic and clinical study that 160°-180° of decompression of the optic canal is technically easy to perform, but that decompression of the superolateral aspect of the optic canal to increase the extent of bony decompression to 270° is more challenging and increases risk of injury to the optic nerve.[30-32]

Rigante et al.[5] described a technique of optic nerve decompression through a supraorbital approach. The maximum percentage of decompression they have accomplished was 180°. Komatsu et al.[9] published a cadaveric study of endoscopic extradural anterior clinoidectomy through a supraorbital keyhole using the high speed-drill technique. Blindness following optic canal decompression and anterior clinoidectomy has been reported. It has been attributed to the spread of heat from the drill.[39] Chang[20] recently described a "*no-drill*" technique of anterior clinoidectomy in which the extradural anterior clinoidectomy was performed using a small bone rongeur.

The MiniEx for optic nerve decompression through a less invasive approach may be performed as part of a more complicated surgery or aiming only optic nerve decompression. Its small incision and minimal dissection of the temporal muscle reduces the risk of temporal muscle atrophy and cosmetic deficit as compared to other techniques. This small craniotomy allows 270° decom pression of the optic nerve and complete removal of the anterior clinoid process that can be performed with “drill” or “no-drill” techniques. We prefer using the no-drill technique to avoid thermal risk to the nerve from the drill. This technique also accesses the superior orbital fissure, the clinoid segment of the carotid and anterior part of the cavernous sinus.[45-48]

CONCLUSION

In this paper we have demonstrated the anatomic and surgical feasibility of adequately decompressing the optic nerve trough a keyhole approach. MiniEx is a novel alternative technique that allows a rapid, easily reproducible and safe decompression of the optic nerve, with a small incision and muscular dissection, reducing the cosmetic deficit. It may be carried out as part of a more complex surgery or as a single surgical procedure only for optic nerve decompression in cases of tumoral, traumatic or chronic optic nerve compression. This paper demonstrated that MiniEx is a safe, effective and less invasive alternative to the traditional techniques.

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FIGURE LEGENDS

FIGURE 1. Osseous relationships of the anterior clinoid process, superior orbital fissure, and optic canal — a superior view. The anterior clinoid process projects backward from the medial end of the lesser wing of the sphenoid bone. The anterior attachment of the anterior clinoid process extends medially from the base of the clinoid to the planum and forms the roof of the optic canal. The posterior attachment of the anterior clinoid process, the optic strut, extends from the inferomedial aspect of the

anterior clinoid to the body of the sphenoid bone and forms the inferior wall of the optic canal. Another small prominence, the middle clinoid process, situated on the medial side of the carotid sulcus at the level of the tips of the anterior clinoid process, projects upward and laterally. B, superior view of a left caroticoclinoid foramen. An osseous bridge extending from the tip of the anterior clinoid to the tip of the middle clinoid process creates a nearly complete bony ring around the artery, called the caroticoclinoid foramen. C, oblique posterior view of the left optic canal and optic strut and right superior orbital fissure. The optic canal has an oval shape and is formed superiorly by the anterior attachment of the anterior clinoid, inferiorly by the optic strut, laterally by the medial side of the anterior clinoid process and the optic strut, and medially by the sphenoid body. The superior orbital fissure has a triangular shape and is formed superiorly by the lesser wing of the sphenoid bone, medially by the optic strut and the sphenoid body, and inferiorly and laterally by the greater sphenoid wing. The maxillary strut is the bridge of bone separating the superior orbital fissure from the foramen rotundum: D, intraorbital view of the optic canal and superior orbital fissure. The optic strut separates the optic canal and superior orbital fissure and forms the floor of the optic canal and the superomedial part of the roof of the superior orbital fissure. Ant., anterior; Car., carotid; Caroticoclin., caroticoclinoid; Clin., clinoid; Fiss., fissure; For., foramen; Gr., greater; Inf., inferior; Less., lesser; Max., maxillary; Mid., middle; Orb., orbital; Post., posterior; Proc., process; Rotund., rotundum; Sphen., sphenoid; Sulc., sulcus; Sup., superior.

FIGURE 2. Dural, arterial and neural relationships of the optic canal, superior orbital fissure, and cavernous sinus. A superolateral view of the cavernous sinus. The cavernous sinus extends from the superior orbital fissure to the petrous apex. The superior petrosal sinus passes above the ostium of Meckel's cave and joins the posterior part of the cavernous sinus. The dura covering the lateral wall has been removed, and the trigeminal ganglion has been exposed. The oculomotor, trochlear, and ophthalmic nerves pass forward to converge on the superior orbital fissure. The ophthalmic nerve has been retracted downward to expose the abducens nerve. B, superior view of the roof of the cavernous sinus and sellar region. The anterior clinoid process is covered by dura, which continues laterally with the dura that includes the

superior aspect of the lesser wing of the sphenoid bone. The falciform ligament, the dural fold extending above the optic nerve proximal to the nerve's entrance into the bony optic canal, extends from the base of the anterior clinoid to the tuberculum. The carotid artery exits the cavernous sinus on the medial side of the anterior clinoid process. The oculomotor nerve enters the narrow oculomotor cistern in the posterior part of the roof of the cavernous sinus referred as the oculomotor triangle. C, lateral view of the cavernous sinus. The anterior clinoid process has been removed, and the dural roof of the oculomotor triangle has been removed to expose the clinoid segment of the internal carotid artery in the clinoidal triangle and the posterior bend of the intracavernous carotid below the oculomotor triangle. The dura that covers the superior aspect of the clinoid continues medially around the carotid artery and forms the distal ring. The trigeminal nerve and the petrolingual ligament, extending from the petrous apex to the lingual process of the sphenoid bone, have been partially removed to expose the entrance of the petrous carotid into the cavernous sinus. The cavernous segment of the artery turns abruptly forward to course along the carotid sulcus and lateral part of the body of the sphenoid. It passes forward in a horizontal direction and terminates by moving upward along the medial side to the distal ring. The abducens nerve passes lateral to the internal carotid artery and medial to the ophthalmic nerve in the lower part of the cavernous sinus. D-F, the relationship of the meningo-periorbital band and anterior clinoid process. D, a right pterional craniotomy. The junction of dura and periorbital forms the meningo-periorbital band at the lateral margin of the superior orbital fissure. E, the anterior clinoid process has been exposed. After dividing the menigo-periorbital band, the dura of the middle fossa has to be peeled away from the anterior part of the cavernous sinus to reveal the anterior clinoid process. F, lateral exposure of the superior orbital fissure, anterior clinoid process, and cavernous sinus. The lateral edge of the superior orbital fissure (red arrow) is located anterolateral to the anterior clinoid process. After dividing the meningo-periorbital band, the dura has to be peeled posterior to the level of the interrupted vertical line to expose the anterior clinoid process for clinoidectomy. A., artery; Ant., anterior; Bas., basilar; Car., carotid; Cav., cavernous; Clin., clinoid; CN, cranial nerve; Dist., distal; Falc., falciform; Fiss., fissure; Front., frontal; Gang., ganglion; Interclin., interclinoidal; Lig., ligament; Men., meningo;

Mid., middle; Oculom., oculomotor; Ophth., ophthalmic; Orb., orbital; P.C.A., posterior cerebral artery; Pet., petrosal, petrous; Petroclin., petroclinoidal; Petroling., petrolingual; Petrosphen., petrosphenoidal; Post., posterior; S.C.A., superior cerebellar artery; Seg., segment; Sup., superior; Temp., temporal; Tent., tentorial; Triang., triangle.

FIGURE 3. Surgical view of a stepwise left anterior clinoid removal and optic nerve decompression through the pterional approach. The inset (upper left) show the head's position and the site of the scalp incision. The scalp has been reflected using subgaleal dissection to expose the frontal bone and the upper part of the temporalis muscle and fascia. The facial nerve courses on the outer surface of the superficial temporal fascia above the zygomatic arch. The superficial layer of temporalis fascia has been divided just above the interfascial fat pad so that the superficial layer of temporalis fascia and the fat pad can be folded downward in continuity with the frontal pericranium to protect the branches of the facial nerve.35 B, the inset (upper left) shows the burr holes and the craniotomy cuts for the bone flap. A cuff of temporalis fascia is preserved along the superior temporal line to aid in anchoring the temporal muscle to the line at the time of closure. The keyhole burr hole is located above and behind the frontozygomatic suture. The bone flap has been elevated to expose the temporal and frontal dura. C, the sphenoid ridge has been flattened, and a thin shell of bone has been left along the roof and lateral wall of the orbit. The frontal and temporal dura has been retracted to expose the meningo-periorbital band at the lateral edge of the superior orbital fissure. D, the meningo-orbital band is cut using curved micro-scissors. E, the dura has been elevated from the anterior clinoid process and along the anterior wall of the cavernous sinus to expose the entrance of the oculomotor, trochlear, and ophthalmic nerves in the superior orbital fissure, and V2 in the foramen rotundum. F, the anterior clinoid process has been removed using "no-drill technique" (insert) to expose the clinoid segment of the internal carotid artery between the proximal and distal dural rings. The deeper part of optic strut has also been removed using the no-drill technique. 270° of the intercanalicular segment of the optic nerve has been decompressed. A., artery; Ant., anterior; Clin., clinoid; CN, cranial nerve., Dist., distal; Fiss., fissure; Front., frontal; Frontozyg., frontozygomatic; Lat., lateral; M., muscle; Men., meningeal, meningo; Mid., middle;

Orb., Orbital; Prox., proximal; Seg., segment; Sphen., sphenoid; Sup., superior; Temp., temporal, temporalis.

FIGURE 4.(A-E): Surgical views of a stepwise right optic nerve decompression through a keyhole approach. A Head position and the site of the scalp incision. The inset (upper right) shows the skin incision; The skin incision should avoid extending more than 40 mm backward from the lateral canthus to prevent the nerve to the frontalis muscle.35 It curves approximately 5 mm above the lateral orbital rim to just posterior to the lateral canthus where it turns posteriorly in one of the horizontal skin lines just inferior to the lateral canthus. B, the scalp has been reflected using subcutaneous dissection to expose the frontal and orbicular muscles and superficial temporal fascia. C, inset (upper left); the frontal muscles have been reflected superiorly and the orbitalis muscle anteriorly. The lateral orbital rim has been exposed. D, the temporal muscle has been elevated, preserving the deep fascia, to expose the pterion and superior temporal line. E, bone flap or craniectomy centered at the keyhole was performed behind the frontozygomatic suture. The keyhole craniotomy exposed the frontal and temporal dura and the periorbital at a Y-shaped bone crossroad formed anteriorly and superiorly by the orbital roof, anteriorly and inferiorly by the edge of the higher wing of the sphenoid bone, and posteriorly by the lesser wing of the sphenoid bone.

FIGURE 4. (F-J): Surgical views of a stepwise extradural anterior clinoidectomy and unroofing of the optic canal through the keyhole approach. F, the lateral part of the lesser wing of the sphenoid bone was removed. G, the frontal and temporal dura were retracted to expose the meningo-orbital band. The temporal dura was elevated to expose the superior orbital fissure. The meningo-orbital band attaches the fronto-temporal basal dura to the periorbita at the level of the lateral part of the superior orbital fissure. H, the meningo-orbital band has been cut. I, the dura has been elevated from the anterior clinoid process and backward along the wall of the cavernous sinus to expose the entrance of the oculomotor, trochlear, and ophthalmic nerves into the superior orbital fissure. The lateral attachment of the anterior clinoid process was removed using the "no-drill technique." J, the anterior clinoid process was removed in one piece, and 270° of the intracannilicular portio n of the optic nerve has been

decompressed. The clinoid segment of the internal carotid artery has been exposed. Inset (lower right) shows that the size of the keyhole craniotomy was 3.5 cm. Ant., anterior; Clin., clinoid; CN, cranial nerve., Front., frontal, frontalis; Frontozyg., frontozygomatic; Gr., greater; Lat., lateral; Less., lesser; Men., meningo; M., muscle; Orb., orbital, orbitalis; Seg., segment; Sup., superior; Temp., temporal, temporalis.

FIGURE 5. Ilustrative Cases 1- Meningioma of the tuberculum sellae: A 55-year-old male, with a year of a headache and progressive decrease in visual acuity. Preoperative imaging revealed a tuberculum sellae meningioma. Visual fields showed right bitemporal hemianopia and left central scotoma. The procedure was performed in two stages. In the first, bilateral MiniEx approach was performed to decompress the optic nerves. In the second, a subfrontal approach aimed tumor removal. The patient had an uneventful postoperative course without complications and was discharged with improved vision. Preoperative (A) and postoperative (B) studies of a case of bilateral optic nerve decompression through a keyhole approach in a patient with a meningioma of tuberculum sellae. A coronal view of T1-weighted contrast MRI study, showing a tumor located at the level of the tuberculum sellae and planum that compressed both optic nerves. B, CT with 3D-reconstruction, showing the bilateral keyhole, extradural anterior clinoidectomies with 270° optic nerve deco mpression. After bilateral optic nerve decompression, the tumor was removed through the subfrontal approach.

FIGURE 6. Ilustrative Cases 2 - Fibrous dysplasia: A 7-year-old male presented with a progressive decrease in visual acuity. Preoperative imaging revealed frontal-ethmoidal-sphenoidal-temporal fibrous dysplasia. Ophthalmic tests showed a reduction in right visual acuity (counting finger visual acuity). Right extradural anterior clinoidectomy through a keyhole approach was performed (Fig. 6). In this case, obtaining a bone flap was impossible because of the fibrous dysplasia, therefore reconstruction was completed with a titanium plate. The patient evolved uneventfully and was discharged with improved vision. Preoperative and postoperative CT of right optic nerve decompression through a keyhole approach for fibrous dysplasia. An axial and coronal view of preoperative CT that showed fibrous dysplasia compressing the right optic nerve. B, axial and coronal postoperative CT showing the right extradural anterior

clinoidectomy and optic nerve decompression through a keyhole approach. C, 3D-reconstruction of the CT showing the right keyhole approach and posterior reconstruction using a titanium plate.

TABLES LEGENDS

TABLE 1. Mean Features of the Clinical Cases.

TABLE 2. Comparison Between The Main Techniques of Optic Nerve Decompression.

VIDEO LEGEND

VIDEO 1. Minimally Invasive Extradural Anterior Clinoidectomy and Optic Nerve Decompression.

TABLE 1. Mean Features of the Clinical Cases.

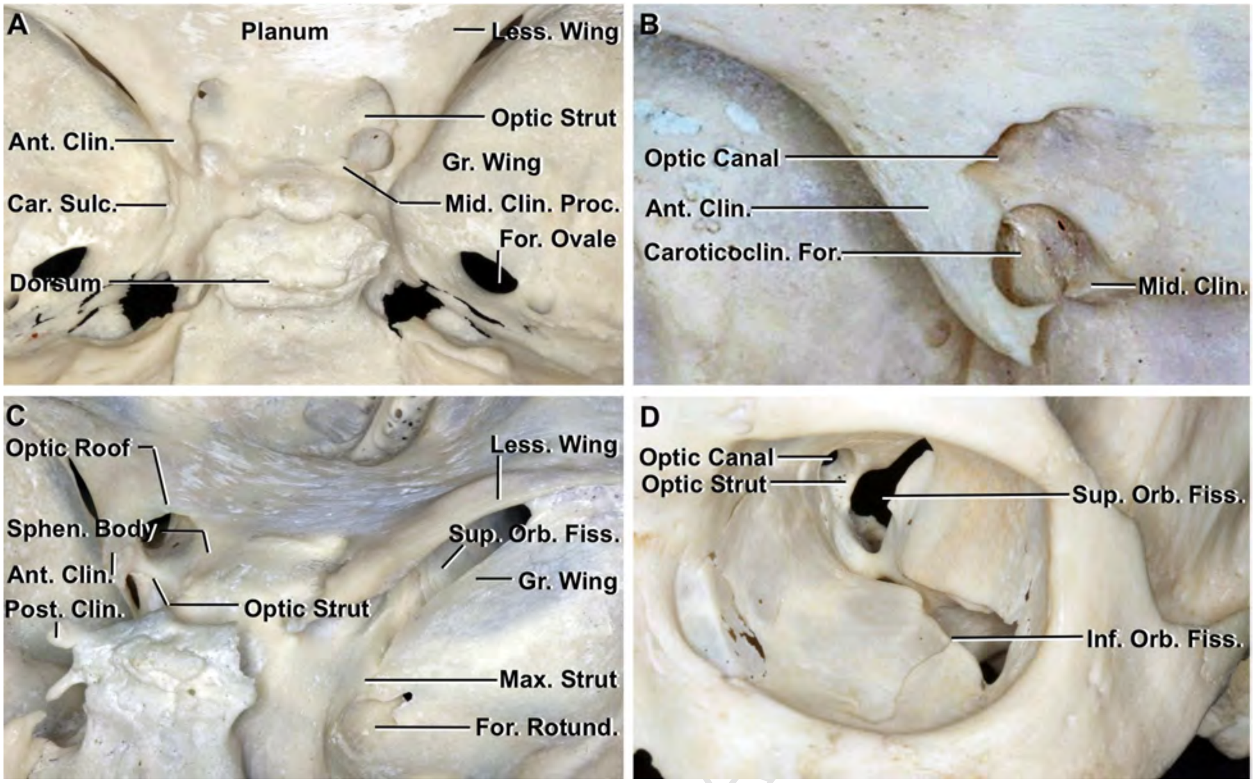
Patients	Age	Sex	Pathology	Clinoidectomy	Surgery	Timing	Optic nerve function
1	57	F	Meningioma of tuberculum sellae	Unilateral	Right Keyhole extradural anterior clinoidectomy and frontobasal craneotomy	Two times	Partially Preserved*
2	44	F	Tumor of cavernous sinus	Unilateral	Left Keyhole extradural anterior clinoidectomy, transcavernus appraoch and tumor removal.	One time	Preserved
3	55	M	Meningioma of tuberculum sellae	Bilateral	Bilateral Keyhole extradural anterior clinoidectomy and frontobasal craneotomy	Two times	Preserved
4	37	F	Meningioma of tuberculum sellae	Bilateral	Bilateral Keyhole extradural anterior clinoidectomy and frontobasal craneotomy	Two times	Preserved
5	20	M	Fibrous dysplasia.	Bilateral	Bilateral Keyhole extradural anterior clinoidectomy	One time	Preserved
6	7	M	Fibrous dysplasia	Unilateral	Right Keyhole extradural anterior clinoidectomy	One time	Preserved

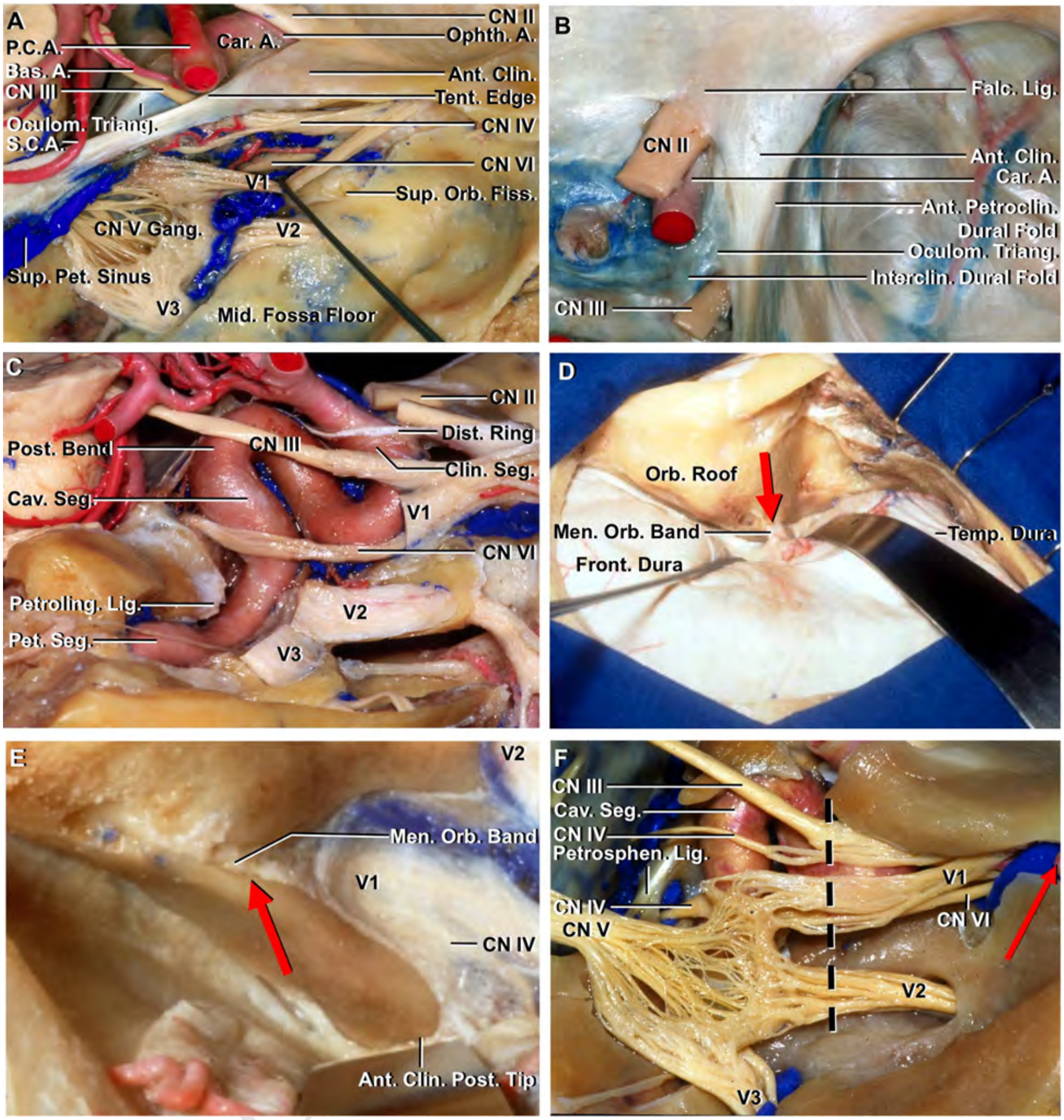
* The patient evolves whit optic chiasm damage and bi-temporal hemianopia as result of tumor removal.

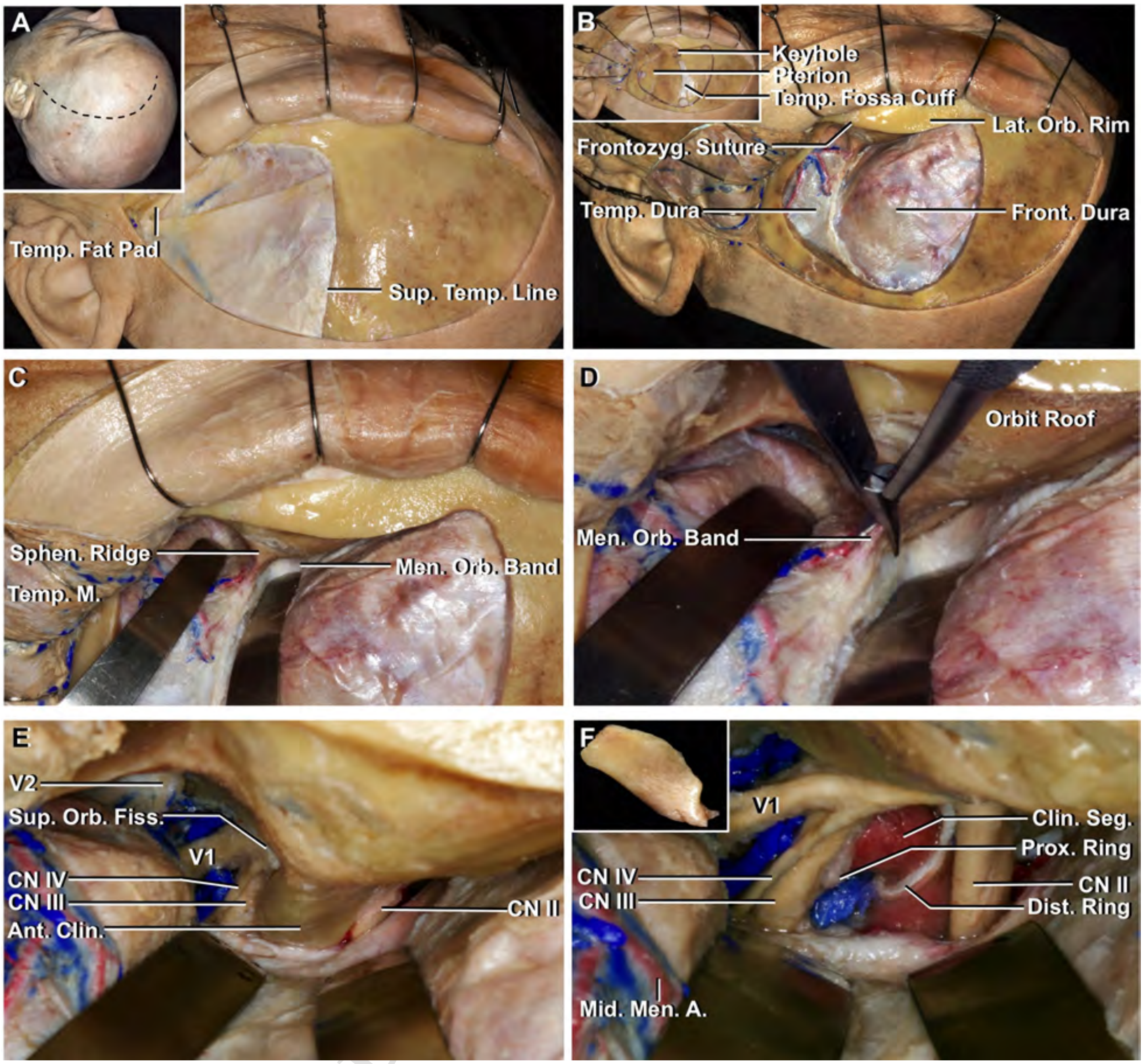
TABLE 2. Comparison Between The Main Techniques of Optic Nerve Decompression.

Main features	Pterional approach (Dolenc).	Keyhole approach.	Endoscopic endonasal approach (Abhinav).	Supraorbital approach (Rigante).
Size of incision and bone flap	Big	Small	-	Small
Cerebral retraction	Minimal*	Minimal*	No	Minimal*
Facial nerve damage risk	Minimal to moderate	Minimal	No	No
No drill-technique	Possible	Possible	Impossible	Impossible
Technique difficulty	Easily reproducible	Easily reproducible	Requires specialized surgeon. The removal of the superior wall is more challenging. It is not easily reproducible	Easily reproducible
Maximal decompression degree	270 degree. Lateral, inferior and superior wall of optic canal	270 degree. Lateral, inferior and superior wall of optic canal	180 – 270 degree. Medial, inferior and superior wall of optic canal	180 degree
Possibility of cosmetic defect	Minimal to moderate	Minimal	No	Minimal

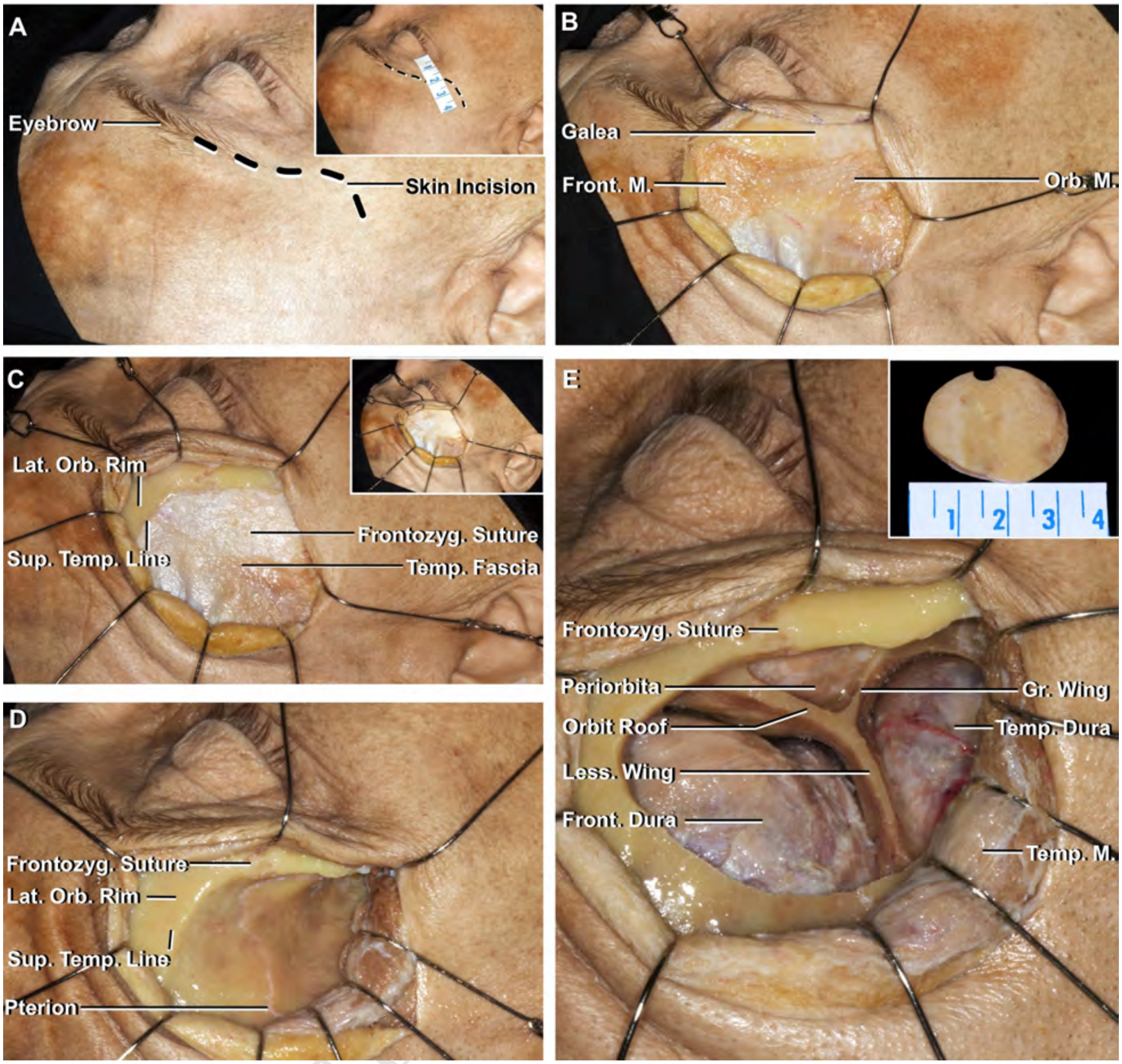
* In surgical case, the placement of a lumbar drainage can decrease the cerebral retraction.

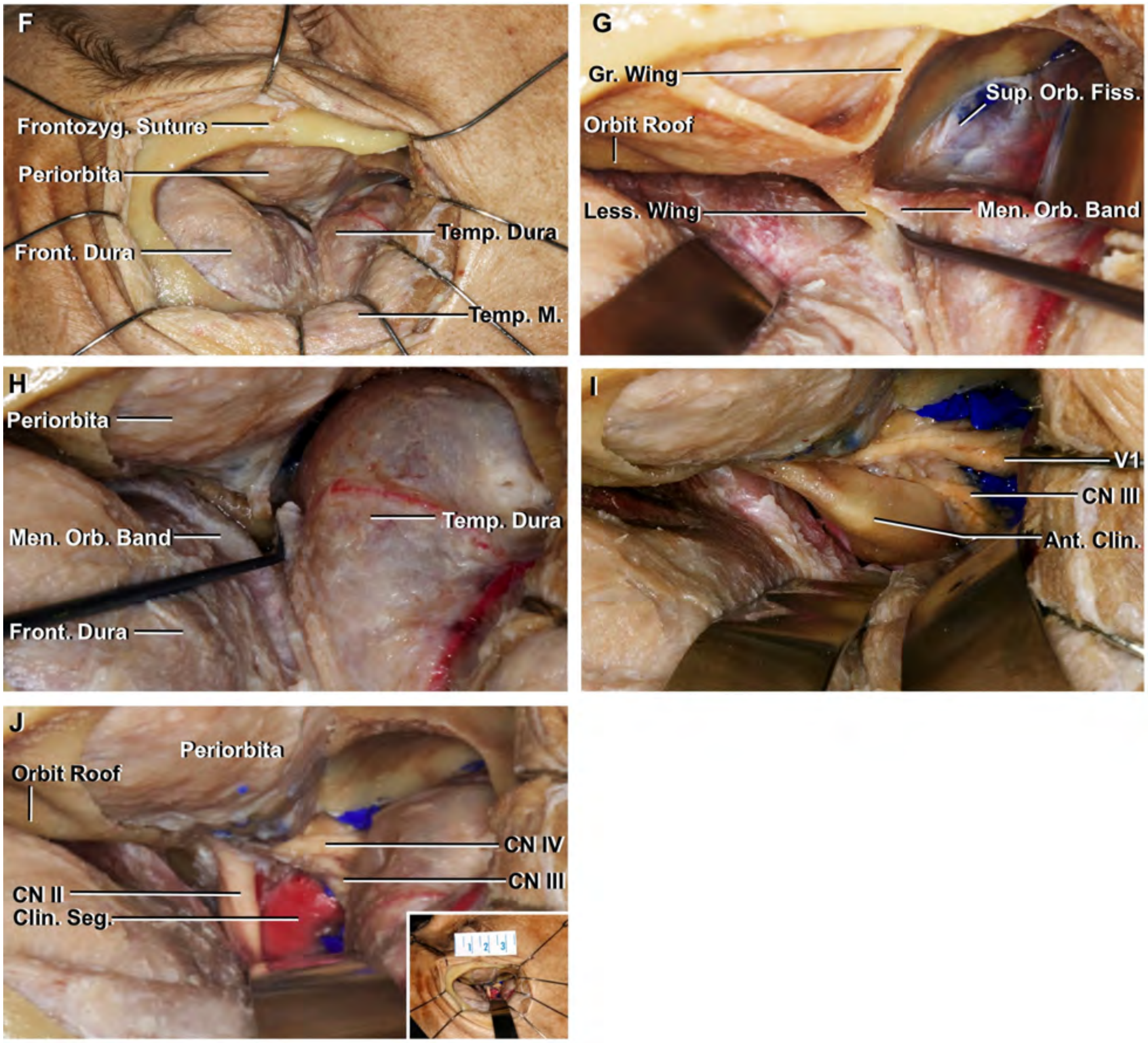

A
Planum
Less. Wing
Optic Strut
Ant. Clin.
Gr. Wing
Car. Sulc.
Mid. Clin. Proc.
For. Ovale
Dorsum
B
Optic Canal
Ant. Clin.
Caroticoclin. For.
Mid. Clin.
C
Optic Roof
Less. Wing
Sphen. Body
Sup. Orb. Fiss.
Ant. Clin.
Gr. Wing
Post. Clin.
Optic Strut
Max. Strut
For. Rotund.
D
Optic Canal
Optic Strut
Sup. Orb. Fiss.
Inf. Orb. Fiss.

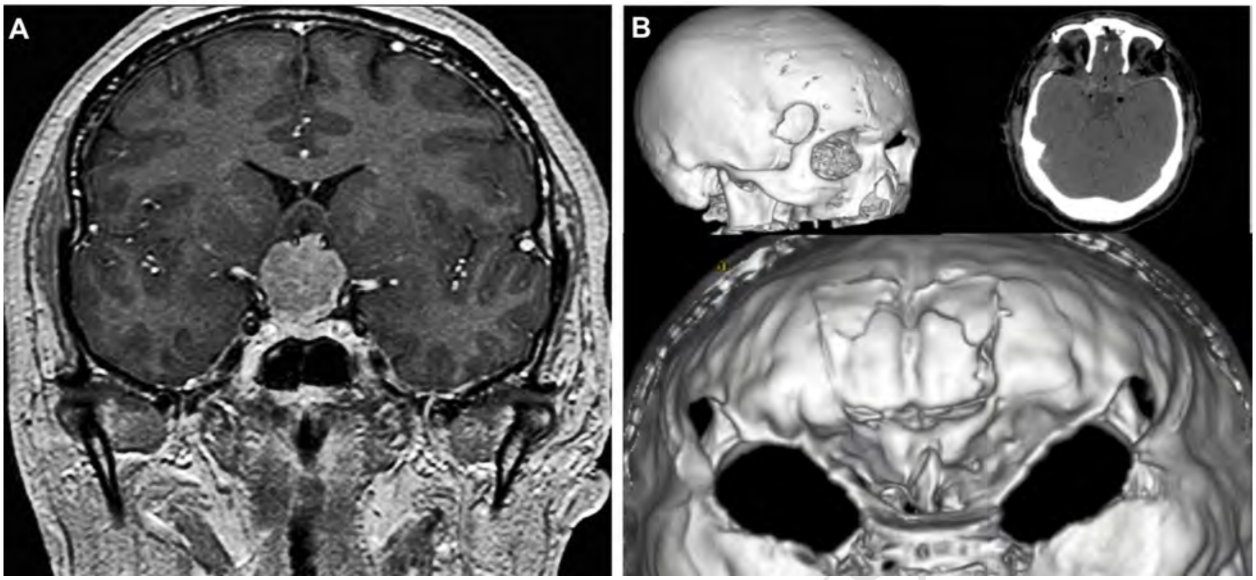

A
CN II
Car. A.
Ophth. A.
P.C.A.
Bas. A.
Ant. Clin.
CN III
Tent. Edge
Oculom. Triang.
CN IV
S.C.A.
CN VI
V1
Sup. Orb. Fiss.
CN V Gang.
V2
Sup. Pet. Sinus
V3
Mid. Fossa Floor
B
Falc. Lig.
CN II
Ant. Clin.
Car. A.
Ant. Petroclin. Dural Fold
Oculom. Triang.
Interclin. Dural Fold
CN III
C
CN II
Dist. Ring
Post. Bend
CN III
Clin. Seg.
Cav. Seg.
V1
CN VI
Petroling. Lig.
V2
Pet. Seg.
V3
D
Orb. Roof
Men. Orb. Band
Temp. Dura
Front. Dura
E
V2
Men. Orb. Band
V1
CN IV
Ant. Clin. Post. Tip
F
CN III
Cav. Seg.
CN IV
Petrosphen. Lig.
V1
CN IV
CN VI
CN V
V2
V3

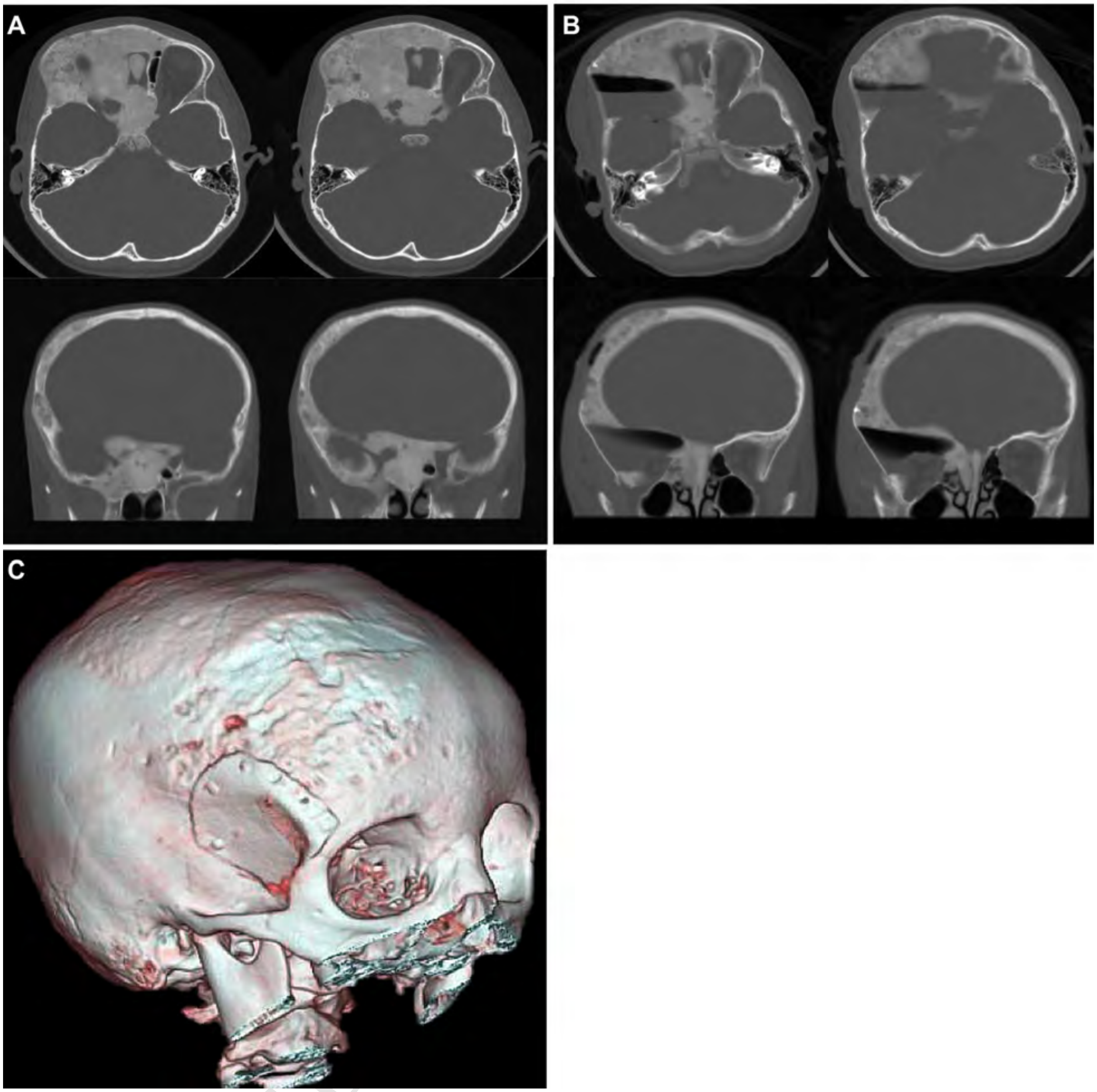


A
Temp. Fat Pad
Sup. Temp. Line
B
Keyhole
Pterion
Temp. Fossa Cuff
Lat. Orb. Rim
Frontozyg. Suture
Temp. Dura
Front. Dura
C
Sphen. Ridge
Men. Orb. Band
Temp. M.
D
Orbit Roof
Men. Orb. Band
E
V2
Sup. Orb. Fiss.
V1
CN IV
CN III
Ant. Clin.
CN II
F
V1
Clin. Seg.
Prox. Ring
CN IV
CN III
CN II
Dist. Ring
Mid. Men. A.


A
Eyebrow
Skin Incision
B
Galea
Front. M.
Orb. M.
C
Lat. Orb. Rim
Frontozyg. Suture
Sup. Temp. Line
Temp. Fascia
D
Frontozyg. Suture
Lat. Orb. Rim
Sup. Temp. Line
Pterion
E
Frontozyg. Suture
Periorbita
Gr. Wing
Orbit Roof
Temp. Dura
Less. Wing
Front. Dura
Temp. M.
1
2
3
4


F
Frontozyg. Suture
Periorbita
Front. Dura
Temp. Dura
Temp. M.
G
Gr. Wing
Sup. Orb. Fiss.
Orbit Roof
Less. Wing
Men. Orb. Band
H
Periorbita
Men. Orb. Band
Temp. Dura
Front. Dura
I
V1
CN III
Ant. Clin.
J
Periorbita
Orbit Roof
CN IV
CN III
CN II
Clin. Seg.


A
B


A
B
C

Abreviation

MiniEX: Minimally invasive extradural anterior Clinoidectomy

MiniPT: Minipterional Craniotomy