Transorbital Microsurgery: An Anatomical Description of a Minimally Invasive Corridor to the Anterior Cranial Fossa and Paramedian Structures

Lena Mary Houlihan[1] Thanapong Loymak[1] Irakliy Abramov[1] Mohamed A. Labib[1]
Michael G. J. O'Sullivan[2] Michael T. Lawton[1] Mark C. Preul[1]

[1] Department of Neurosurgery, The Loyal and Edith Davis Neurosurgical Research Laboratory, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona, United States
[2] Department of Neurosurgery, Cork University Hospital, Wilton, Cork, Ireland

Address for correspondence Mark C. Preul, MD, c/o Neuroscience Publications; Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, 350 W. Thomas Rd.; Phoenix, AZ 85013, United States (e-mail: Neuropub@barrowneuro.org).

J Neurol Surg B Skull Base 2024;85:470–480.

Abstract

Objectives Transorbital neuroendoscopic surgery (TONES) has ignited interest in the transorbital access corridor, increasing its use for single and multi-portal skull base interventions. However, the crowding of a small corridor and two-dimensional viewing restrict this access portal.

Design Cadaveric qualitative study to assess the feasibility of transorbital microsurgery (TMS).

Setting Anatomical dissection steps and instrumentation were recorded for homogeneous methodology.

Participants Six cadaveric specimens were systematically dissected using TMS to the anterior cranial fossa and paramedian structures.

Main Outcome Measures Anatomical parameters of the TMS craniectomy were established, and the visible and accessible neuroanatomy was highlighted.

Results A superior lid crease incision achieved essential orbital rim exposure and preseptal dissection. The orbital roof craniectomy is defined by three boundaries: (1) frontozygomatic suture to the frontosphenoid suture, (2) frontal sinus and cribriform plate, and (3) frontal sinus and orbital rim. The mean (standard deviation) craniectomy was 440 mm^2 (78 mm^2). Exposing the ipsilateral optic nerve and internal carotid artery obviated the need for frontal lobe retraction to identify the A1–M1 bifurcation as well as near-complete visualization of the M1 artery.

Conclusion TMS is a feasible corridor for intracranial access. Mobilization of orbital contents is imperative for maximal intracranial access and protection of the globe. TMS enables access to the frontal lobe base, ipsilateral optic nerve, and most of the ipsilateral anterior circulation. This cosmetically satisfactory approach causes minimal destruction of the anterior skull base with satisfactory exposure of the anterior cranial fossa floor without sinus invasion.

Keywords
- anterior cranial fossa
- microsurgery
- paramedian structures
- transorbital approach

received
November 16, 2022
accepted after revision
July 5, 2023
article published online
September 4, 2023

Georg Thieme Verlag KG,
Rüdigerstraße 14,
70469 Stuttgart, Germany

DOI https://doi.org/10.1055/s-0043-1772202.
ISSN 2193-6331.

Introduction

Transorbital neuroendoscopic surgery (TONES) is an advanced minimally invasive, minimally disfiguring type of skull base surgery that maximizes surgical visualization.[1] Previously, the term *transorbital* had diverse meanings, and the approach usually included variations of the lateral orbitotomy or zygoma-sphenotomy.[2,3] Increased use of the TONES access corridor has increased recognition of the transorbital approach. The drive toward minimally invasive surgical interventions has helped to identify an operative corridor to the skull base through the orbital bone without removing the orbital rim, thereby preserving structural integrity.[4,5]

Introduced in 2010, TONES has been documented for use in treating multiple anterior skull base pathologies, including cerebrospinal fluid (CSF) leaks, meningoencephaloceles, optic nerve decompression, skull base fractures, inflammatory intraorbital lesions, intracranial abscesses, and skull base tumors.[4,6,7] Despite its technological advances, TONES has weaknesses and advantages that require elucidation. Disadvantages associated with TONES include a paucity of evidence (level IV, at best), the lack of adequate orbital instrumentation appropriate to surgical depth, and surgical corridor crowding.[8] Inserting both an endoscope and standard instrumentation through a periorbital incision may injure surrounding structures more than when some of the surgical instruments enter the cranial vault through a larger opening or an additional keyhole. Furthermore, pioneers in the field remain cautious and advocate maintaining the ability to convert swiftly to an open craniotomy in an emergency.[9,10]

Such concerns highlight potential weaknesses of TONES, specifically regarding its instrumentation and visualization methods, and they raise questions about how to best minimize intraportal instrumentation when using the transorbital corridor. The feasibility, accessible structures, and advantages of transorbital microsurgery (TMS) have yet to be investigated. The transorbital approach is relatively novel for neurosurgery, and its use is becoming increasingly pertinent in research and clinical practice. In addition, the incorporation of technologies and methods of visualization into our operative practice requires the publication of detailed research to provide surgeons with objective comparison.

The merits of our study are twofold. It describes a transorbital craniectomy completed using an operating microscope. We aimed to establish a satisfactory exposure with minimal destruction of the skull base and to identify the accessible intracranial structures most appropriate to this surgical corridor. Our goal was to elucidate the merits of the microscopic visualization method, which would allow further detailed anatomic analysis of the transorbital approach.

Methods

This study was conducted in a surgical neuroanatomy laboratory. Six cadaveric heads embalmed in an alcohol-formalin-based solution were dissected, and arteries and veins were injected with red and blue silicone. The transorbital approach to the anterior cranial fossa (ACF) and paramedian structures was systematically completed and visualized using a clinical neurosurgery operating microscope (OPMI Pentero, Carl Zeiss Meditec AG, Oberkochen, Germany). Dissection steps and instrumentation were recorded to ensure a homogeneous approach methodology. High-definition (HD) three-dimensional (3D) video images were obtained using the Trenion 3D HD system (Carl Zeiss Meditec) and displayed on an HD LED monitor.

The orbital roof craniectomy was measured three times in all six specimens by different neurosurgeons to account for intrarater and interrater variability and to obtain the mean size, thereby ensuring standardized and feasible technical replication. Repeated measurements were made to facilitate the estimation of variability and improve the power of the analysis. Measurements were performed using a clinical neurosurgery navigation system (StealthStation, Medtronic, Dublin, Ireland). This method of visualization enabled us to establish the anatomical parameters of the TMS craniectomy and the visible and accessible neuroanatomy specific to this access corridor.

Statistical Analysis

Statistical analysis of measurements was performed using open-source statistical software: R.app (GUI 1.72 [7847 Catalina build], S. Urbanek & H.-J. Bibiko, R Foundation for Statistical Computing, Vienna, Austria, 2020) and RStudio (1.3.1073, Rstudio, PBC, Boston, Massachusetts, United States). Data were reported as means with ranges and standard deviations.

TMS Superior Lid Crease Approach: Surgical Technique

Step 1: Positioning

The head was positioned supine with a shoulder roll. Subtle extension produced the optimal angle for review of the frontal lobe base, especially anteriorly, and for access to deeper neurovascular structures (►**Fig. 1**). The head was fixed with a three-pin holder and rotated from 0° to 45° contralaterally. Optimal positioning and rotation were based on the surgical target of interest. Rotation from 10° to 30° is optimal for review of the ipsilateral internal carotid artery (ICA) and up to 45° for viewing the anterior communicating artery and circumferential midline region.

Step 2: Superior Lid Crease Incision

In vivo, a lubricated corneal protector should be placed over the orbit. The supraorbital notch and exit point of the supraorbital nerve were identified (►**Fig. 2**). The natural crease in the upper eyelid was used to plan a 4- to 5-cm incision. The orbital rim must be identified for direct dissection along that trajectory. Eyebrow skin was elevated and undermined for full visualization. Sharp dissection through the orbicularis oculi muscle was completed along the preseptal plane to identify the superior orbital rim. Injury of the levator aponeurosis, which in the in vivo setting can lead to ptosis, was avoided by exposing the orbital rim superficial to the fat pad. The supraorbital nerve was identified and preserved. For maximal mobilization, the nerve was released from the supraorbital canal. The periosteum was incised to enable subperiosteal

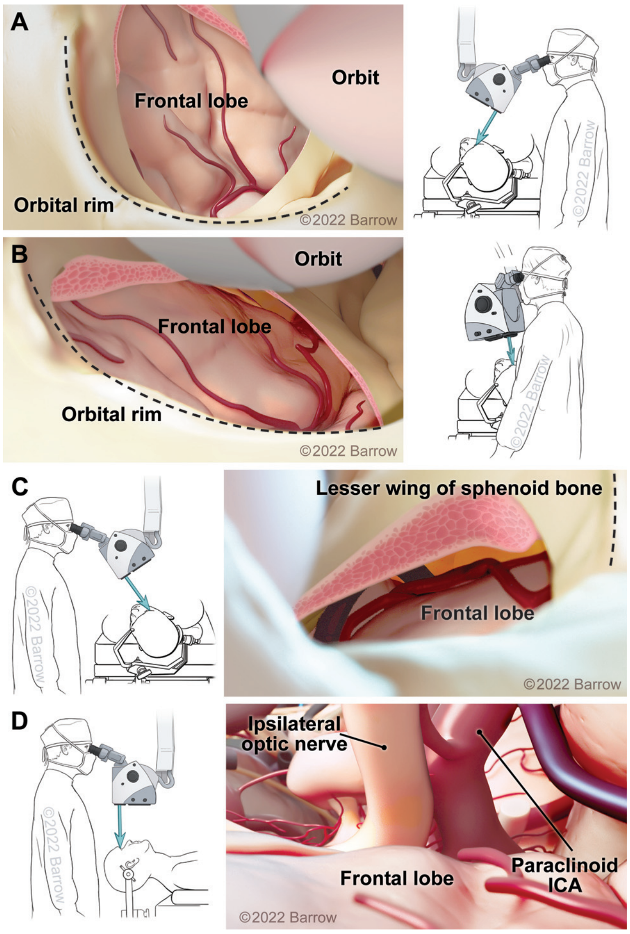

Fig. 1 Illustration depicts the positioning of the patient, microscope, and surgeon for access to particular anatomical structures from a right-sided superior lid crease approach. Dashed curved lines indicate position of orbital rim. (**A**) Medial view of the frontal lobe base with the microscope tilted superomedially. The surgeon is positioned parallel to the patient's ipsilateral shoulder. (**B**) Positioning needed to achieve the most superior-anterior view of the frontal lobe base, with the microscope tilted superiorly along the axis of the mid-pupillary line. The surgeon and microscope are positioned at a 45° angle to the patient's ipsilateral shoulder. (**C**) Positioning needed for the most lateral view of the frontal lobe base, with the microscope tilted superolaterally. The surgeon is positioned on the patient's contralateral side either parallel to or along the axis of the patient's shoulder. (**D**) Positioning for evaluation of deep neurovascular structures. The surgeon is positioned at the patient's head, with the microscope directed straight down through the transorbital incision. This positioning of the microscope provides a coplanar view of the intracranial paramedian components at the level of the orbital roof. ICA, internal carotid artery. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona*.)

dissection. The frontozygomatic suture was identified along the lateral orbital rim (►**Fig. 3**). The suture represents the lateral and inferior boundary of the ACF.

Step 3: Periorbital Dissection

After the periosteum was incised at the orbital rim, a window was opened for subperiosteal dissection along the intraorbital roof. A dissector was first used to gently sweep laterally to release the lateral orbital contents before sweeping medially and posteriorly to the supraorbital nerve while avoiding retraction of the nerve. A periosteal window was then incised medial to the supraorbital nerve, and the subperiosteal dissection was advanced medially. The anterior ethmoidal artery was identified (cauterization would be required in vivo) and cut along the side of the periorbita (►**Fig. 4**). The vessel should be cut distal to the ethmoidal canal border to avoid retraction of an inadequately cauterized vessel, resulting in inaccessible hemorrhage. The medioinferior bony region corresponds with the lamina papyracea. Subperiosteal dissection posteromedially was continued using a periosteal dissector. The posterior ethmoidal artery along the same plane can be identified and cut. Just superior to the anterior and posterior ethmoidal arteries was the frontoethmoidal suture, which continues anteriorly as the frontolacrimal suture. Deep dissection farther along the medial wall leads to the optic nerve, where it standardly exits the optic canal. Laterally, the optic strut, which projects posteromedially, separated the optic canal from the superior orbital fissure. The frontosphenoid suture lay at the superolateral apex of the superior orbital fissure (►**Fig. 4**). Drilling superior to the fissure led to the ACF, which was inferior to the middle cranial fossa (MCF). The bone superior to the optic canal represented the most posterior, most medial, and deepest angle of the TMS craniectomy. This point also represented the axial plane (the optic canal roof) along which intraparenchymal structures were identified.

Adequate subperiosteal dissection ensured that the globe was mobile, that satisfactory space existed for a safe craniectomy, and that the surgical corridor was maximized for intracranial work and instrument access. Ample mobilization of orbital contents maximized the access corridor and minimized aggressive retraction.

During completion of the cutaneous and subperiosteal dissection, the dissector and suction were used as dynamic retractors. This dual-purpose usage avoided the need for constant, fixed retraction and maximized a small, potentially crowded, surgical corridor. Both dynamic and fixed retraction using malleable ribbon retractors were used to complete the craniectomy. A fixed retractor was used during intracranial manipulation and dissection. During retraction, the retractor was placed along the natural curve of the globe; ventral pulling was avoided to prevent injury to intracranial structures. When performed in vivo, another key component of any transorbital approach is awareness of the pressure applied to the globe during intraorbital and intraparenchymal dissection. In the clinical scenario, all instruments should be removed from the orbit every 15 to 20 minutes, at which point the pupils are checked for symmetry.

Step 4: Orbital Roof Craniectomy

The transorbital craniectomy was established with three boundaries (►**Fig. 5**):

- Lateral boundary: frontozygomatic suture to frontosphenoid suture leading back to the roof of the optic canal.
- Medial boundary: frontal sinus anteriorly and the junction of the frontal bone and cribriform plate of the ethmoid bone.

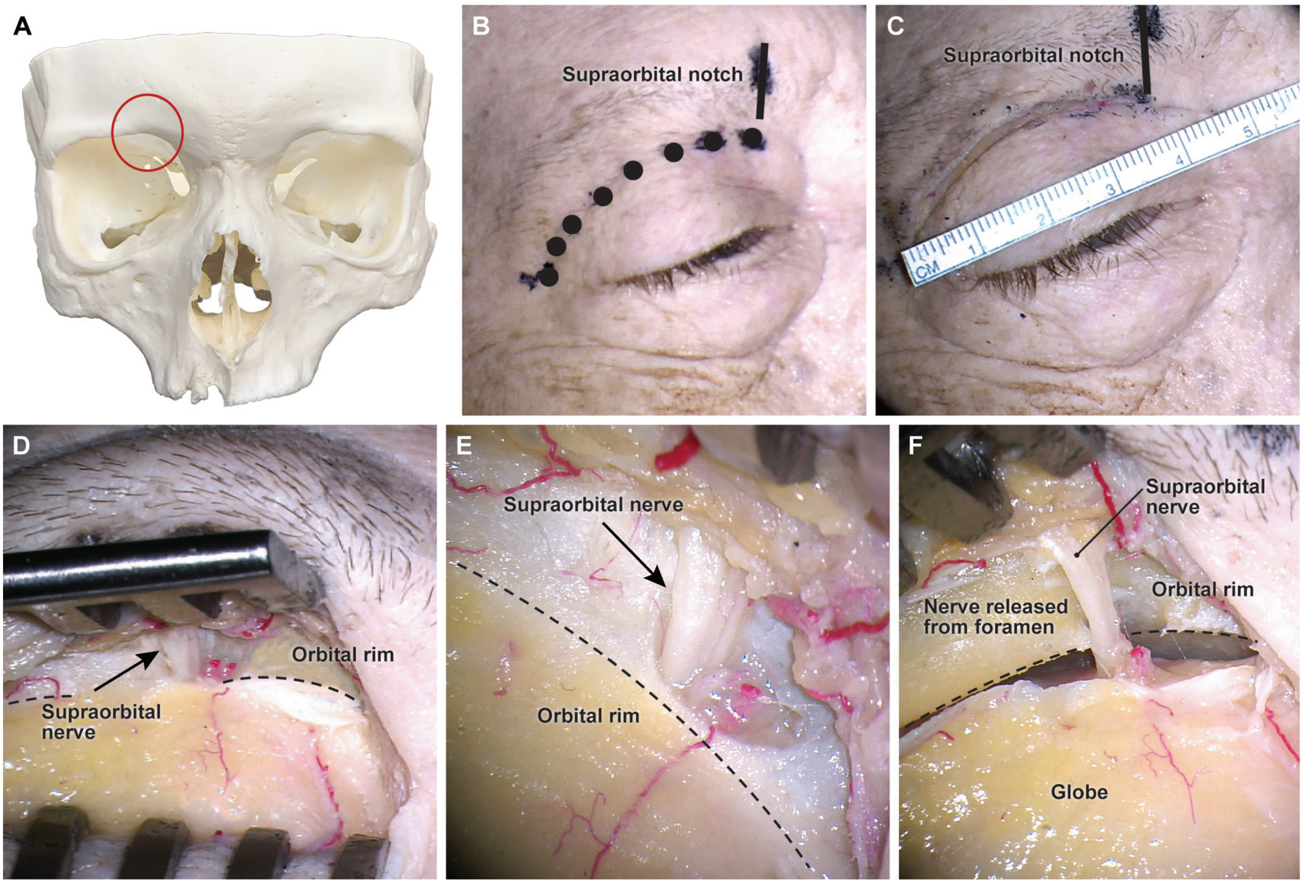

Fig. 2 Incision marking and superficial dissection. (**A**) Depiction of the photographic marker of the region of interest (supraorbital nerve) with anatomical annotator (*circle*) for orientation. (**B**) Marking for the superior lid crease (SLC) incision, with identification of the supraorbital notch (*vertical line*). (**C**) The SLC incision measures ~4 to 5 cm. The vertical line represents the palpation point of the supraorbital notch. (**D**) Undermining of the subcutaneous tissues to expose the orbital rim and supraorbital nerve. (**E**) Exit of the supraorbital nerve from the supraorbital foramen. (**F**) The supraorbital nerve has been released from the supraorbital foramen to allow increased mobilization and manipulation. Dashed curved lines in D, E, and F indicate position of orbital rim. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

- Anterior boundary: frontal sinus medially and orbital rim laterally.

The craniectomy was completed using a high-speed bone-cutting and removal system (Midas Rex Legend, Medtronic) with a telescoping tube attachment (T12BA20) and upcutting rongeurs (1 mm). The aim was to complete a maximal craniectomy for feasible exposure and access to the ACF and paramedian contents (►**Video 1**). All drilling was completed lateral to the supraorbital nerve (►**Fig. 6**).

Video 1

Demonstration of the transorbital microsurgery craniectomy to reach the anterior cranial fossa and paramedian structures. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*) Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/s-0043-1772202.

A safe, advantageous point to commence the craniectomy (after identifying and avoiding the frontal sinus) was approximately 1 cm lateral to the lateral margin of the supraorbital nerve and 1.5 cm posterior to the orbital rim (►**Video 1**). This region consisted of thin shell-like bone that is accessible to drilling, enabling quick extradural infiltration of the cranium. After the dura was identified and a craniectomy window established, the dura was preserved during craniectomy enlargement to protect the frontal lobe parenchyma. After a defect was created, a blunt dissector was used to sweep the dura from the fossa floor. Undermining the dura is important for better dural repair later in the operative intervention. Drilling and upcutting rongeurs were used while advancing anteriorly, laterally, and medially. In thin regions, the orbital roof was down-fractured. Extradural insertion of olfactory fibers entering the cribriform perforations was appreciated as the dura was detached along the medial boundary. Palpation of these perforations is an additional intraoperative means to identify the medial boundary of the TMS craniectomy.

The thick lateral border of the craniectomy superior to the frontozygomatic suture and frontosphenoid suture warranted a drill instead of a bone punch on the lesser wing of

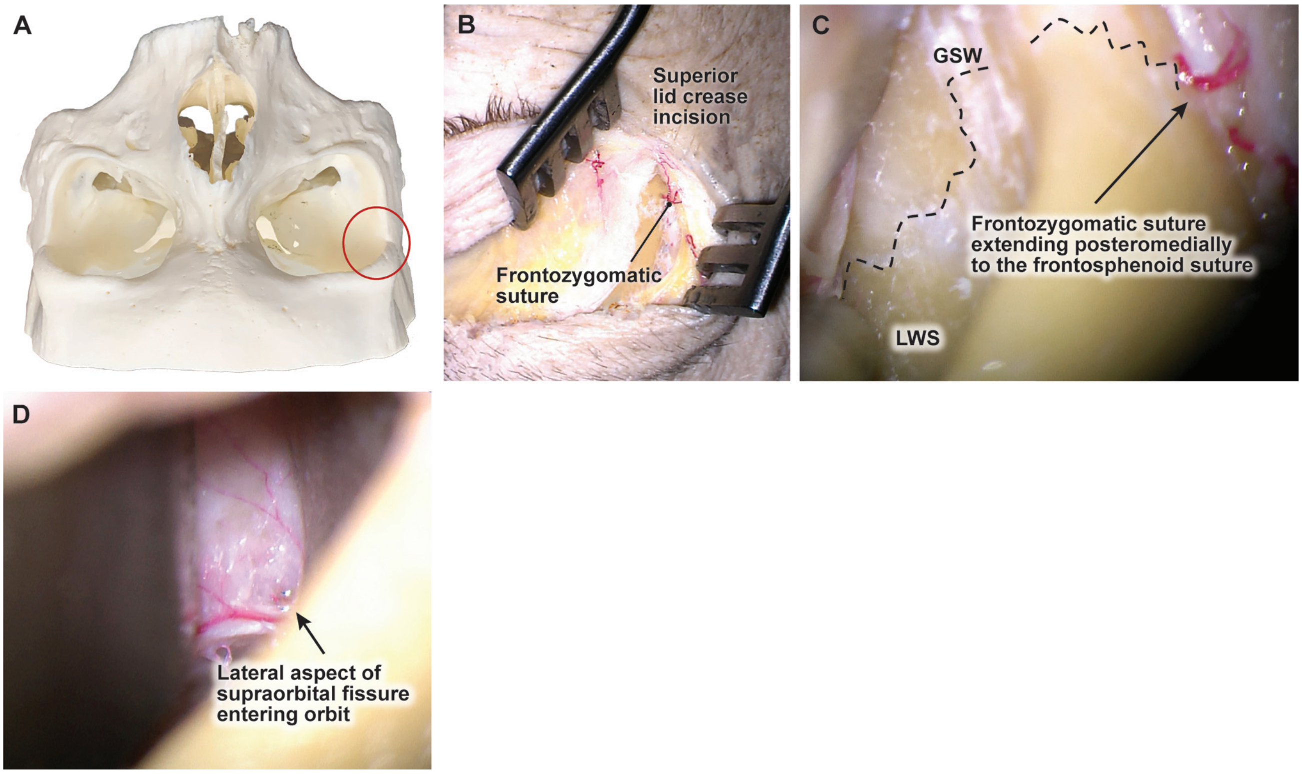

Fig. 3 Cutaneous dissection, identification of the lateral boundaries, and subperiosteal dissection toward the superior orbital fissure. (**A**) Orientation image showing microscope trajectory used in ►**Fig. 3B–D**. The frontozygomatic suture (*circle*) marks the lateral and most inferior boundary of the anterior cranial fossa (ACF) and delineates the ACF and the middle cranial fossa (MCF) as the frontozygomatic suture extends posteromedially. (**B**) Superior lid crease incision allows exposure of the lateral orbital rim and the frontozygomatic suture as it extends posteromedially and intersects with the frontosphenoid suture. (**C**) Microscopic deep view of the lateral orbital wall following the frontozygomatic suture to the frontosphenoid suture (*wavy dashed line*) to the lateral margin (*arrow*) of the superior orbital fissure. (**D**) Lateral aspect of the supraorbital fissure (*arrow*) entering the orbit. GWS, greater wing of sphenoid; LWS, lesser wing of sphenoid. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

the sphenoid bone to extend the craniectomy (►**Fig. 7**). The frontosphenoid suture, which projects posteromedially, represented the most lateral boundary of the craniectomy. Drilling above this suture retains the procedure in the ACF, whereas drilling below it results in entry into the MCF. A dissector was used to palpate the extradural inner table of the lesser sphenoid wing, and the deep lateral extent was appreciated when the ridge dividing the ACF and MCF was visualized. Drilling progressed medially until the medial and lateral craniectomy boundaries converged at a deep apex, i.e., the roof of the optic canal.

A deeper extension was achieved by careful drilling with a telescoping tube attachment. The deepest extension of the craniectomy was determined by visualization of bone quality changing from cortical to cancellous at the root of the anterior clinoid process and by palpation of the flat level of the intracranial optic canal roof medial to it, which represents the lowest accessible plane of this approach. The roof of the optic canal can be removed and the optic nerve decompressed, but doing so will not increase craniocaudal exposure and may increase the risk of injury to the ophthalmic artery as this artery transverses the canal along the inferomedial surface of the nerve.

Discretionary anterior drilling of the orbital roof was limited by the extent of the frontal sinus. For frontal lobe pathology, the anterior craniectomy boundary should be maximized to the orbital rim. Interventions focused on paramedian and neurovascular structures do not require anterior exposure. However, greater maneuverability and access to medial structures was achieved by continuing the craniectomy to the most lateral boundary.

High-resolution computed tomography is essential for preoperative planning. Intraoperative neuronavigation can aid identification of the borders of sinuses and further delineates the superomedial and medial craniectomy boundaries. The frontal and ethmoidal sinuses are key structures that influence the anatomical breadth and boundaries of this approach. Without computed tomography, the surgeon may inadvertently enter the frontal sinus and blindly extend the craniectomy anteromedially. Drilling inferior to the foramina of the anterior and posterior ethmoidal vessels results in fracture of the lamina papyracea and invasion of the ethmoid ostium. Although entry into the ethmoidal sinus can be completed for a more medial approach or may be appropriate for lesions invading the sinus, doing so requires repair of an additional defect. Thus, every attempt should be made to preserve the lamina papyracea. Although the junction of the frontal bone and cribriform plate is not appreciable through an intraorbital view because of the curvature of the ethmoidal sinus, neuronavigation can facilitate its identification.

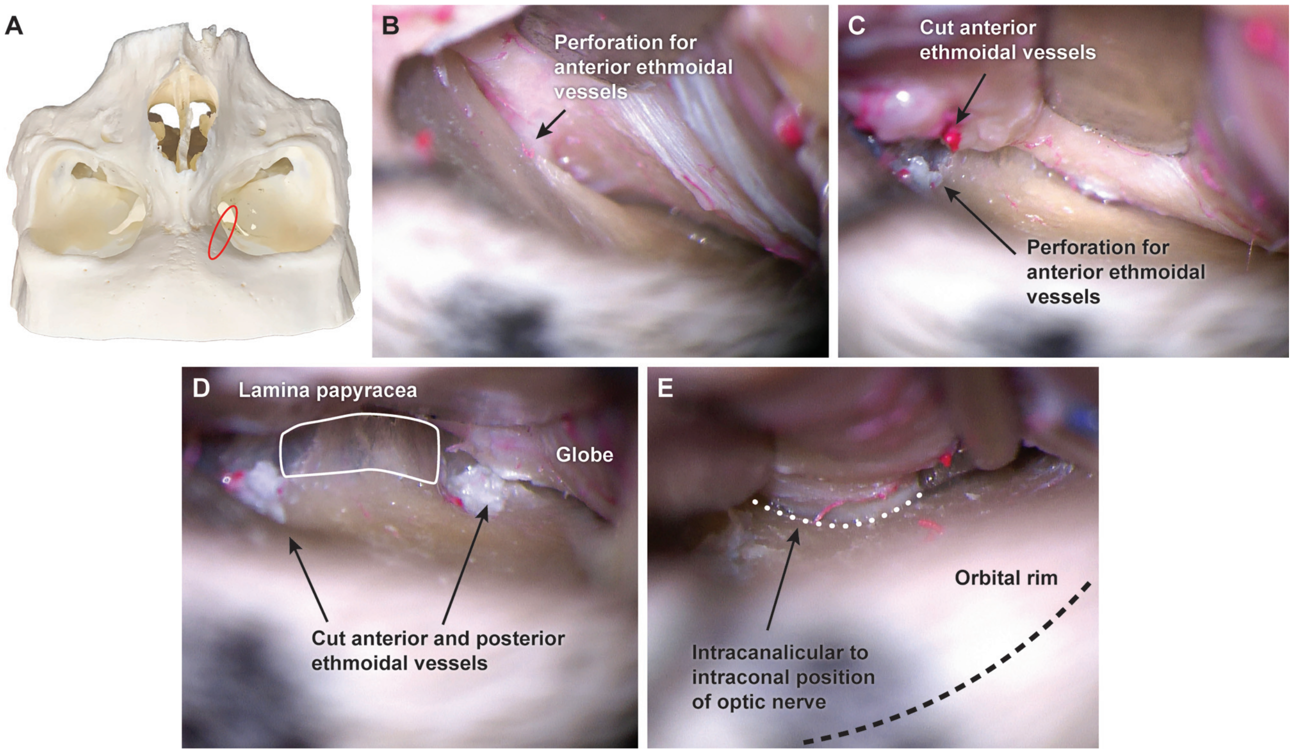

Fig. 4 Microscopic view of the medial subperiosteal dissection that permits full mobilization of the globe. (**A**) Orientation image showing the microscope trajectory (*circle*) used in ►**Fig. 4B–E**. (**B**) The first medial structure is the perforation of the lamina papyracea (*arrow*) for the anterior ethmoidal vessels. (**C**) Transection of the anterior ethmoidal vessels (*arrows*) permits further mobilization of the orbital contents. This mobilization allows deeper dissection and exposure of the posterior ethmoidal vessels along the same plane. (**D**) Transection of the anterior and posterior ethmoidal vessels (*arrows*) allows full medial exposure of the optic canal. *White outline* indicates location of the lamina papyracea. (**E**) Medial disconnection of the ethmoidal vessels and content mobilization enables deep microscopic intraorbital visualization. The *dotted white line* indicates the transition between intracanalicular portion and the intraconal portion of the optic nerve. Dynamic retraction during extracranial dissection minimizes the need for long periods of fixed globe retraction. The dashed curved line indicates the position of the orbital rim. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

Alternatively, when the original defect has been made in the orbital roof, systematic lateral-to-medial bone removal can also delineate this junction extradurally.

Step 5: Dural Opening

The shape of the dural incision is based on the site where access is warranted. For frontal lobe lesions, the dura should be incised in a cruciate fashion, with the reflection of the leaflets inferiorly from the field of interest. This incision substantially assists with dural closure. For access to the deep neurovascular structures, the dura should be incised proximal to the anteromedial boundaries of the craniectomy. For increased mobilization, this incision should be extended around the anterolateral curvature of the craniectomy. After the incision reaches the deep apex at the roof of the optic canal, the single dural leaflet should be reflected laterally for maximal medial exposure. A fixed retractor can be used.

Results

Qualitative Analysis

Accessible Brain Parenchyma

The base of the frontal lobe is easily accessible through the craniectomy defect (►**Fig. 6**). Complete visualization is not possible with the operating microscope. Thus, different angular views are used to appreciate the full extent of the exposure. Given the preservation of the cribriform plate, visualization of the gyrus rectus is not obvious.

Neurovascular Elements

An important component in the surgical setting to maximize intracranial exposure would be to follow the anterior floor posteriorly until identification of the ipsilateral optic nerve and proceed to opening the chiasmatic cistern. CSF drainage will allow the brain to relax and provide better working angles. The first appreciable deep structure is the ipsilateral optic nerve, as it follows the trajectory of the optic canal medially (►**Fig. 7**). Lateral to the ipsilateral optic nerve, the paraclinoid ICA can be visualized. The full length of the intracranial ICA to the A1–M1 bifurcation is accessible without parenchymal retraction. Gentle arachnoid dissection medially allows atraumatic splitting of the sylvian fissure and impressive exposure of the proximal M1 artery. Following the ICA terminus medially reveals the complete length of the ipsilateral A1 artery as it traverses across the optic chiasm toward the anterior communicating artery complex. As the vasculature is followed medially, microscopic visualization and instrumentation maneuverability are limited by the lateral orbital rim. The confluence of the

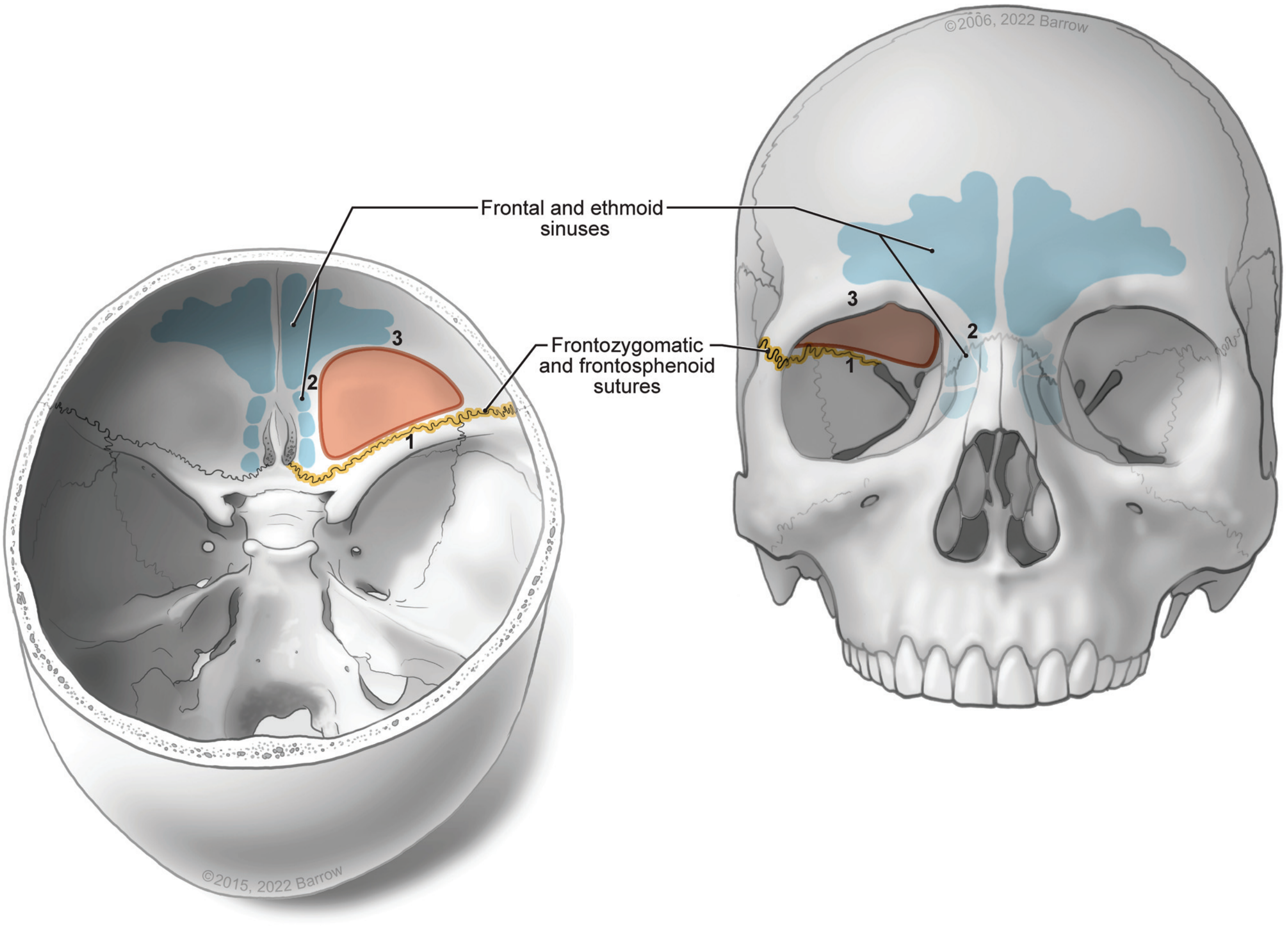

Fig. 5 Boundaries of the transorbital microsurgery (TMS) craniectomy (*shaded areas with solid outline*). Anterior view (*right*) of the critical structures that dictate the extent of the craniectomy when the orbit is retracted inferiorly, including the frontal and ethmoidal sinuses medially and the frontozygomatic suture to the frontosphenoid suture laterally. Superior view (*left*) delineating the boundaries of the craniectomy established using TMS: (1) lateral boundary—frontozygomatic suture to frontosphenoid suture leading back to the roof of the optic canal; (2) medial boundary—frontal sinus and junction of the frontal bone and cribriform plate of ethmoid bone; and (3) anterior boundary—frontal sinus medially and orbital rim laterally. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

bilateral A1 vessels is evident, but no form of manipulation is possible because of the restricted instrument freedom (►**Fig. 7F**).

Size of TMS Craniectomy

The size of the craniectomies in the six cadaver specimens ranged from 337.07 to 572.34 mm^2. The mean (standard deviation) size was 440.53 mm^2 (78 mm^2). The size of the defect does not include the natural curvature of the orbital roof, as it would increase the reported area of exposure.

Discussion

TMS versus Tones

TONES is a clinically significant development in skull base surgery. It encompasses the modern requirements of a proficient surgical technique, minimizing morbidity, being minimally invasive, producing aesthetically satisfactory results, and decreasing hospital length of stay.[1,10] The aim of orbital access is to achieve equal visibility and to surpass the anatomical limitations of the endonasal approach, thereby decreasing the overall invasiveness and complications of open skull base surgery.[1,4,11]

Both the microscope and endoscope provide different technical and surgical benefits and disadvantages. The microscope was the first means for the visualization of minutiae, and it resulted in the advent of microsurgery technique. Conversely, midline interventions require deep open dissection, and visualization attempts increase the risk of injury to superficial structures. Use of the endoscope overcomes these obstacles, producing impressive midline illumination and panoramic views while avoiding the crossing of neurovascular structures. The endoscope is not without drawbacks, especially in minimally invasive approaches. Unlike the microscope, which offers a 3D view and sophisticated proprioceptive awareness, the endoscope is two-dimensional.

Crowding of the surgical corridor is a key limitation of the TONES visualization technique. Clinical sequelae of TONES include transient diplopia, V2 numbness, and ptosis.[12] In contrast, the combined transorbital–transnasal approach

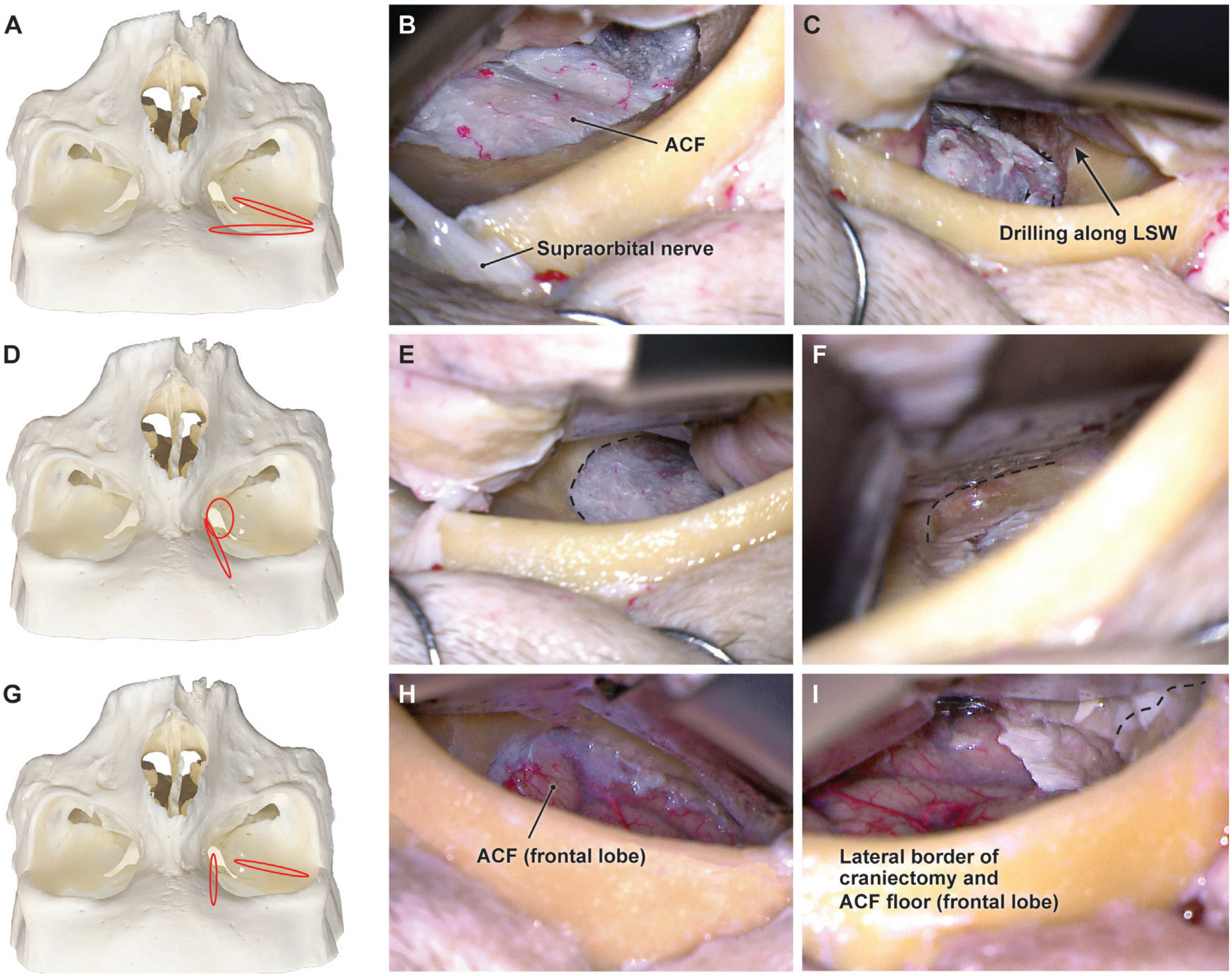

Fig. 6 Microscopic extradural and intradural views after removal of the floor of the anterior cranial fossa (ACF) upon completion of the craniectomy performed using transorbital microsurgery (TMS). **(A)** Orientation image showing the microscope trajectory (*circles*) used in ►**Fig. 6(B, C)**. (**B**) Anterosuperior view of the ACF, in which more bone is preserved medially as evidenced by the presence of the frontal sinus and preservation of the supraorbital nerve. (**C**) Anterolateral view of the extradural exposure, where the lesser sphenoid wing (LSW) has been drilled to extend the craniectomy posteriorly. (**D**) Orientation image showing the microscope trajectory (*circles*) used in ►**Fig. 6(E, F)**. (**E**) Microscopic view of the medial boundary of the craniectomy (*curved dashed line*) at the junction of the frontal bone and the cribriform plate of the ethmoid bone. The boundary of the craniectomy at this stage approaches the extradural insertion of the olfactory fibers into the cribriform plate. (**F**) Apex of the craniectomy (*curved dashed line*), marking its deepest, most medial point. The flat level of the roof of the intracranial optic canal, which represents the lowest accessible plane of this approach, can be palpated extradurally. (**G**) Orientation image showing the microscope trajectory (*circles*) used in ►**Fig. 6(H, I)**. (**H**) Medial microscopic view of the frontal lobe parenchyma within the ACF. (**I**) Lateral microscopic view of the frontal lobe parenchyma within the ACF. The *wavy dashed line* delineates the juncture of the ACF and middle cranial fossa. Note that the full extent of the TMS craniectomy cannot be visualized in only one view because of the curvature of the orbital rim. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

has a reduced rate of these adverse events. Inserting both an endoscope and instruments through a single periorbital incision may injure surrounding structures more than in cases where some of the surgical instruments enter the cranial vault through an additional keyhole. Various reports in the neurosurgery literature have documented attempts to develop multiportal access in interventions that can still be considered minimally invasive. Multiportal endoscopic skull base approaches have evolved to maximize transorbital–transnasal and transorbital–open working angles to anatomical targets with multiple compartments.[10,13,14] Quantitative measurements of different parameters support the superiority of these approaches. The ultimate addition of a second working port will provide better visualization of structures and easier dissection because it will facilitate a two-handed technique. In contrast, a technical weakness of TONES is that it requires so much intraportal instrumentation. However, TMS, which is also a two-handed technique, does not require an additional port.

TMS Considerations

Differences between the two approaches are inherent within the nuance of the operative technique. The TMS craniectomy provides a minimally invasive skull base-sparing corridor to the intracranial regions. Unlike TONES, TMS provides clearly defined anatomical parameters for maximal parenchymal

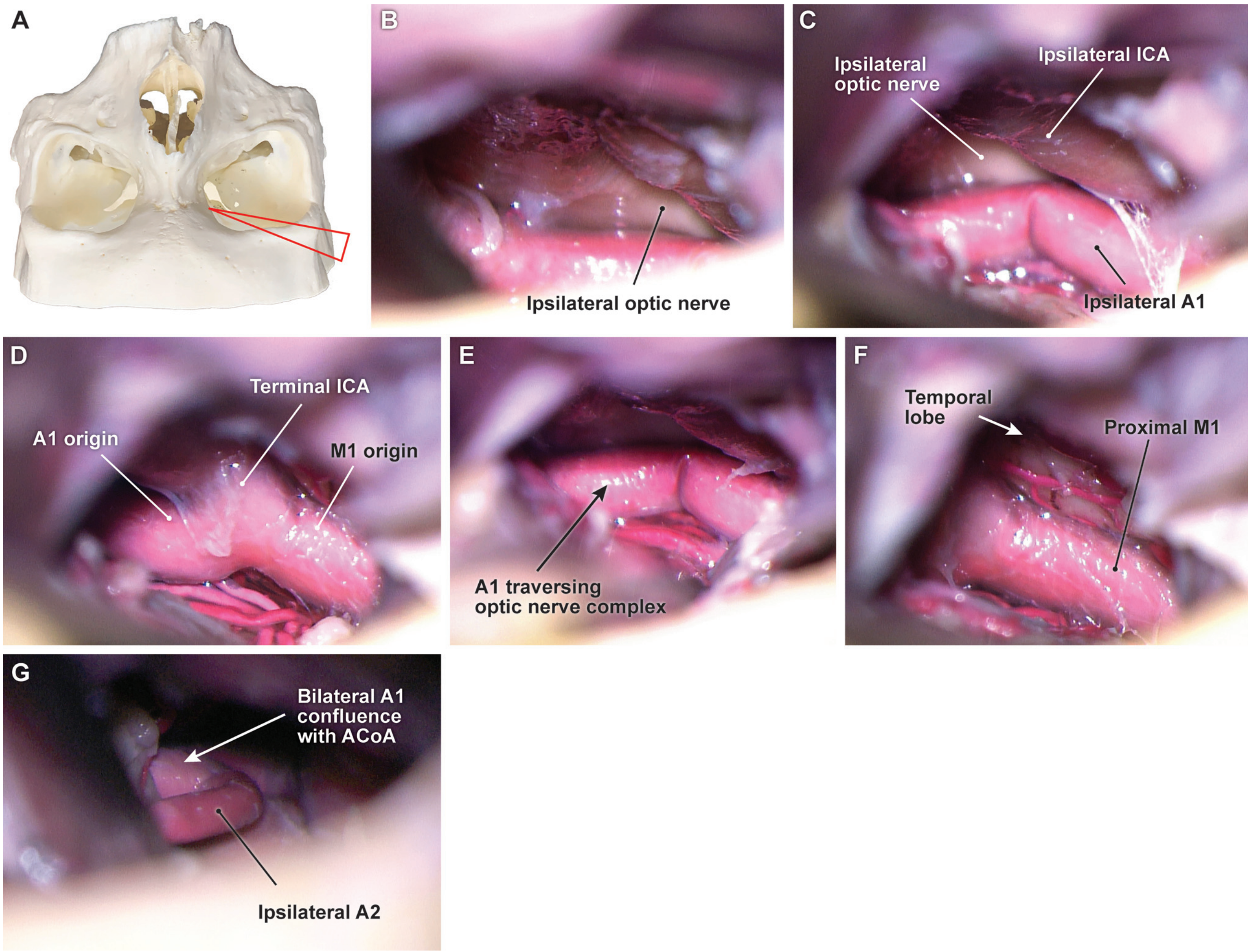

Fig. 7 Microscopic view of the neurovascular structures visible and accessible through the transorbital microsurgery (TMS) craniectomy. (**A**) Orientation image showing the microscope trajectory (*triangle*) used in ►**Fig. 7B–G**. (**B**) The first identifiable structure through this approach is the ipsilateral optic nerve. (**C**) Lateral to this is the ipsilateral internal carotid artery (ICA), which is fully exposed from the paraclinoid section to the terminus. (**D**) This trajectory leads to the ICA terminus, and the origins of the ipsilateral A1 and M1 are fully exposed. (**E**) The complete length of the ipsilateral A1 is visible and accessible. (**F**) Gentle arachnoid dissection allows atraumatic splitting of the sylvian fissure and impressive exposure of the proximal M1 artery. (**G**) Deep visualization of the confluence of the bilateral A1 vessels with the anterior communicating artery (ACoA). Instrumentation use is hindered by the orbital rim. (*Used with permission from Barrow Neurological Institute, Phoenix, Arizona.*)

and neurovascular exposure, while preserving the structural and functional integrity of the skull base.

Lesions on the ACF floor may require large cosmetically unsatisfactory incisions,[15] but, even more worryingly, they harbor an increased risk of serious complications. The superior lid crease incision used in the current study is the most frequently reported cutaneous approach.[12] This incision provides wide medial and lateral access, allows maximal mobilization of the globe, and produces optimal maneuverability for accessing the ACF. It is also frequently used to access the MCF.[16]

Previous anatomical reports detailing TONES used the anterior and posterior ethmoidal vessels as the medial boundary of the orbital roof craniectomy.[4] However, extending the craniectomy medially this far inevitably results in an invasion of the ethmoidal sinus. Breaching the ethmoidal sinus should be considered an adverse event unless the target is pathology in the ethmoidal sinus or a biportal, transorbital–transnasal approach is being used. In contrast, TMS provides a safe medial boundary that preserves the sinuses and protects the olfactory fibers perforating the cribriform plate.

Although no reports have documented postoperative visual deficits after the use of TONES, this possibility is a consideration of any transorbital approach. Vision should be assessed both preoperatively and postoperatively, and intraoperative efforts should focus on minimizing retraction injury. Using dynamic retraction during cutaneous and periosteal dissection minimizes fixed retraction of the globe throughout the procedure.

Published reports on TONES mention the use of fixed retractors only.[17] However, in TMS, surgical instrumentation and suction are used for dynamic retraction only during the preliminary steps of the operation, thus minimizing the risk of injury. Increased intraocular pressure is caused by direct compression of the optic nerve or its vasculature.[18,19] The ophthalmic artery should also be protected. This artery enters the optic canal at the inferomedial aspect of the nerve and then courses laterally as it enters the orbit. The artery lies inferolateral to the nerve in 81% of patients and inferior to the nerve in 19%.[20] When the globe contents are retracted while drilling superiorly, an awareness of these vascular structures at the apex is pivotal.

Another advantage of the transorbital access corridor is the low rate of CSF leaks, both iatrogenically and after defect repair. Neurosurgeons are adept not only at large open craniotomies to access the ACF but also at exclusively transnasal approaches. Craniotomies for the repair of CSF leaks have a low (70–80%) success rate,[21] with potential risks of anosmia, memory deficits, seizures, osteomyelitis, and recurrence.[22,23] The CSF leak recurrence rate after TONES repair is 7%.[12] A CSF pseudomeningocele has been reported in only one patient after tumor resection.[24] These TONES results are comparable, if not superior, to those for open and transnasal interventions. It has been hypothesized that these impressive outcomes regarding CSF leaks are due to the intraorbital pressure exerted by the globe's contents on the orbital roof defect.[4] Since normal intraocular pressure is approximately 15 mm Hg,[25] the idea that this pressure gradient facilitates superior dural defect closure and improved repair is noteworthy, albeit not scientifically assessed.

Indications for TMS

Lesions appropriate for TMS predominantly depend on select factors, including anatomical site and positioning of the frontal and ethmoidal sinuses.

Anatomical Site

Two-handed functional instrumentation is possible in this surgical corridor when the microscope is used for visualization. ACF base meningiomas and low frontal intraparenchymal lesions can be approached because of low skull base access. The ipsilateral anterior circulation can be manipulated with little or no lobar retraction and, when necessary, easy and rapid proximal control can be obtained at the level of the paraclinoid ICA. The cerebrovascular value of a transorbital approach has been reported previously.[19] Drilling the posterior wall of the orbit and the lesser sphenoid wing exposes the sphenoidal portion of the sylvian fissure and the M1 and M2 segments of the middle cerebral artery. No published reports document the use of the transorbital approach for clinical management of aneurysms, arteriovenous malformations, or cavernomas. Access to the mesiotemporal lobe has been completed via TONES.[26] The application of this corridor to neurovascular surgery will depend on instrument maneuverability and proximal control. Determinants include the degree of the attacking angle in specific axes, satisfactory visualization for vessel interrogation, and surgical freedom. Preservation of the lateral orbital rim precludes using the TMS approach for visualization and access to more midline structures, including midline or contralateral vasculature.

Position of the Frontal and Ethmoidal Sinuses

With frontal craniotomies, invasion of the frontal sinus or inadequate dural repair results in a 41% risk of CSF leak after craniotomy.[27] Thus, minimally invasive methods like TMS for accessing the ACF and the ACF floor are pivotal to minimizing morbidity and mortality. The frontal and ethmoidal sinuses are anatomically significant factors to consider when assessing whether TMS is an appropriate surgical corridor for a specific lesion. These structures may represent the entire anteromedial boundary for the craniectomy. If the aim is to tackle a low frontal anterior lesion, special attention should be paid to the extent of the frontal sinus. The transorbital craniectomy would be substantially restricted along the anterior boundary, making an invasion of the frontal sinus more likely during drilling. Therefore, in patients with a large frontal sinus, using TMS for these conditions is not recommended.

Study Limitations

This is a preclinical study, an anatomical dissection that proves the feasibility of using the microscope for adequate visualization of the ACF. Preserved tissue is known to be more rigid than brain parenchyma,[28] and it should also be noted that the globe is dehydrated within cadaveric specimens. Regardless, cadaveric dissection remains the best method of safely trialing surgical approaches and improving the surgical skills of clinicians.

The endoscope has been the only instrument used to date in the clinical setting. The next step in the assessment of TMS is its use in surgical practice, which requires a surgeon who is competent in the anatomy, access corridor, and both methods of visualization. Given that transorbital intracranial surgery has yet to reach the mainstream of neurosurgical practice, such experience would likely occur only in a high-level center of excellence, where the approach is already standard practice and where sufficient cases are completed to ensure competent surgical expertise.

Our recommendation of TMS as an operative intervention is limited in that it is based on a cadaveric dissection study. However, this report is the first in the literature on the use of the operating microscope as the method of visualization while using a solely transorbital access corridor. In many ways, this study is a surgical anatomical feasibility and concept study to define a more comprehensive presentation and analysis of this novel approach for neurosurgery.

Conclusion

In detailing the integral components of TMS, the anatomical and clinically essential considerations, and the related surgical contraindications, we aimed to emphasize its merits for visualization through the transorbital access corridor and to identify select pathologies for which it can be used safely and effectively rather than to proclaim that TMS is better than TONES. Although the use of the microscope for visualization is limited in its midline accessibility, this method of visualization displays potential aspects of operative and technical superiority over the endoscope. This study confirms that this selective craniectomy provides satisfactory intracranial access to specific structures considering the small size of the skull base defect. The approach also facilitates preservation of normal skull base anatomy. This study provides the first anatomical description of the TMS craniectomy to the ACF and neurovascular structures. The use of this approach in clinical practice is warranted to test its efficacy and to evaluate its proposed merits as a minimally invasive, minimally destructive skull base corridor.

Funding
This study was supported by funds from the Newsome Chair of Neurosurgery Research held by Dr. Mark Preul and from the Barrow Neurological Foundation.

Conflict of Interest
None declared.

Acknowledgments
The authors thank the staff of Neuroscience Publications at Barrow Neurological Institute for assistance with manuscript and video preparation.

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