Expanded exposure and detailed anatomic analysis of the superior orbital fissure: Implications for endonasal and transorbital approaches

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Abstract
This study aimed to ascertain the maximal exposure of the superior orbital fissure (SOF) afforded by combining endonasal and transorbital endoscopic approaches. Six cadaveric specimens (12 sides) were dissected using endonasal and transorbital endoscopic approaches to access the SOF. The order of the approaches was alternated in each specimen (eg, starting with an endonasal approach in one side followed by a transorbital exposure and reversing the order on the contralateral side). Maximal exposure of the SOF and its contents for individual and combined approaches were explored. The endonasal corridor provided adequate access to the inferomedial 1/3 of the SOF and including the proximal segments of cranial nerves (CN) III, V1 and VI. A transorbital approach was superior accessing the superolateral 2/3’s of the SOF, including the superior ophthalmic vein, lacrimal nerve, and distal segment of the CN VI at the lateral aspect; the nasociliary nerve and divisions of CN III centrally; and the frontal nerve and CN IV at the dorsal aspect of levator palpabre superioris. This study suggests that a combined endonasal and transorbital exposure of the SOF may be advantageous to address lesions in this challenging region.

Keywords
cranial nerve, endonasal approach, exposure, superior orbital fissure, transorbital approach

1 | INTRODUCTION

Advances in endoscopic equipment and experience with expanded endonasal approaches (EEA) have expanded
their use for lesions at the orbital apex and superior orbital fissure (SOF). While the optic nerve and the ophthalmic artery travel through the optic canal, other cranial nerves (CN) related to ocular function, including the oculomotor nerve (CN III), trochlear nerve (CN IV), ophthalmic nerve (CN V<sub>1</sub>), abducens nerve (CN VI), and the superior ophthalmic vein travel through the SOF. Tumors or trauma may affect the orbital apex and SOF leading to SOF syndrome or orbital apex syndrome (with vision loss).  

In appropriately selected cases, an EEA may successfully access lesions adjacent to the orbital apex. Previous studies regarding management of the orbital apex via an EEA, mostly focused on the optic canal and the medial aspect of the SOF. Therefore, its potential to fully expose the SOF and its associated structures including the CNs III, IV, V<sub>1</sub>, and VI has not been sufficiently explored. Moreover, transorbital approaches have gained popularity during the past decade, and are seemingly suitable for accessing the lateral orbit, anterior and middle cranial fossa, petrous apex, Meckel’s cave, and cavernous sinus. 

To the authors’ knowledge, the potential exposure of the SOF and its associated neurovascular structures combining the endoscopic endonasal and transorbital perspectives, has not been ascertained. Therefore, this cadaveric study aims to combine an endonasal with a transorbital approach to perform a detailed anatomic investigation of the SOF and its associated neurovascular structures exploring the surgical implications for these surgical corridors, when used in isolation and combined. In addition, it aims to establish the potential maximal exposure of SOF and its neurovascular bundles afforded by this combination of approaches.

2 MATERIALS AND METHODS

Endonasal and transorbital endoscopic approaches to the SOF were performed on both sides of six adult cadaveric specimens (12 sides), attempting to reach maximal exposure of the SOF and its neurovascular bundles. The order in which the approaches were completed was alternated for each side, that is, if an endonasal exposure was followed by a transorbital corridor then the transorbital corridor would be done first in the contralateral side. This study was conducted at the Anatomy Laboratory Toward Visuospatial Surgical Innovations in Otolaryngology and Neurosurgery (ALT-VISION) at the Wexner Medical Center of The Ohio State University. All specimens had been commercially prepared with intravascular injections of red (arterial) and blue (venous) latex and were preserved in 70% alcohol. ALT-VISION and all authors were certified by local regulatory agencies dealing with the use of human tissues and cadaveric studies.

Endoscopic visualization was achieved using rigid rod-lens endoscopes (4 mm diameter, 18 cm length) with 0° scope (Karl Storz Endoscopy; Karl Storz, Tuttingen, Germany), coupled to a high-definition camera and video monitor. Both video and standard digital images were recorded during dissections using the AIDA recording system (Karl Storz, Tuttingen, Germany).

3 RESULTS

3.1 Endonasal approach

The dissection began with the resection of the ipsilateral middle turbinate, followed by a total ethmoidectomy, posterior septectomy (to facilitate the two surgeons-two nares-four hands technique) and bilateral sphenoidotomy. A wide maxillary antrostomy was then performed, and the lamina papyracea and medial aspect of the inferior orbital wall were carefully removed exposing the periorbita and extending superiorly to the level of anterior and posterior ethmoidal foramina and inferiorly to the infraorbital canal (Figure 1A). The infraorbital nerve (Figure 1B) was identified in its canal at the orbital floor and traced posteriorly to the foramen rotundum (Figure 1C). The maxillary nerve (V<sub>2</sub>) foramen and canal were skeletonized and the maxillary strut was removed to expose the medial aspect of the SOF (Figure 1D).

The bone overlying the parasellar and paracavernous segments of the internal carotid artery (ICA) was removed to expose the medial and anterior aspects of the ICA (Figure 2A). The abducens nerve (CN VI) and the sympathetic nerve fibers arising from the carotid plexus were identified at the quadrangular space (Figure 2B). Upon medial displacement of the ICA, the CNs III, IV, V<sub>1</sub>, and VI were identified at the lateral wall of the cavernous sinus (Figure 2C).

The periorbita was subsequently opened, and the annulus of Zinn was identified close to orbital apex (Figure 3A). After decompression of the optic canal, the annulus of Zinn was identified to be continuous with the peristeum of the optic nerve in all 12 sides (Figure 3A). The annulus of Zinn was subsequently released, and the proximal segment of CN VI, CN III, and CN V<sub>1</sub> could be identified traveling from the cavernous sinus crossing the inferomedial 1/3 of the SOF (Figure 3B); CN VI subsequently travels an oblique course followed by a lateral direction to the lateral rectus muscle.

To enhance the exposure of distal neurovascular bundles transmitted through the SOF into the intraconal space, the extraconal and intraconal orbital fat was
carefully removed. The inferior division of CN III could be identified within a corridor between medial and inferior recti muscles (Figure 4A); whereas, the superior division of CN III innervating the superior rectus muscle could be visualized through the gap between the superior oblique and medial recti muscles (Figure 4B). The
FIGURE 3  Exposure of the left orbital apex and SOF via an endonasal corridor with 0° scope. A, The annulus of Zinn (An, enclosed dotted line) is in continuity with the periosteum of the optic canal (OC, highlighted portion); B, the CN III, V<sub>1</sub>, and VI could be visualized between the annulus and the greater wing of sphenoid (GW). CN, cranial nerves; SOF, superior orbital fissure [Color figure can be viewed at wileyonlinelibrary.com]

FIGURE 4  Exposure of intraconal space (left orbit) via endonasal approach with 0° scope. A, The inferior division of the CN III to the medial recti muscle (MRM, red arrow) and inferior recti muscle (IRM, blue arrow); B, the superior division to the superior rectus muscle (SRM, red arrow); C, the nasociliary nerve (NCN) and the ophthalmic artery (OA); D, at the dorsal aspect of the levator palpebrae superioris (LPS), the frontal nerve (FN) and the trochlear nerve (TN) were visualized. CN, cranial nerves; ON, optic nerve [Color figure can be viewed at wileyonlinelibrary.com]
ophthalmic artery and the distal segment of the nasociliary nerve (a branch of V1) in the superomedial orbit were also visualized in continuity with the respective anterior ethmoid artery and nerve (Figure 4C). CN IV and the frontal nerve (a branch of V1) could be seen at the dorsal aspect of the levator palpebrae superioris (Figure 4D). However, through the EEA, it was difficult to expose structures lateral to the optic nerve.

### 3.2 Transorbital approach

A 1.5-cm lateral canthotomy was carried down to the lateral orbital rim. The lateral periorbita was then identified and medially elevated from the lateral orbital rim (Figure 5A), which was then drilled to expose the fascia of the temporalis muscle (Figure 5B). In 8/12 sides, the Hyrtl’s foramen, transmitting a meningolacrimal artery, was identified prior to exposing the SOF (Figure 5C).

Following the opening of the superolateral periorbita, orbital fat was carefully removed and the levator palpebrae superioris, as well as the superior and lateral recti muscles were identified. In all 12 sides, the lacrimal nerve (a branch of V1) was found to exit the lateral aspect of the SOF and travel upward along the superior border of lateral rectus muscle (Figure 6A). The superior ophthalmic vein was also identified at the lateral aspect of the SOF (Figure 6B) in all 12 sides; whereas, the distal segment of the CN VI exits the lateral aspect of the SOF and runs anteriorly to reach the medial aspect of the lateral rectus muscle (Figure 6C); after crossing the superolateral SOF, the nasociliary nerve lies at the lateral aspect of the optic nerve, which subsequently turns around the superior border of optic nerve toward the superomedial compartment (Figure 6C). At this stage, the
superolateral 2/3’s of SOF and its contents were sufficiently exposed. Moreover, when tracing the nasociliary nerve forward, the distal segment of the nasociliary nerve could be clearly inspected through an endonasal corridor as previously recorded (Figure 4C).

Through the transorbital corridor, the superior division of the oculomotor nerve was detected at the inferior aspect of the superior rectus muscle (Figure 7A). At the dorsal aspect of the levator palpebrae superioris, the frontal nerve and CN IV were identified to travel anteroinferiorly (Figure 7B). However, exposure of structures medial to the optic nerve was difficult via a transorbital approach.

Additional advantages and drawbacks of the endonasal and transorbital approaches for exposure of the SOF are presented in Table 1.

### Table 1

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<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td><strong>Transnasal approach</strong></td>
<td>1. Better exposure of structures in cavernous sinus and medial SOF</td>
<td>1. Only the anteroinferior 1/3 of SOF could be exposed</td>
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<td>2. The orbital apex and adjacent structures are better exposed</td>
<td>2. Potential for damage to the annulus of Zinn</td>
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<td>3. The terminal branches of CN III to VI in the medial intracranial space are better accessed</td>
<td>3. Potential for damage to the MRM, IRM and SOM</td>
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<td><strong>Transorbital approach</strong></td>
<td>1. The lateral 2/3 of the SOF could be exposed</td>
<td>1. Narrow corridor</td>
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<td>2. The superolateral intracranial space could be accessed</td>
<td>2. Lateral incision and potential esthetics issues</td>
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<td></td>
<td>3. The terminal branches of CN III to VI in superolateral intracranial space are better accessed</td>
<td>3. Potential damage to the frontal branch of facial nerve</td>
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Abbreviations: CN, cranial nerves; IRM, inferior rectus muscle; MRM, medial rectus muscle; SOF, superior orbital fissure; SOM, superior oblique muscle.

**DISCUSSION**

Others have ascertained the feasibility of exposing the optic canal and medial aspect of the SOF through an...
However, despite significant advances in EEA techniques, surgical exposure and management of lesions arising at the orbital apex and SOF remain challenging. Moreover, studies regarding the maximal exposure of neurovascular structures traversing the SOF and its subsequent course through the intraconal space are sparse. In the present study, the combined endonasal and transorbital approaches provided exposure of the entire SOF and its associated neurovascular bundles, which seems to be beneficial for choosing a surgical corridor.

The SOF syndrome is not rare, as trauma, infection and tumor mass effect are common predisposing factors. Previous studies have reported on the surgical exposure of the medial orbital apex and the medial aspect of the SOF. However, this study demonstrated some new highlights. The proximal segments of the CNs VI, V1 and III are enclosed by the annulus of Zinn and the greater wing of the sphenoid after crossing the medial aspect of SOF. Thus, an EEA may serve as a rationale corridor to address the effects of trauma, infection or tumors extending from the cavernous sinus to the inferomedial 1/3 of the SOF where the periorbita, Müller’s muscle and the annulus of Zinn may be appropriately released. Moreover, the superior aspect of the annulus of Zinn is intimately attached to the optic strut (or lateral opticocarotid recess) and is continuous with the peristeum of the optic canal; therefore, particular attention is warranted when separating the intersecting portion between the annulus of Zinn and the optic strut to decrease inadvertent injury to the optic nerve. Of note, the complex structural relationships surrounding the SOF also can be technically demanding for exposure of the medial and lateral aspects of the SOF, respectively. During the cadaveric dissection, we found that releasing the medial orbit via an endonasal corridor can help exposure of the lateral SOF through a transorbital corridor. Conversely, dissection of the lateral orbit had little impact on the exposure of the medial SOF via an EEA, the exposure of which was mainly restricted by the annulus of Zinn.

After traversing the medial SOF, the CNs VI, V1, and III enter the intraconal space, innervating their respective recti and oblique muscles or glands. The CN VI runs an oblique course traveling in a lateral direction to innervate the lateral rectus muscle while crossing the SOF. Moreover, the distal segments of the CN III, optic nerve, ophthalmic artery and nasociliary nerve within the medial intraconal space could be sufficiently exposed via a transnasal corridor. This suggests that intra-orbital lesions or those originating in intraconal space with a limited extension into the SOF (i.e., trauma, foreign body, abscess, cavernous hemangioma, schwannoma) may be appropriately managed via an endonasal corridor. Lesions arising from the orbital apex or SOF with significant intracranial extension, however, are best managed through a craniotomy approach. Nonetheless, an open orbital resection or craniotomy, may also face similar challenges of function preservation in this complex region.

The superolateral orbit has been traditionally accessed through a lateral open corridor. This study used a small lateral canthus incision (1.5 cm) to facilitate the exposure of both the superolateral intraconal space and the superolateral 2/3’s SOF, and its content including the superior ophthamlic vein, CNs III, IV, V1, and VI. The endoscopic visualization in combination with the use of appropriate instruments can facilitate maximal exposure of the superolateral 2/3’s SOF. Therefore, it may provide an alternative means or may be used as an adjunctive corridor to address lesions originating or extending into the superolateral 2/3’s of the SOF and the superolateral intraconal space. However, like with open approaches to the SOF, it could result in postoperative deficits due to damage to the recti muscles, levator palpebrae superioris or optic nerve, leading to ocular mobility dysfunction or vision loss.

The terminal segment of the CN IV and the frontal nerve were identified at the dorsal aspect of the levator palpebrae superioris. Although these structures could be sufficiently exposed through the gap between the superior oblique and medial rectus muscles on a cadaveric dissection, the employment of an endonasal corridor to address lesions arising from the SOF with extension into the dorsal aspect of the levator palpebrae superioris is extremely limited on live patients. It may serve as an auxiliary corridor for tumor biopsy or abscess drainage; to act as a reasonable window for tumor resection or bleeding control, however, is not recommended. Similarly, the dorsal aspect of the levator palpebrae superioris could also be accessed via an endoscopic transorbital corridor; however, its clinical applicability also carries great technical challenges and deserves further clinical validation.

The anatomical position of the optic nerve is of paramount importance for any procedure accessing into the SOF and the intraconal space. The optic nerve is lateral to the SOF when accessed through the EEA; therefore, it is protected as long as one does not surpass the boundaries of the SOF. Conversely, when addressing lesions originating in the superolateral orbit via a transorbital approach, the optic nerve is found at its dorsoventral aspect, and; thus, at risk. Therefore, the vertical line bisecting the optic nerve may be helpful to select an approach to access the inferomedial 1/3 and the superolateral 2/3’s of the SOF using an endonasal corridor (medial to lateral direction) and an endoscopic transorbital corridor (lateral to medial direction), respectively.

The entire SOF and its contents could be sufficiently exposed through endonasal and transorbital approaches.
However, the limitations for each separate corridor are significant. As with any cadaveric feasibility studies, the described technique in this complex region needs clinical validation. Moreover, the EEA may carry great risk of damage to the branches of ophthalmic artery and the optic nerve when accessing the medial SOF and intracranial space; whereas for an endoscopic transorbital approach, a lateral canthotomy most often heals well but may still impact facial esthetics; the working space between the lateral orbital rim and the periorbita is narrow, which may restrict the instrument maneuverability for the management of complex situations; and retraction of the globe may cause additional injury to the orbit. In addition, the extraconal and intracanal orbital fat was partially removed to enhance exposure on cadaveric dissection, and bleeding and mass effect factors are not considered. In live cases, using bipolar diathermy or compression of the fat with cotton pledgets helps to manage the intracanal fat and bleeding.

5 | CONCLUSIONS

Whereas the EEA is appropriate for exposure of the inferomedial 1/3 of the SOF and the cavernous sinus, the transorbital approach provides a superior exposure of the superolateral 2/3’s of the SOF. Using their complementary features, it is feasible to access the entire SOF and its contents through a combined endonasal and transorbital approaches.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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