Intraconal Anatomy of the Anterior Ethmoidal Neurovascular Bundle: Implications for Surgery in the Superomedial Orbit

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Abstract

Background: The anterior ethmoidal artery (AEA) branches from the ophthalmic artery in the superomedial intraconal space. The feasibility of management of lesions arising from the superomedial intraconal space via an endoscopic endonasal approach has not been sufficiently explored.

Objective: To yield a detailed anatomic description of the anterior ethmoidal neurovascular bundle and its variants to serve as the foundation for possible management of lesions in the superomedial intraconal space.

Methods: Eight cadaveric specimens (16 sides) were dissected using an endonasal approach, tracing the AEA proximally through the superomedial intraconal space. Furthermore, the anatomy of adjacent structures was noted, and distances from the anterior ethmoidal foramen to the origin of the AEA at the ophthalmic artery were measured.

Results: Supraorbital cells were found in 13/16 sides (81.25%), and a bony dehiscence of the anterior ethmoidal canal was observed in 5/16 sides (31.25%). The nasociliary nerve, ophthalmic artery, superior division of the oculomotor nerve, superior rectus muscle, and levator palpebrae superioris were routinely identified in the superomedial intraconal space. The AEA passed through a corridor between the medial rectus and superior oblique muscles after arising from the ophthalmic artery (lateral to the foramen) in all specimens. The average distance from its origin to the anterior ethmoidal foramen was 5.19 ± 0.98 mm.

Conclusion: Anatomically, it is feasible to access the superomedial intraconal space via an endoscopic endonasal approach. This study provides the anatomical basis for procedures in the superomedial intraconal space.

Keywords

anterior ethmoidal artery, supraorbital cell, medial rectus muscle, superior oblique muscle, intraconal space

Introduction

Advances in endoscopic techniques have led to significant progress in the management of sinonasal and skull base diseases.^{1,2} Expanded endoscopic approaches (EEAs) have been widely applied to lesions of the skull base with satisfactory outcomes.^{3–5} Improved illumination, decreased brain manipulation, and short-term hospital stay are major advantages of the EEA.³ However, comorbidities such as cerebrospinal fluid leak, anterior ethmoidal artery (AEA) injury, and penetration into the orbit were not rare in the early stages of endoscopic endonasal surgery.^{3,6}

The AEA is an important landmark for surgery of the anterior skull base.⁶ Bony dehiscence of the anterior

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ethmoidal canal has been reported in up to 46.4% of cadaveric specimens.⁷ Appropriate identification of the AEA is an important step to prevent its inadvertent injury or transection.^{8,9} Others have correlated the posterior wall of the frontal sinus and the supraorbital ethmoidal cells with the location of the AEA.^{10,11} However, the course of the AEA and the relationship between the supraorbital cells are variable.¹²

EEAs have been utilized to manage lesions originating in the intraconal space; however, their indication has been restricted mainly to lesions (eg, cavernous hemangioma, retrobulbar abscess, foreign body) arising from the inferomedial intraconal space.^{13–15} Both the transethmoidal and prelacrimal approaches have been well described for access into the inferomedial intraconal space.^{16,17} Nonetheless, with the progressive development of endoscopic techniques and surgical instruments, the application of EEAs for the management of orbital lesions may be further expanded; moreover, the feasibility to access the superomedial orbit has not been sufficiently explored.^{16–18} Previous studies demonstrated that the AEA and anterior ethmoidal nerve branch from the ophthalmic artery and the nasociliary nerve in the superomedial intraconal space, respectively.¹⁶ We thereby hypothesized that the gap between the medial rectus muscle and the superior oblique muscle potentially offers a route to access the superomedial intraconal space via EEA.

The purpose of this study is to explore the anatomical relationships of the anterior ethmoidal neurovascular bundle to offer a detailed description of its course and adjacent structures with the identification of surgical landmarks and their possible surgical implications.

Materials and Methods

This study comprised the dissection of 8 adult cadaveric specimens (16 sides) prepared with intravascular injections of colored latex. All dissections were 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. ALT-VISION and all coauthors were certified by local regulatory agencies dealing with the use of cadaveric studies.

An endoscopic transethmoidal approach to the superomedial intraconal space was performed on each side. Visualization was provided by rigid rod-lens endoscopes (4-mm diameter and 18-cm length) with 0°, 30°, and 45° lenses (Karl Storz Endoscopy; Karl Storz, Tuttlingen, Germany), coupled to a high-definition camera and video monitor. A high-resolution computed tomography scan was performed prior to the dissection, and data were exported to a surgical navigation system (Stryker, Kalamazoo, Michigan) that served to confirm the surgical impression of pertinent structures. Video and standard digital images were recorded using an advanced image and data acquisition (AIDA) recording system (Karl Storz Endoscopy; Karl Storz).

Results

Following the resection of the uncinate process and an osteomeatal antrostomy, a total ethmoidectomy and a posterior nasal septectomy were performed exposing the anterior skull base and enhancing instrument maneuverability in the posterior nasal cavity. All anterior ethmoidal cells adjacent or below the frontonasal recess were resected, and the frontal sinus was visualized with a 45° scope. The opening to the frontal sinus was maximally expanded to visualize its posterior wall and to identify the presence of a supraorbital cell (Figure 1(A)). The incidence of supraorbital cells and bony dehiscences of the AEA canals were noted. Following the removal of the lamina papyracea, the periorbita was opened (Figure 1(B)) and orbital fat in the extraconal space was removed to better expose the medial rectus and superior oblique muscles (Figure 1(C)). This facilitated dissecting the AEA proximally. The distance from the origin of the AEA from the ophthalmic artery to the

Figure 1. The anterior skull base on left side. A, AEA, SOC, and FS. B, The periorbita (P) was incised to expose the orbital fat (F). C, MRM and SOM. AEA, anterior ethmoidal artery; FS, frontal sinus; MRM, medial rectus muscle; SOC, supraorbital cell; SOM, superior oblique muscle.

anterior ethmoidal foramen was measured using a microruler.

A supraorbital cell was observed in 13/16 sides (81.25%), 11 of which the superior orbital cell was immediately adjacent to the anterior ethmoidal canal. In the remaining 2 sides, however, the cell was not adjacent to the anterior ethmoidal canal (Figure 2(A)). In 5/16 sides (31.25%), the anterior ethmoidal canal was dehiscent (Figure 2(B)).

Terminal branches of the AEA were observed to supply the nasal septum, and some small offshoots entered into the intracranial cavity through the posterior aspect of the frontal sinus (Figure 3(A)). Both the AEA and anterior ethmoidal nerve exited the orbit through the anterior ethmoidal foramen (Figure 3(B)).

The AEA transited under the superior oblique muscle (Figure 4(A)) and branching from the ophthalmic artery lateral to the anterior ethmoidal foramen in all 16 sides (Figure 4(B)). The average distance from the anterior ethmoidal foramen to the origin of the AEA from the

ophthalmic artery (Figure 4(B), red line) was 5.19 ± 0.98 mm (Table 1). After giving origin to the AEA, the ophthalmic artery ran along the medial border of the superomedial orbit immediately adjacent to the supraorbital air cell in an anterior direction (Figure 4(C)). The posterior ethmoidal artery was seen to arise from the ophthalmic artery within the superomedial intraconal space, opposite to the inferomedial muscular trunk (Figure 5(A)).

The anterior ethmoidal nerve arises from the nasociliary nerve and follows a long route almost parallel to the ophthalmic artery (Figure 5(B)). At the superolateral aspect of the nasociliary nerve, one could identify the superior division of oculomotor nerve, superior rectus muscle, and levator palpebrae superioris (Figure 6(A)). Inferior retraction of the levator palpebrae superioris exposed the trochlear nerve and frontal nerve branching from the ophthalmic nerve (V_1) (Figure 6(B)). Exposure of the optic nerve could be achieved through the corridor between the superior oblique muscle and medial rectus

Figure 2. A, The gap between the SOC and AEA (highlighted portion, left side). B, Bony dehiscence of anterior ethmoidal canal (enclosed portion, left side). AEA, anterior ethmoidal artery; SOC, superior orbital cell (For interpretation of the references to colours in this figure legend, refer to the online version of this article).

Figure 3. A, The AEA (left side) can be divided into a septal branch (red arrow) and a cranial branch (white arrow). B, The AEA and the anterior ethmoidal nerve (red arrow) exit the anterior ethmoidal foramen (highlighted portion, left side). AEA, anterior ethmoidal artery (For interpretation of the references to colours in this figure legend, refer to the online version of this article).

Figure 4. Intraconal structures on the left side. A, Both the AEA and AEN transit the inferior border of SOM. B, AEA originates from the OA (highlighted portion), the red line represents the distance (D) from AEF to the origin of AEA from OA. C, The OA travels forward along the lateral wall of SOC. AEA, anterior ethmoidal artery; AEF, anterior ethmoidal foramen; AEN, anterior ethmoidal nerve; MRM, medial rectus muscle; NCN, nasociliary nerve; OA, ophthalmic artery; SOC, superior orbital cell; SOM, superior oblique muscle (For interpretation of the references to colours in this figure legend, refer to the online version of this article).

Table 1. The Distance From AEF to OA Was Measured, the Results was Presented as Mean $\pm$ Standard Deviation (mm).

Number	Laterality	AEF to OA (mm)
1	Left	6
2	Right	7
3	Left	3
4	Right	5
5	Left	5
6	Right	5
7	Left	5
8	Right	6
9	Left	6
10	Right	6
11	Left	5
12	Right	4
13	Left	5
14	Right	5
15	Left	4
16	Right	6
Average		5.19 ± 0.98

Abbreviations: AEF: anterior ethmoidal foramen; OA: ophthalmic artery.

muscle (Figure 6(C)); however, significant retraction of the medial rectus muscle was necessary.

In addition, the anterior pole of the superomedial orbit including the equator and the posterior aspect of the globe could not be visualized even under the guidance of an angled endoscope through the EEA corridor.

Discussion

The superomedial orbit is located close to the ethmoidal sinus and the anterior skull base,¹⁹ and the AEA and anterior ethmoidal nerve exit from the superomedial orbit and run along the anterior skull base toward a

medial direction.²⁰ Through the cadaveric dissection presented in this study, the neurovascular bundles and ocular muscles in superomedial orbit could be sufficiently exposed via an EEA corridor, which may provide the anatomical basis for surgical procedures of the superomedial orbit.

The supraorbital cell has been used previously as a landmark to identify the AEA.^{10,11} A supraorbital cell was detected in 13/16 sides (81.25%) and in 11/13 sides the supraorbital cell was adjacent to the anterior ethmoidal canal. In the remaining 2 sides, however, a short distance existed between these 2 structures. When there is no supraorbital cell, the opening to the frontal sinus can be used for its identification although the relationship and distances between each other are variable.

Ferrari et al. reported that dehiscences of the anterior ethmoidal canal occur in 46.4% of cases.⁷ Similar findings were observed in this study (31.25%). In the setting of a bony dehiscence, the AEA will be covered by mucosa, thus mandating careful attention to avoid injuring the vessel. When traced proximally toward the superomedial intraconal space, the AEA traveled under the superior oblique muscle in all 16 sides included in this study, which was in accordance with previous reports.²¹

The AEA is a critical landmark for surgical procedures of the anterior skull base.⁶ If inadvertently injured, its proximal segment may retract into the orbit resulting in an expanding hematoma within the intraconal space.¹³ When traced proximally specimen, the AEA was identified to arise from the ophthalmic artery lateral to the anterior ethmoidal foramen. This study revealed that the AEA originates from the ophthalmic artery at an average distance of 5.19 ± 0.98 mm from the anterior ethmoidal foramen. In all specimens, both the AEA and the ophthalmic artery could be dissected through a corridor between the superior oblique muscle and medial

Figure 5. Intraconal structures on the left side. A, PEA and IMT branching from the OA. B, The NCN. AEA, anterior ethmoidal artery; IMT, inferomedial muscular trunk; LPS, levator palpebrae superioris; MRM, medial rectus muscle; NCN, nasociliary nerve; OA, ophthalmic artery; PEA, posterior ethmoidal artery; SOM, superior oblique muscle; SRM, superior rectus muscle.

Figure 6. Intraconal structures on the left side. A, LPS and SRM, and superior division of oculomotor nerve to SRM (arrow). B, After inferior retraction of the LPS, the FN and the TN could be identified. C, The ON could also be exposed after inferior retraction of the MRM. AEA, anterior ethmoidal artery; FN, frontal nerve; LPS, levator palpebrae superioris; MRM, medial rectus muscle; NCN, nasociliary nerve; OA, ophthalmic artery; ON, optic nerve; SOM, superior oblique muscle; SRM, superior rectus muscle; TN, trochlear nerve.

rectus muscle. Understanding the anatomical intricacies of the AEA pathway as it arises from the ophthalmic artery to avoid its injury during approaches to the superomedial orbit.

The anterior ethmoidal nerve originates from the nasociliary nerve and exits the anterior ethmoidal foramen to accompany the artery along the anterior skull base.¹² The nasociliary nerve in the superomedial intraconal space appears as a thin fiber accompanying the ophthalmic artery.²² Thus, its preservation mandates a careful and attentive dissection.

The position of the optic nerve, reported to be at the same level of the superior border of the medial rectus muscle, is a major consideration during any dissection or procedures of the intraconal space.^{17,23,24} Therefore, exposure of the optic nerve through the corridor between the medial rectus and the superior oblique muscles requires the inferior retraction of the medial rectus muscle. However, exposure of its most anterior aspect,

entering the globe, is not feasible through an endoscopic corridor, even when using an angled endoscope and inferiorly retracting the medial rectus muscle. Therefore, an orbitotomy should be considered as an adjunct if the lesion extends to the anterior most aspect of the superomedial orbit.^{25,26} Moreover, the superomedial intraconal space contains multiple small branches from the ophthalmic artery; thus, any cauterization should be cautious to decrease the possibility of damaging the ophthalmic artery or optic nerve.

Others have explored the superomedial intraconal space for exposure of lesions, traditionally via transcranial or transconjunctival approaches.^{4,25–27} In a cadaveric study, Gras-Cabrero et al. investigated the anatomy of the AEA and its exit from the orbit.²¹ However, surgical implications of the anatomy of the anterior ethmoidal neurovascular bundle in the superomedial intraconal space were not sufficiently described. This study revealed that the orbital fat, ophthalmic

artery and branches, and nasociliary nerve are the main contents of the superomedial intraconal space, and that even the trochlear nerve and frontal nerve at the dorsal aspect of levator palpebrae superioris could also be exposed via an EEA corridor. Therefore, this technique may provide an alternative method to manage lesions in the superomedial intraconal space via an endoscopic approach, including drainage of abscess, biopsy of tumor, or removal of a foreign body. However, more aggressive procedures within the superomedial intraconal space via an EEA corridor are not advocated.

There are significant limitations to this preclinical (ie, cadaveric) study. Most notably, orbital fat was removed which allowed for exposure of all the surrounding structures whereas these structures would not likely be readily visible during a live dissection. In live surgery, the intraconal fat should be cautiously retracted with small cottonoids. Any surgical procedure in the superomedial intraconal space via an EEA is extremely challenging and its clinical application still deserves further validation. Nonetheless, its anatomical principles are demonstrated in this study.

Conclusion

The anterior ethmoidal neurovascular bundle is a landmark to locate structures in the superomedial orbit. Anatomically, this study provides the anatomical basis and suggests the feasibility to access the superomedial intraconal space through a corridor between the medial rectus and the superior oblique muscles.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: N. R. London hold stock in Navigen Pharmaceuticals and was a consultant for Cooltech Inc., neither of which are relevant to this manuscript.

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References

- Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica. *Neurosurg Focus*. 2005;19:E3.
- Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. *Neurosurg Focus*. 2005;19:E4.
- Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. *J Neurosurg*. 2011;114:1544–1568.
- Prevedello DM, Ditzel Filho LF, Solari D, Carrau RL, Kassam AB. Expanded endonasal approaches to middle cranial fossa and posterior fossa tumors. *Neurosurg Clin N Am*. 2010;21:621–635.
- Zanation AM, Snyderman CH, Carrau RL, Gardner PA, Prevedello DM, Kassam AB. Endoscopic endonasal surgery for petrous apex lesions. *Laryngoscope*. 2009;119:19–25.
- de Almeida JR, Snyderman CH, Gardner PA, Carrau RL, Vescan AD. Nasal morbidity following endoscopic skull base surgery: a prospective cohort study. *Head Neck*. 2011;33:547–551.
- Ferrari M, Pianta L, Borghesi A, et al. The ethmoidal arteries: a cadaveric study based on cone beam computed tomography and endoscopic dissection. *Surg Radiol Anat*. 2017;39:991–998.
- Abdullah B, Lim EH, Husain S, Snidvongs K, Wang Y. Anatomical variations of anterior ethmoidal artery and their significance in endoscopic sinus surgery: a systematic review. *Surg Radiol Anat*. 2019;41:491–499.
- Pernas FG, Coughlin AM, Hughes SE, Riascos R, Maeso PA. A novel use of a landmark to avoid injury of the anterior ethmoidal artery during endoscopic sinus surgery. *Am J Rhinol Allergy*. 2011;25:54–57.
- Jang DW, Lachanas VA, White LC, Kountakis SE. Supraorbital ethmoid cell: a consistent landmark for endoscopic identification of the anterior ethmoidal artery. *Otolaryngol Head Neck Surg*. 2014;151:1073–1077.
- Simmen D, Raghavan U, Briner HR, et al. The surgeon's view of the anterior ethmoid artery. *Clin Otolaryngol*. 2006;31:187–191.
- Erdogmus S, Govsa F. The anatomic landmarks of ethmoidal arteries for the surgical approaches. *J Craniofac Surg*. 2006;17:280–285.
- Lenzi R, Bleier BS, Felisati G, Muscatello L. Purely endoscopic trans-nasal management of orbital intraconal cavernous haemangiomas: a systematic review of the literature. *Eur Arch Otorhinolaryngol*. 2016;273:2319–2322.
- Teh D, Mohamad NF, Lim E, Zulkiflee AB, Narayanan P, Kamalden TA. Endoscopic transnasal removal of an intraconal foreign body using an image-guided surgical system. *Comput Assist Surg (Abingdon)*. 2016;21:25–28.
- Calandriello L, Grimaldi G, Petrone G, et al. Cavernous venous malformation (cavernous hemangioma) of the orbit: current concepts and a review of the literature. *Surv Ophthalmol*. 2017;62:393–403.
- Dallan I, Seccia V, Lenzi R, et al. Transnasal approach to the medial intraconal space: anatomic study and clinical considerations. *Minim Invasive Neurosurg*. 2010;53:164–168.
- Li L, London NR Jr, Silva S, Prevedello D, Carrau RL. Transnasal prelacrimal approach to the inferior intraconal space: a feasibility study. *Int Forum Allergy Rhinol*. 2019;9:1063–1068.

18. Li L, London NR Jr, Prevedello DM, Carrau RL. Anatomical variants of the infraorbital canal: implications for the prelacrimal approach to the orbital floor. *Am J Rhinol Allergy*. 2019;1945892419882127.
19. Tan SH, Prepageran N. Endoscopic transnasal approach to medial orbital lesions. *J Laryngol Otol*. 2015;129:928–931.
20. Hwang SH, Joo YH, Seo JH, Kim SW, Kang JM. Endoscopic endonasal approach of the medial intraconal space: CT analysis of the anatomic relation between paranasal structures and orbital contents. *J Craniofac Surg*. 2012;23:966–969.
21. Gras-Cabrerizo JR, Martel-Martin M, Garcia-Lorenzo J, et al. Surgical anatomy of the medial wall of the orbit in 14 human cadavers. *J Neurol Surg B Skull Base*. 2016;77:439–444.
22. Seredyka-Burduk M, Burduk PK, Wierzchowska M, Kaluzny B, Malukiewicz G. Ophthalmic complications of endoscopic sinus surgery. *Braz J Otorhinolaryngol*. 2017;83:318–323.
23. Bleier BS, Healy DY Jr, Chhabra N, Freitag S. Compartmental endoscopic surgical anatomy of the medial intraconal orbital space. *Int Forum Allergy Rhinol*. 2014;4:587–591.
24. Petrov D, Craig J, Thawani J, et al. Relationship of the optic nerve to the medial rectus muscle during endonasal dissection of the medial intraconal orbital apex. *Oper Neurosurg (Hagerstown)*. 2017;13:131–137.
25. Park SJ, Yang JW. The transconjunctival approach a minimally invasive approach to various kinds of retrobulbar tumors. *J Craniofac Surg*. 2013;24:1991–1995.
26. Surej Kumar LK, Vinod MK, Menon PV. Lateral orbital approach: gateway to intraorbital lesions. *Natl J Maxillofac Surg*. 2014;5:217–220.
27. Lyson T, Sieskiewicz A, Rogowski M, et al. Endoscopic transconjunctival surgical approach to intraconal space of the orbit: first clinical experience. *Neurol Neurochir Pol*. 2014;48:248–253.