Morphological Characteristics of the Anterior Ethmoidal Artery in Ethmoid Roof and Endoscopic Localization

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ABSTRACT

Objectives: To provide anatomical data to help identify and locate the anterior ethmoidal artery (AEA) precisely during endoscopic procedures. **Method:** We dissected 15 adult cadaver heads, which provided 30 specimens, to study morphological characteristics, courses, and several types of variations. **Results:** We found the average diameter of the AEA to be 0.80 ± 0.24 mm. In 85.7% of the cases, the artery was seen between the second and third lamella. Other locations were over the roof of the frontal recess cells (10.7%) and the roof of the posterior ethmoid sinus (3.6%). The AEA ran parallel to the ethmoid roof and formed a slight curve. When viewed from the superior side, the angle formed by the long axis of the artery and the lamina papyracea was $60.5 \text{ degrees} \pm 16.4 \text{ degrees}$. In 83.3% of the cases, the anterior ethmoidal canal (AEC) was identified as a separate canal, and in 16.7% the canal was embedded in the ethmoid roof. In 10 of the 30 cases (33.3%), the AEC presented some degree of dehiscence. **Conclusion:** As a result of these dissections, we found that the AEA's course in the ethmoid roof varies. The morphological characteristics—that the AEA runs parallel to the ethmoid roof, forming a slight posterolateral to anteromedial curve as it passes from the orbit to the cribriform plate—are the most reliable factors used to identify the artery during surgery.

KEYWORDS: Anterior ethmoidal artery, anterior ethmoidal canal, ethmoid roof

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With the advancement of the endoscopic technologies, endoscopic sinus surgery has been applied beyond the nasal cavity and the paranasal sinuses to proximal regions such as the naso-ocular region, the anterior skull base, and the lateral skull base. Due to the special anatomical course in the ethmoid roof, which is behind the posterior border of the frontal recess or the floor of the anterior skull base, the anterior ethmoidal artery (AEA) is regarded as an important anatomical landmark in the surgical approach to the frontal recess and the anterior skull base.^{1,2} However, its deep position, multiple variations, and complicated connections with adjacent structures make it a high-risk area³ for the surgeon. Damage to the artery during surgery may cause serious complications, such as intense bleeding, cerebrospinal fluid leak, orbit hematoma due to artery retraction toward the intra-orbital region, and even cerebral infections.

Many scholars worldwide have conducted research concerning anatomical features of the AEA. The literature provides significant information on the measurement of the distance from the AEA to the nasal columella,⁴ middle turbinate recesses,^{5,6} and nasal valves;^{7,8} data on the artery's anatomy from radiological studies have also been helpful.^{9–12} These studies provide some guidelines to improve the identification and localization of the artery during surgery. Notwithstanding all this research, it is difficult clinically to locate the artery purely based on these data, particularly due to anatomical variations.

In this article, the authors studied 30 specimens in 15 formalin-processed adult cadaver heads to investigate the course characteristics of the AEA in the ethmoid roof. The anatomical data can be used to help identify and localize the AEA, to outline the operation limits during nasal endoscopic procedures, and, therefore, to reduce the risk of complications.

MATERIAL AND METHODS

Thirty specimens from 15 randomly selected adult cadaver heads processed in 10% formalin were

studied. Among the cadaver heads studied, nine were males and six were females. All the specimens were perfused with red latex in carotid arteries.

The dissection, always performed by the same surgeon, comprised the following: The cranial roof was cut open horizontally at 1.0 cm above the connecting line between the superciliary arch and external occipital protuberance, and the brain tissue was subsequently removed; the cadaver head was then sagittally split along the midline, the orbit roof, and the medial orbital wall and dissected to expose the anterior ethmoidal foramen. The AEA was identified at point a_1 , where the artery penetrated the lamina papyracea, into the anterior ethmoidal canal. Point a_3 was defined as the intracranial end of the AEA, and point a_2 was indicated as the midpoint of the curved line from a_1 to a_3 (Fig. 1).

After that, the existence of the AEA was counted and the diameter of the artery at point a_1

Figure 1 The anterior ethmoidal artery (AEA) coursing in ethmoid roof. It is seen forming a slight posterolateral to anteromedial curve as it passes from the orbit to the cribriform plate (right side, top view). The features shown are (a_1) the point that the AEA penetrates the lamina papyracea, (a_2) the midpoint of the curved line from a_1 to a_3 , (a_3) the intracranial end of the AEA, (b) posterior ethmoidal artery, (c) superior oblique, (d) frontal nerve, (e) crista galli, and (a_1 to f) joint line formed by the plane $a_1a_2a_3$ and the lamina papyracea. The $\angle a_3a_1f$ is the angle formed by long axis of the AEA and the lamina papyracea.

was measured. The roof of the ethmoid sinus and sphenoid sinus, the uncinate process, and the ethmoidal bulla were removed to observe the relationship of the artery to the ethmoidal cells and study the canal dehiscence. Points a_1 , a_2 , and a_3 were used to measure the thicknesses of the superior and inferior bony canal of the AEA. The angle $\angle a_3a_1f$ (Fig. 1), formed by the long axis of the AEA and the lamina papyracea, was measured. A Vernier caliper (precision of 0.02 mm), a protractor (precision of 1 degree), and compasses were used to measure the thicknesses, and angles. The average of the three measurements was reported.

All the data were analyzed using Concise Statistical Software (version CS 10.3, Shandong University, China) and recorded as mean $\pm$ SD $\bar{x} \pm s$. Due to the inhomogeneity regarding the variance in the data among the groups, the Cochran and Cox t test was performed to analyze the thickness of the superior and inferior bony canal for points a_1 , a_2 , and a_3 in the anterior ethmoidal canal (AEC). The level of significance was set at $p < 0.05$.

RESULTS

In this group, AEAs were found in 28 of 30 cases (93.3%), and no multiple branches were observed. All the AEAs ran in the AEC with the anterior ethmoidal nerves. The average diameter of the AEAs was 0.80 ± 0.24 mm. The AEA was absent in two cases, on both sides of the same cadaver head. In both of these cases, the posterior ethmoidal artery branched in the ethmoid roof and ran anteriorly and inferiorly, via the bilateral of the crista galli suture, into the very region where the AEA would normally be nurturing.

We found that the AEA was most commonly seen (24 of 28 cases [85.7%]) between the second and third lamellae (Fig. 2). When the lamellae of ethmoidal bulla did not attach to the ethmoid roof (Fig. 3), the AEA coursed via the suprabullar recess. The AEA was found over the roof of the frontal recess cell and the roof of the posterior ethmoid

Figure 2 The anterior ethmoidal artery (AEA) coursing between the second and third lamellae (right side, lateral view). The features shown are (I) lamella of agger nasi, (II) lamella of ethmoidal bulla, (III) lamella of middle turbinate, and (IV) lamella of superior turbinate. FS, frontal sinus; SS, sphenoid sinus; MT, middle turbinate.

sinus in 10.7% (3 of 28) and 3.6% (1 of 28) of the cases, respectively. In one case, the posterior ethmoid sinus was highly pneumatized, the middle turbinate lamella was located to the anterior, and

Figure 3 The anterior ethmoidal artery (AEA) coursing via suprabullar recess with lamella of ethmoidal bullar not attached to the ethmoid roof (right side, top view). The features shown are (a) AEA, (b) posterior ethmoidal artery, (c) anterior ethmoidal nerve, (d) superior oblique, and (e) crista galli. EB, ethmoidal bulla; OA, ophthalmic artery; FS, frontal sinus; arrows pointing left, lamella of middle turbinate; arrows pointing right, posterior wall of the frontal recess.

Figure 4 The ethmoidal artery (AEA) seen located behind the lamella of middle turbinate (right side, bottom view). The features shown are (a) AEA and (b) posterior ethmoidal artery. ST, superior turbinate; MT, middle turbinate; UP, uncinate process; EB, ethmoidal bulla; *, inferior semilunar hiatus; arrows pointing up, ethmoid roof; arrows pointing left, lamella of middle turbinate.

the AEA extended via the posterior ethmoid sinus (Fig. 4).

The AEA pierced the medial orbital wall, traveling in the AEC to the cribriform plate. In its course, all the AECs expanded to the shape of a trumpet at the anterior ethmoidal foramen, and all the AEAs ran parallel to the ethmoid roof and formed a slight posterolateral to anteromedial curve. When viewed from the superior side, the angle $\angle a_3a_1f$, which is formed by the long axis of the AEA and the lamina papyracea, was of $60.5^\circ \pm 16.4^\circ$ (Fig. 1), ranging from 22° to 87° .

We found AECs in all 30 specimens. The average length of the straight line from a_1 to a_3 was measured as 8.4 ± 1.5 mm. In the AECs of two cases, only the anterior ethmoidal nerves were found; no arteries presented. In 10 of 30 cases (33.3%), the AEC was partially dehiscence. The dehiscence was distributed as follows: Partial dehiscence in the superior bony canal was present in two cases, one at a_1 and the other at a_2 . The dehiscence rate was 6.7%. Partial dehiscence in the inferior bony canal was present in eight specimens, corresponding to a dehiscence rate of 26.7%,

including one at point a_1 , three at both a_1 and a_2 , one at a_2 , one at a_2 and a_3 , and two at a_3 . No AEC was found completely dehiscence throughout its course. The dehiscence parts were not included in the calculation of the average thickness of the bony canal.

The thicknesses of the superior and inferior bony canals of the AEA on points a_1 , a_2 , and a_3 were measured as 1.02 ± 0.46 mm and 0.40 ± 0.20 mm, 1.03 ± 0.37 mm and 0.35 ± 0.17 mm, 0.99 ± 0.55 mm and 0.37 ± 0.17 mm, respectively. The difference between thicknesses of the superior and inferior bony canals at these points was statistically significant, with $p < 0.05$ in Cochran and Cox approximate t test.

In 25 of 30 cases (83.3%), the AEC was seen as a separate canal; and in 5 of 30 cases (16.7%), the canal was embedded in the ethmoid roof. In the former case, the AEC ran mostly along the osteal mesenterium and entered the nasal cavity via the bilateral of the crista galli suture, without branches in the ethmoid sinus. In one specimen, the AEC was suspended with its lower edge 4.12 mm below the roof of the ethmoid sinus. However, its morphological characteristics were obvious: The AEC ran parallel to the ethmoid roof and formed a slight posterolateral to anteromedial curve in its course. During the dissections, it was found that when the ethmoidal cells were well pneumatized, the AEC often extended via the ethmoid sinus; when they were poorly pneumatized, it ran and via the ethmoid roof.

DISCUSSION

The AEA, originating from the distal ophthalmic artery, extended medially and reached the anterior ethmoidal foramen where it extended out of the orbit and combined with the homonymous vein and nerves to form the neurovascular bundle; the bundle entered and passed through the AEC, into the nasal cavity via the bilateral of the crista galli suture on the cribriform plate, where the artery turned superiorly to become the anterior flax artery.¹³ The AEA

was responsible for irrigating anterior ethmoidal cells and the frontal sinus, as well as the anterior third of the nasal septum and the lateral wall of the adjacent nasal cavity.³

In its course, we observed that the relationship of the AEA to the ethmoidal cells varied, but was mostly located between the second and third lamellae—that is, between the lamella of the ethmoidal bulla and the lamella of the middle turbinate—in 85.7% of the cases. Previous literature reported corresponding percentages of 29 of 38 (76.3%),⁷ 61 of 70 (87.1%),⁸ and 34 of 34 (100%).¹⁴ Therefore, on the basis of our research and previous studies, we propose that the second and third lamellae can be used as anatomical references to locate the artery during endoscopic sinus surgery. Nevertheless, the variations of AEA's course, such as running over the roof of the frontal recess cells and the roof of the posterior ethmoid sinus, and the discontinuity and irregularity of the lamellae impose challenges to locating the artery.

In 83.3% of the cases, the AEC was identified as a separate canal, whereas in 16.7% the canal was embedded in the ethmoid roof. This was consistent with the data from the computed tomography (CT) scan by Cankal et al.¹⁵ Their numbers were 84% and 16%, respectively. Contrary to our results, Moon et al.⁸ reported that the AEC was identified as a separate canal in only 14.3% of the cases, and in 85.7% it was attached to the skull base. The obvious discrepancy may be attributed to racial differences and analysis method.⁸ In our study, it was found that when the ethmoidal cells were well pneumatized, the AEC was often identified as a separate canal; when the ethmoidal cells were poorly pneumatized, the canal was usually embedded in the ethmoid roof. The strict correlation between the two was not further investigated.

Simmen et al.¹⁴ studied the association of the degree of pneumatization of the suprabullar recess/supraorbital cells with the distance between the AEA and the skull base. Their results showed that when the supraorbital cells were well pneumatized, the artery was lying 3.7 mm (1 to 8 mm) away from the skull base; when the cells were poorly pneu-

matized, the artery was found close to or within the skull base. In specimens without a supraorbital cell, the artery lay at the skull base in all but one. The mean thicknesses of the superior and inferior bony canals of the AEA were 1.01 ± 0.46 mm and 0.37 ± 0.18 mm, respectively. The difference in thickness between the two was significant (Cochran and Cox *t* test, $p < 0.05$). In addition, the AEC presented a partial dehiscence in 33.3% of the cases, compared with defect rates of 11.4%,⁸ 16%,¹⁶ and 66.7%⁵ reported in the literature. The data demonstrated that the inferior bone wall's protection to the artery is weak, and the artery is more accessible—when distant from the ethmoid roof. If not handled carefully during surgery, the artery is prone to unwanted injuries.

The more recent studies of the morphological characteristics of the AEA show that the artery crosses the ethmoid sinus in a diagonally anteromedial course to reach the cribriform plate.^{7,13,17} Floreani et al.¹⁶ measured the range of the posterolateral to anteromedial angle as 30 degrees to 45 degrees as it passed from the orbit to the anterior cranial fossa. Cankal et al.¹⁵ observed that AEC left the orbit at an angle of 12 to 50 degrees anteriorly, and the angle was superiorly 0 to 45 degrees and inferiorly 0 to 20 degrees on coronal images. However, none of these studies mention the curve characteristic of the AEA. Irrespective of the complex anatomical relationship between the AEA and the ethmoidal cells, as well as the AEA's multiple variations, we observed that the morphological characteristics of the AEA—running parallel to the ethmoid roof and forming a slight curve in its course posterolaterally to anteromedially as it passed from the orbit to the cribriform plate—were constant (Figs. 1–3). This discovery is extremely helpful in the endoscopic search for the AEA because it provides the surgeon with a more specific anatomical image.

In the last decade, many scholars worldwide have made great efforts and tried different approaches to locate the AEA. In 1998, Basak et al.⁹ measured the distance between the inferior turbinate and the artery as 30.05 mm by CT scan.

In 2000, Lee et al⁶ surveyed the distance between the artery and the axilla formed by the anterior attachment of the middle turbinate and the lateral nasal wall. The distance had a mean of 20 mm (range, 17 to 25 mm) and was considered having the least intraindividual and interindividual variation. In 2001, Moon et al⁸ suggested using the mean distance and angle between the limen nasi and the AEC to locate the artery. This distance was measured as 49.0 mm and the angle 54.5 degrees. Using similar methodology, Erdogmus et al⁷ reported the distance as 48.1 ± 3.2 mm. Similar to Lee et al's results, Araujo et al⁵ found that the middle conchae axilla was the most reliable point of reference to locate the artery in 2006. However, the complex anatomical relationship between the AEA and the ethmoidal cells, as well as the existence of variations, made the artery difficult to locate during surgery, according to those data alone. Moreover, it was impossible to use measurement instruments during surgery.

Based on our research on the course and morphological characteristics of the AEA, we suggest the following steps to locate the artery: First, locate the second lamella. Follow the Messerklinger approach¹⁸ to excise the anterior wall of the ethmoidal bulla and keep the area where the wall was attached to the ethmoid roof as a landmark of the second lamella. Second, locate the third lamella by anterior ethmoidectomy. If a suprabullar (Fig. 3) recess is found, remove the superior or posterior wall of the ethmoidal bulla completely. The AEA is most likely located between the two lamellae. Then, identify the artery by the morphological characteristics; it runs parallel to the ethmoidal roof, forming a slight posterolateral to anteromedial curve in its course at an angle of 60 degrees to the lamina papyracea. These morphological characteristics are also applicable to the AEA that courses over the roof of the frontal recess cells or the roof of the posterior ethmoid sinus.

Due to AEA's importance as an anatomical reference point for anterior skull base and frontal recess,^{1,2,8,19} accurate localization of the artery is crucial during endoscopic sinus surgery. Because the

AEA is parallel to the ethmoid roof, inferior to the anterior skull base, and superior to the ethmoid sinus, it can be used as a boundary between the ethmoid sinus and anterior skull base. In addition, because the position of the AEA is below the level of the cribriform plate,¹⁸ surgical operations must be limited to the level of the artery. Because of the variable anatomical relationship between the AEA and the frontal recess,²⁰ some scholars have presented different results using different approaches. Stammberger¹⁸ used the junction of the posterior wall of the frontal recess with the roof of the anterior ethmoidal cell as a reference point, and reported the artery was 1 to 2 mm posterior to this skull base junction. Simmen et al¹⁴ measured the average distance between the AEA and the posterior wall of the frontal recess as 11 mm (range, 6 to 15 mm), and de Notaris et al¹⁷ measured the distance between the AEA and the anterior margin of the frontal recess as 10 mm. Our dissection showed that not all AEAs were located behind the posterior wall of the frontal recess. In our specimens, 10.7% of them were located over the roof of the frontal recess cell. However, despite these different results, after the AEA is identified, treating lesions in the frontal recess anterior to the AEA is safe.

Knowledge of the variations in the course of the AEA is important in endoscopic sinus surgery. In this study, four types of variations were observed: (1) defects in AEA, (2) partial dehiscence in the inferior bony canal of the AEA, (3) partial dehiscence in the superior bony canal of the AEA, and (4) location of the AEA posterior to the lamella of the middle turbinate. To our knowledge, the fourth variation has not been reported in previous literature. Among the four types of variations, partial dehiscence in the inferior wall of the AEC holds great clinical significance for sinus surgery because dehiscence of the bony canal makes the artery more susceptible to injuries, increasing the risk of complications. In endoscopic sinus surgery, polyps or mucosal thickening often occur in ethmoid sinus. The artery without the bone protection is difficult to distinguish from the lesions; in this circumstance,

its morphological characteristics are the main factors used to identify the artery. In addition, as the artery always runs along with the anterior ethmoidal nerve (Fig. 3), patients under partial anesthesia can respond to the provoking of a blunt instrument. This also helps in artery identification.

CONCLUSION

Our cadaveric dissections show variable courses of the AEA in the ethmoid roof. Our study reveals that the second and the third lamellae are the two important anatomical landmarks for endoscopic localization. Moreover, the morphological characteristics of the AEA—running parallel to the ethmoidal roof and forming a slight posterolateral to anteromedial curve on its course as it passes from the orbit to the cribriform plate—provide good guidelines to improve identification and localization of the artery during surgery.

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