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REVIEW

Anatomical variations of anterior ethmoidal artery and their significance in endoscopic sinus surgery: a systematic review

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Abstract

Purpose Anterior ethmoidal artery (AEA) is at risk of injury in endoscopic sinus surgery due to its location. The aim of this review was to assess the anatomical variations of AEA and their significance.

Methods A literature search was performed on PUBMED, SCOPUS AND EMBASE. The following keywords were used: ethmoidal artery; anterior ethmoidal artery; anterior ethmoidal canal; ethmoid sinus; ethmoid roof; skull base. The search was conducted over a period of 6 months between October 2016 and April 2017.

Results 105 articles were retrieved. 76 articles which were either case reports or unrelated topics were excluded. Out of the 29 full text articles retrieved, 16 articles were selected; 3 were cadaveric dissection, 5 combined cadaveric dissection and computed tomography (CT) and the rest were of CT studies. All studies were of level III evidence and a total of 1985 arteries were studied. Its position at the skull base was influenced by the presence of supraorbital ethmoid cell (SOEC) and length of the lateral lamella of cribriform plate (LLCP). Inter population morphological variations contribute to the anatomical variations.

Conclusions The average diameter of AEA was 0.80 mm and the intranasal length was 5.82 mm. 79.2% was found between the second and third lamellae, 12.0% in the third lamella, 6% posterior to third lamella and 1.2% in the second lamella. Extra precaution should be taken in the presence of a well-pneumatized SOEC and a long LLCP as AEA tends to run freely below skull base.

Keywords Anterior skull base · Endoscopic sinus surgery · Sinus anatomy · Skull base · Endoscopic skull base surgery

Introduction

Endoscopic sinus surgery (ESS) has revolutionized the surgical management of sinonasal pathologies from open surgery to minimally invasive surgery [14]. The extent of ESS has dramatically increased over the past 2 decades and ranges from partial uncinectomy to extended surgery of the frontal, maxillary and sphenoid sinuses [35]. Although widely practiced, ESS has its own complications. Complications related to ESS lie in its proximity to the orbit and anterior skull base. Thus, high-risk areas prone to surgical complications should be identified preoperatively.

Anterior ethmoidal artery (AEA) is regarded as one of the high-risk areas in ESS as it courses along the roof of ethmoid from orbit to anterior cranial fossa [23]. Accidental injury to AEA during surgery may result in significant bleeding and cerebrospinal fluid (CSF) leak. It is particularly dangerous if the cut lateral end of the artery is retracted into the orbit and causes a retro orbital hematoma. It will cause

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compression of optic nerve and may lead to blindness. Conversely, a medial injury where the artery enters the lateral lamella of cribriform plate (LLCP) may result in CSF leak. Routine identification of AEA is usually unnecessary in ESS as there is a risk of damaging it [28]. Nonetheless, the identification of AEA has important significance. It serves as an important landmark while dissecting at the frontal recess as the position of AEA at the posterior wall of frontal recess serves as the posterior limit of dissection [22, 30, 31].

The position of AEA in the ethmoid sinus has been reported to be very variable even in between the two sides of the same person. This inevitably places the artery at risk during ESS. In terms of its distance from skull base, the artery may be closely apposed to skull base, particularly when the roof of ethmoid is low, or courses freely below skull base within a bony canal and being connected to skull base by a thin bony mesentery [2, 13, 22]. This relationship of AEA with skull base is important because the chance of injuring the artery during surgery is higher when it lies freely below skull base. It is imperative to understand the relevant anatomy and its possible variations before any surgeon embarks upon ESS. Imaging studies, particularly computed tomography (CT), play an important role in evaluating of the complex anatomy of AEA preoperatively. This review aimed to analyze the anatomical variations of AEA and their significance in ESS.

Method

A search was performed on electronic databases namely PUBMED, SCOPUS AND EMBASE that retrieved 105 relevant articles. The following keywords were used either individually or in combination: ethmoidal artery; anterior ethmoidal artery; anterior ethmoidal canal; ethmoid sinus; ethmoid roof; skull base. Additional relevant articles pertinent to this review were identified by reviewing the references of articles that had been retrieved. Certain information provided in the articles were counter checked and compared with standard textbooks. The search was conducted over a period of 6 months between October 2016 and April 2017 in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [20] and the Cochrane Handbook [10] when appropriate. After screening the abstracts, 76 articles which were either case reports or unrelated topics were excluded. Out of the 29 full text articles retrieved, 16 articles (Fig. 1; Table 1) were selected after being scrutinized by the author and the remaining were excluded from this review owing to lack of relevant information or lack of similar study that analyze same variable to compare with. All studies were of level III evidence prospective or retrospective studies.

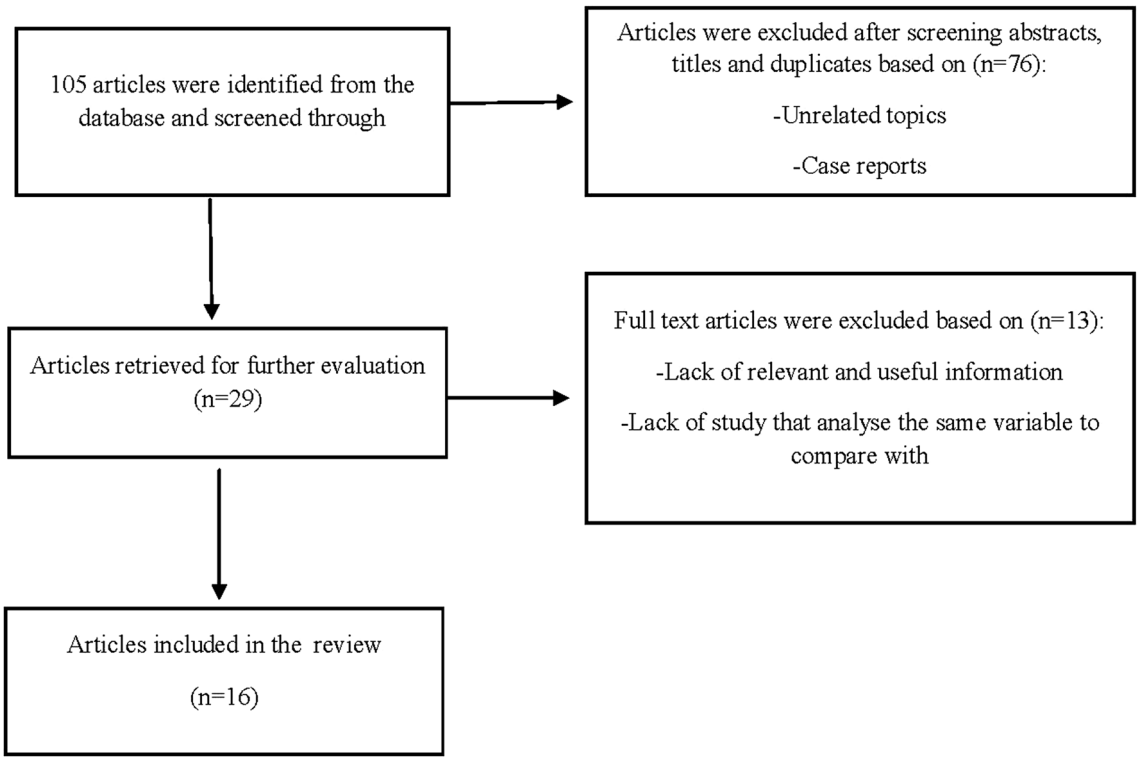

Fig. 1 The flow diagram of study selection

Table 1 The summary of studies included in the systematic review

References	Year of study	Type of study	No of arteries
Basak et al. [3]	1998	CT	222
Moon et al. [22]	2001	Cadaver and CT	70
Cankal et al. [4]	2004	CT	300
Simmen et al. [28]	2006	Cadaver and CT	34
Erdogmus and Govsa [6]	2006	Cadaver	36
Lannoy et al. [17]	2006	Cadaver and CT	18
Araujo et al. [2]	2006	Cadaver	50
Han et al. [9]	2008	Cadaver and CT	48
McDonald et al. [19]	2008	CT	42
Yang et al. [36]	2009	Cadaver	30
Souza et al. [30]	2009	CT	396
Joshi et al. [12]	2010	CT	100
Monjas et al. [21]	2011	Cadaver and CT	40
Ko et al. [16]	2014	CT	119
Jang et al. [11]	2014	CT	112
Yenigun et al. [37]	2016	CT	368
		Total	1985

CT computed tomography

Results

Dehiscence of the bony anterior ethmoidal artery

The average diameter of AEA was 0.80 ± 0.24 mm and the average intranasal length was 5.82 ± 1.41 mm, respectively [2, 36]. The mean thickness of the superior and inferior portions of the bony anterior ethmoidal canal (AEC) was 1.01 ± 0.46 mm and 0.37 ± 0.18 mm, respectively [36]. A partial or total dehiscence of the bony AEC has been observed and the rate varies according to different studies. Kainz and Stammberger [13] reported rate of 40%, Moon et al. [22] of 11%, Simmen et al. [28] of 6%, Araujo et al. [2] of 66%, and Yang et al. [36] of 33.3%. At the point where the artery enters anterior cranial fossa (ACF) through the LLCP, the bone is extremely thin and is in fact the thinnest bony structure of the entire anterior skull base which offers the least resistance to damage during surgery [2, 30]. The AEA was unilaterally absent in approximately 14% of cases and bilaterally absent up to 4% of cases. If AEA is absent, it is replaced by a branch of posterior ethmoid artery [27].

Relationship with the four lamellae

Six articles studied the location of AEA with respect to the lamellae [6, 9, 21, 22, 28, 36]. The lamellae refer to vertical bony structures that compartmentalize the ethmoid sinus. The first lamella corresponds to the uncinate process, anterior face of ethmoid bulla forms the second lamella and the third lamella is the basal lamella of the middle turbinate, which divides the anterior and posterior ethmoid cells. The fourth lamella corresponds to the superior turbinate, and the fifth lamella corresponds to the anterior face of the sphenoid sinus (Fig. 2). Determining the relationship of AEA to the lamella is important considering that the artery may be injured while the lamella is being removed during surgery. Of the total 252 AEA studied, the artery was found in between the second and the third lamellae in 198 cases (79.2%) (Table 2); in the third lamella in 30 cases (12.0%); posterior to third lamella in 15 cases (6%); and in the second lamella in 3 cases (1.2%) [6, 9, 21, 22, 28, 36]. In the study by Yang et al. [36], AEA was also found in the roof of the frontal recess cell in 3 cases and in the roof of posterior ethmoid cell in 1 case. Except for one study [9], all articles consistently showed that AEA was located between the

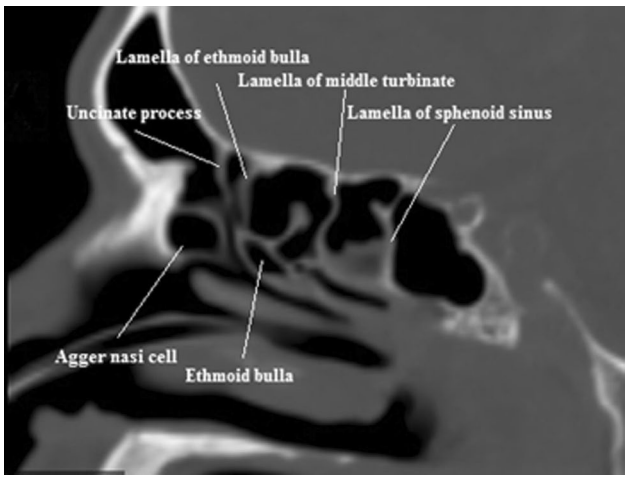

Fig. 2 The lamellae of ethmoid sinus in the sagittal section of computed tomography

Table 2 The prevalence of anterior ethmoidal artery position between the second and third lamellae

References	Case	AEA located between second and third lamellae	
		Case	%
Simmen et al. [28]	34	34	100.0
Moon et al. [22]	70	61	87.1
Erdogmus and Govsa [6]	36	29	80.1
Han et al. [9]	46	14	30.4
Yang et al. [36]	30	24	80.0
Monjas et al. [21]	36	36	100.0
Total	252	198	79.2

AEA anterior ethmoidal artery

second and third lamella in most cases [6, 21, 22, 28, 36]. A study by Han et al. [9] found AEA was located anterior to the third lamella in 31%, within the third lamella in 37% and posterior to the third lamella in 32% of their 46 cadaveric specimens. The possible explanation for the difference may be due to population or sampling variation.

Relationship with the skull base

The relationship of AEA and skull base has been extensively studied with different results (Table 3) [2–4, 12, 16, 17, 19, 22, 28, 36]. In two separate studies, Moon et al. [22] and Araujo et al. [2] reported that AEA was embedded in skull base in 85.7% and 83.3% of cases, respectively. The remainder coursed freely in the ethmoid sinus. On the contrary, other studies found that AEA was located below skull base with a mesentery connecting it to skull base in most cases [4, 12, 16, 36]. The possible explanation for the discrepancy is due to different populations or methods being applied as there might be discrepancy between CT images and actual cadaveric studies (Table 4).

Relationship with the supraorbital ethmoid cell

The prevalence of supraorbital ethmoid cell (SOEC) in six studies varies widely from 15.0 to 55.8% (Table 5) [11, 12, 21, 28, 30, 37]. There appears to be a difference in prevalence of SOEC in different populations and this again highlights the importance of studying the patterns of pneumatization in local population. Simmen et al. [28], Joshi et al. [12], Yenigun et al. [37] and Jang et al. [11] further analyzed the effect of pneumatization of SOEC on the distance of AEA from skull base and all authors agreed that there exists a strong correlation between the presence of SOEC and the distance of AEA from skull base. A well-pneumatized SOEC causes AEA to be located further below skull base making it more susceptible to injury during surgery [6, 12, 28, 30, 37]. The relationship between AEA and SOEC was further explored by another study that found AEA was always located posterior to SOEC [38]. Considering this observation, Jang et al. [11] proposed that SOEC may serve as a consistent landmark for locating AEA.

Relationship with the cribriform plate

The position of AEA relative to LLCP also varies. Simmen et al. [28], Souza et al. [30] and Floreani et al. [8] had pointed out that the length of LLCP is highly predictive of the position of AEA at skull base. When LLCP height is longer, hence olfactory fossa is deeper and roof of ethmoid is higher, the more likely AEA is to be found running freely in the ethmoid sinus [32]. Recognizing the significance of the length of LLCP, Yenigun et al. [37] modified the Keros classification [15] to include its anteroposterior length. They classified the anteroposterior length of LLCP into 3 types: type I measures 6–10 mm, type II measures 11–15 mm and type III measures 16–20 mm. They further demonstrated that with the increase in the anteroposterior length of LLCP, AEA is more likely to run freely below skull base, thus more prone to injury during surgery [37].

Discussion

The anterior ethmoidal artery arises from the ophthalmic artery, a branch of internal carotid artery. In its course from the orbit to the olfactory fossa and back into the nasal cavity, the artery crosses three cavities of the head—the orbit, the ethmoid sinus and the anterior cranial fossa. The anterior ethmoidal artery enters AEC on the medial wall of the orbit. It courses across ethmoid sinus together with anterior ethmoidal vein and anterior ethmoidal nerve inside the bony AEC. The artery runs obliquely from posterolateral to anteromedial direction to reach LLCP and enters the olfactory fossa. After intracranial entry into the olfactory fossa, AEA turns anteriorly forming the anterior

Table 3 The relationship of the anterior ethmoidal artery to the skull base

References	Case	At skull base		On protrusion		Below skull base	
		Case	%	Case	%	Case	%
Basak et al. [3]	182	104	57.0	–	–	78	43.0
Cankal et al. [4]	300	48	16.0	–	–	268	84.0
Simmen et al. [28]	34	22	64.7	–	–	12	35.3
Moon et al. [22]	70	60	85.7	–	–	10	14.3
Araujo et al. [2]	50	42	83.3	–	–	8	16.7
Lannoy et al. [17]	18	8	44.4	3	16.7	7	38.9
McDonald et al. [19]	42	30	71.4	–	–	12	28.6
Yang et al. [36]	30	5	16.7	–	–	25	83.3
Joshi et al. [12]	97	19	20.0	–	–	78	80.0
Ko et al. [16]	119	19	16.0	40	33.6	60	50.4

Table 4 Different populations and methods (CT versus actual cadaveric studies) contribute to discrepancy of results of anterior ethmoidal artery relation to skull base

References	Type	Region	Case				
			Total	Right	Left	Male	Female
Basak et al. [3]	CT	Turkey	222	111	111	134	88
Moon et al. [22][a]	Cadaver and CT	Korea	70	–	–	–	–
Cankal et al. [4]	CT	Turkey	300	150	150	164	136
Simmen et al. [28][a]	Cadaver and CT	UK	34	–	–	–	–
Erdogmus and Govsa [6]	Cadaver	Turkey	36	18	18	36	0
Lannoy et al. [17][c]	Cadaver and CT	France	18	9	9	–	–
Araujo et al. [2]	Cadaver	Brazil	50	25	25	20	30
Han et al. [9][c]	Cadaver and CT	USA	48	24	24	–	–
McDonald et al. [19][c]	CT	UK	42	21	21	–	–
Yang et al. [36]	Cadaver	China	30	15	15	18	12
Souza et al. [30]	CT	Brazil	396	198	198	164	116
Joshi et al. [12][c]	CT	India	100	50	50	–	–
Monjas et al. [21][c]	Cadaver and CT	Spain	40	20	20	–	–
Ko et al. [16][b]	CT	USA	119	–	–	–	–
Jang et al. [11]	CT	USA	112	56	56	60	52
Yenigun et al. [37]	CT	Turkey	368	184	184	232	136
		Total	1985				

CT computed tomography

[a]Moon et al. [22] and Simmen et al. [28] used cadaver half heads in their study. The gender of subjects and side of anterior ethmoidal artery were not mentioned in their study

[b]Ko et al. [16] used only 119 images of anterior ethmoidal artery based on sagittal reconstruction images. The gender of subjects and the site of the anterior ethmoidal artery were also not specified

[c]Lannoy et al. [17], Han et al. [9], McDonald et al. [19], Joshi et al. [12] and Monjas et al. [21] did not specify the gender of their study subjects

Table 5 The prevalence of the supraorbital ethmoid cell

References	Case	SOEC present		SOEC absent	
		Case	%	Case	%
Simmen et al. [28]	34	16	47.1	18	52.9
Souza et al. [30]	396	139	35.0	257	65.0
Joshi et al. [12]	100	45	45.0	55	55.0
Monjas et al. [21]	40	6	15.0	34	85.0
Jang et al. [11]	156	68	43.6	88	56.4
Yenigun et al. [37]	368	148	40.2	220	59.8

SOEC supraorbital ethmoid cell

ethmoidal sulcus in LLCP. The artery then reaches the nasal cavity through the anterior ethmoidal orifice of the cribriform plate (CP) and divides into anterior septal branches and anterior lateral nasal branches [18]. The position of this artery along skull base is variable, but the ratio of 24:12:6 mm is commonly quoted as the average distance from anterior lacrimal crest to AEA, from AEA to posterior ethmoid artery and then from posterior ethmoid artery to optic canal, respectively [18].

Understanding anterior ethmoidal artery variability to prevent injury

The anterior ethmoidal artery courses across the skull base at variable height toward LLCP, adding an element of complexity to its anatomy. The artery may be closely related to skull base or runs freely in ethmoid sinus and being attached to skull base only by a thin bony mesentery (Fig. 3). In the former group, the artery is either completely embedded within skull base or courses at the level of skull base producing some degree of bony protrusion [13, 16, 17, 22]. The relationship of AEA with skull base is essential, particularly when the artery is hanging below skull base and the chance of encountering and injuring the artery is high (Figs. 4, 5). Also, the presence of the bony mesentery further placed the artery at risk during surgery. If AEA is not recognized as being on a mesentery, the artery might be accidentally injured while septations are being dissected on the skull base [29].

The lateral lamella of cribriform plate is part of ethmoid bone that constitutes the lateral border of the olfactory fossa, with the cribriform plate forming the floor. Laterally, it articulates with the fovea ethmoidalis. The fovea ethmoidalis is an extension of the orbital plate of frontal

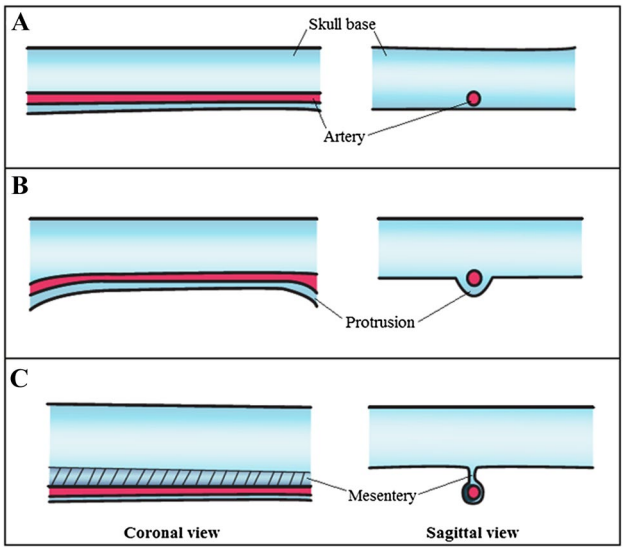

Fig. 3 The variable position of anterior ethmoidal artery at skull base in coronal view and corresponding sagittal view. **a** The anterior ethmoidal artery is within skull base. **b** The anterior ethmoidal artery courses at the level of skull base producing bony protrusion. **c** The anterior ethmoidal artery courses freely in ethmoid sinus within a bony anterior ethmoidal canal and is connected to skull base by a thin bony mesentery

bone that forms the roof of ethmoid, separating ethmoid sinus from the ACF. The lateral lamella of cribriform plate is the thinnest bone of the entire anterior skull base and has lower resistance to trauma and surgical maneuver making it a common site of injury during surgery [1, 34]. The average thickness of LLCP is 0.2 mm and this may be reduced to 0.05 mm at the point where AEA penetrates LLCP to enter ACF [32]. This is the thinnest bone at skull base where CSF leak commonly occurs. The fovea ethmoidalis, on the other hand, is much thicker and stronger than LLCP with an average thickness of 0.5 mm [32]. For this reason, extra precaution should be taken when clearing disease off the skull base medially to avoid inadvertent intracranial entry and causing cerebrospinal fluid leak.

Radioanatomical assessment of anterior ethmoidal artery anatomical variations

Lannoy-Penisson et al. [17] and Ko et al. [16] outlined a classification used to describe the course of AEA variation relative to skull base. The location of AEA is categorized as grade I when it is found to be included in skull base. It is grade II when it courses under skull base and considered as prominent. Grade III classification refers to AEA that travels freely at a distant from skull base. This classification is useful as the presence of grade III AEA may warn the surgeons to exercise more precaution during surgery.

The relationship of AEA with skull base varies with the degree of pneumatization of ethmoid sinus, particularly when SOEC is present [12, 21, 28, 30]. The supraorbital ethmoid cell refers to anterior ethmoidal air cell that arises from pneumatization of the orbital plate of frontal bone. It extends superolaterally over the orbit from frontal recess. However, the prevalence of SOEC is significantly influenced by ancestry and it is found to be overwhelmingly more frequent in the European population than the Korean population with the prevalence of 64.6% and 2.6%, respectively [5]. This low prevalence renders SOEC an insignificant landmark in Korean population.

Besides SOEC, another pattern of pneumatization of ethmoid sinus that has an important impact on the position of AEA is the suprabullar space [28]. The space lies above ethmoid bulla but below skull base. It is an anatomical area that exists when the anterior face of ethmoid bulla fails to reach skull base. When suprabullar space is an open space, the term "suprabullar recess (SBR)" is used; when it is contained, it is termed as suprabullar cell (SBC). Besides SOEC, the suprabullar space is clinically important because in 85.3% of cases, AEA was found in the space which is located below skull base [28]. However, it does not affect

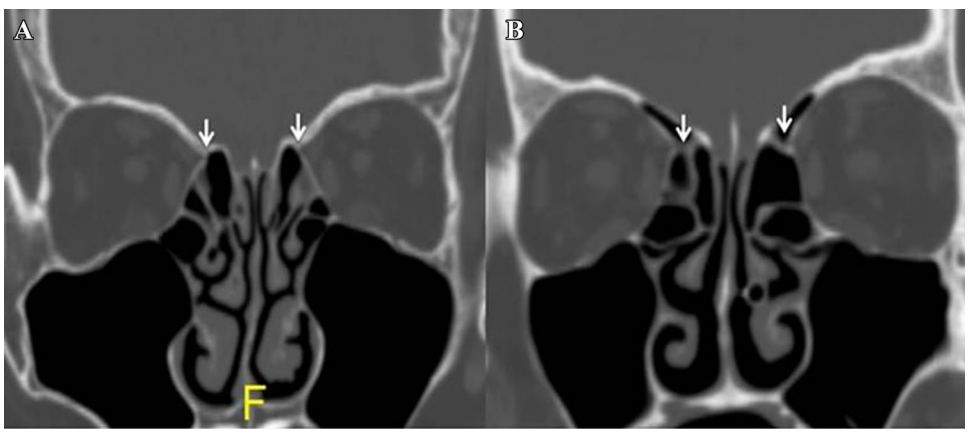

Fig. 4 Coronal computed tomography showing variations of anterior ethmoidal artery's course in relation to skull base. **a** The anterior ethmoidal artery travelled within skull base (arrows). **b** The anterior ethmoidal artery travelled freely below skull base (arrows). The chance of encountering and thus injuring the artery in surgery is higher in the latter group

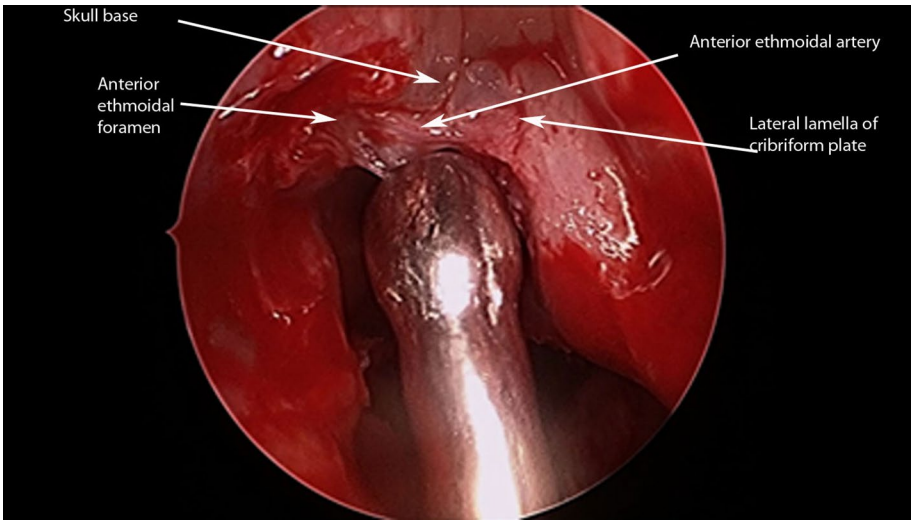

Fig. 5 An endoscopic view of a low hanging right anterior ethmoidal artery which is at risk of injury during surgery

the position of AEA at the 4 lamellae. Recent studies [7, 24, 33] have highlighted the role of suprabullar space (SBR and SBC) in the variations of frontal sinus drainage, but its relationship with the anatomical variations of AEA has yet to be fully understood. Two separate studies on the prevalence of suprabullar space based on CT scan of 60 and 105 Koreans had reported a prevalence of 39.5% and 7.8%, respectively [5, 25]. It is interesting to note that these 2 studies showed inconsistent results even though they were conducted among the same population.

The configuration of LLCP varies considerably from case to case. Keros [15] proposed a 3 types classification based on the height of LLCP according to the analysis of 450 skulls. In Keros type I, the depth of the olfactory fossa is 1–3 mm, 4–7 mm in Keros type II and 8–16 mm in Keros type III (Fig. 6). As the length of LLCP increases, the possibility of penetrating the skull base increases [26].

Conclusions

The average diameter of AEA was 0.80 mm and the average intranasal length was 5.82 mm. The mean thickness of the superior and inferior portions of the bony AEC was 1.01 mm and 0.37 mm, respectively. The AEA was found in between the second and the third lamellae in 79.2% of cases, in the third lamella in 12.0% of cases, posterior to third lamella in 6% of cases and in the second lamella in 1.2% of cases. Its position at skull base is influenced by the presence of SOEC and length of LLCP. Inter population morphological variations contribute to the anatomical variations.

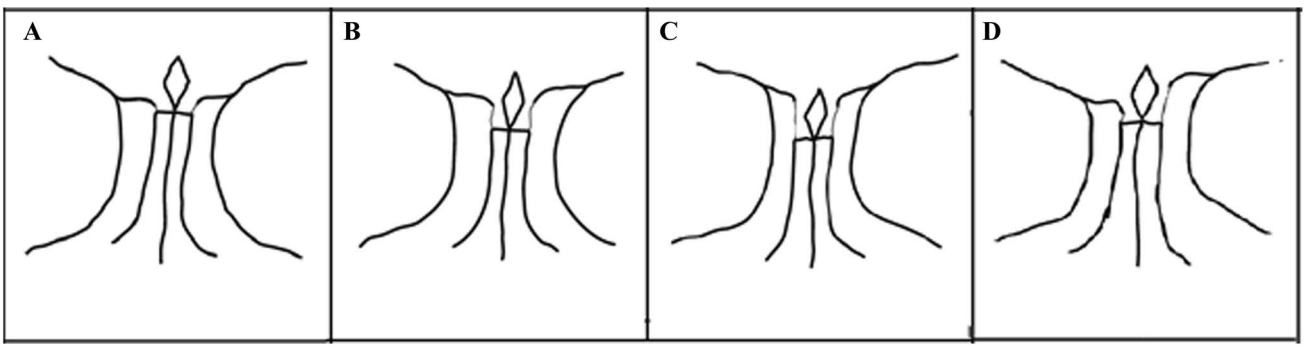

Fig. 6 Keros classification [15] of the height of the olfactory fossa. **a** Type I is 1–3 mm, **b** type II is 4–7 mm, **c** type III is 8–16 mm, **d** type IV is asymmetry in the height of right and left olfactory fossa

Author contributions BA and EHL: protocol/project development. BA and EHL: data collection or management. BA, EHL, SH, KS and DYW: data analysis. BA, EHL, SH, KS and DYW: manuscript writing/editing.

Compliance with ethical standards

Conflict of interest K. S. has been on the speakers' bureau for Merck Sharp & Dohme, Glaxo Smith Kline and Mylan. All other authors have no financial disclosures or conflicts of interest.

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