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ORIGINAL ARTICLE

Anatomical variations of anterior ethmoidal artery at the ethmoidal roof and anterior skull base in Asians

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Abstract

Purpose The variations of the anterior ethmoidal artery (AEA) in different populations should be recognized by surgeons to prevent unwarranted complications during surgery. The aim of this study was to assess the anatomical variations of AEA in Asian population.

Methods A cross-sectional study of 252 AEA identified by computed tomography (CT) of the paranasal sinuses. The multiplanar CT images were acquired from SOMATOM® Definition AS+ and reconstructed to axial, coronal and sagittal view at 1 mm slice thickness.

Results 42.5% of AEA was within skull base (grade I), 20.2% at skull base (grade II) and 37.3% coursed freely below skull base (grade III). The prevalence of supraorbital ethmoid cell (SOEC) and suprabullar cell (SBC) was 29.8% and 48.0%. The position of AEA at skull base has significant association with SOEC ($p < 0.001$), but not with SBC ($p = 0.268$). Type I Keros was 42.1% and Type 11 Keros was 57.9%. When lateral lamella's height is longer, the probability increases for AEA to course freely within the ethmoid sinus ($p = 0.016$). The mean distance of AEA from skull base was 1.93 ± 2.03 mm, orbital floor 21.91 ± 2.47 mm and nasal floor 49.01 ± 3.53 mm.

Conclusions The position of AEA at skull base depends on the presence of SOEC and length of lateral lamella, but not with SBC. When compared to European population, the mean distance between AEA and nasal floor is shorter in Asians.

Keywords Anterior ethmoidal artery · Ethmoid cell · Suprabullar cell · Supraorbital ethmoid cell · Cribriform plate · Skull base

Introduction

The anterior ethmoidal artery (AEA) is a structure of great interest to surgeon in endoscopic sinus surgery and is regarded as an important landmark to locate the frontal sinus and anterior skull base [16, 23, 24]. It arises from the ophthalmic artery, a branch of internal carotid artery. It enters the anterior ethmoidal foramen (AEF) on the medial wall of the orbit. The artery runs obliquely from posterolateral to anteromedial direction to reach the lateral lamella of the

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cribriform plate and enters the olfactory fossa. After intracranial entry into the olfactory fossa, it turns anteriorly forming the anterior ethmoidal sulcus in the lateral lamella of the cribriform plate. It then reaches the nasal cavity through the anterior ethmoidal orifice of the cribriform plate and divides into anterior septal branches and anterior lateral nasal branches [25]. It exhibits considerable variability as it crosses the ethmoid sinus from the orbit in an anteromedial direction to reach the lateral lamella of the cribriform plate (LLCP) [12]. The location of the AEA is categorized as grade I when it is found to be embedded in the skull base. It is grade II when it courses under the skull base and seen as protrusion at the skull base. Grade III classification refers to AEA that travels freely at a distant from the skull base (Fig. 1) [11]. Poor recognition of this variation places the artery at risk during endoscopic sinus surgery. Iatrogenic injury to the AEA can result in major complications such as retro-orbital hematoma, vision loss and cerebrospinal fluid leak. Therefore, detailed knowledge of the relevant anatomy of the AEA and its possible variation is essential to avoid potential complication during endoscopic sinus surgery. A preoperative computed tomography (CT) scan is crucial in evaluating the complex anatomy of AEA [20].

Cadaveric and radiographic studies have contributed to the current understanding of the surgical anatomy of AEA. However, most of the studies were on European population and very limited information can be found on Asian population. This study was conducted to determine the variability of AEA in Asian population by using CT scan of paranasal sinus. The relationship of AEA with skull base, the effect of pneumatization of ethmoid sinus on their relationship and the distances of the AEA from important adjacent reference points were also assessed.

Methods

This was a cross-sectional study of the CT scan of the paranasal sinuses (CT PNS) performed at the Department of Radiology of a tertiary center in Malaysia acquired between 1st January 2014 and 31st December 2016. The inclusion criteria were subjects' age 18 years and above who underwent CT PNS at the hospital. The following exclusion criteria were applied: subjects with craniofacial anomaly, sinonasal tumour, chronic rhinosinusitis with nasal polyps, skull base or facial trauma, or previous surgery to the paranasal sinuses and skull base. The sampling method was simple random sampling using computer software http://www.randomizer.org. The study protocol was reviewed and approved by the university's research ethics committee (USM/JEPeM/16070232) and was performed in adherence with the Declaration of Helsinki. All data were anonymous

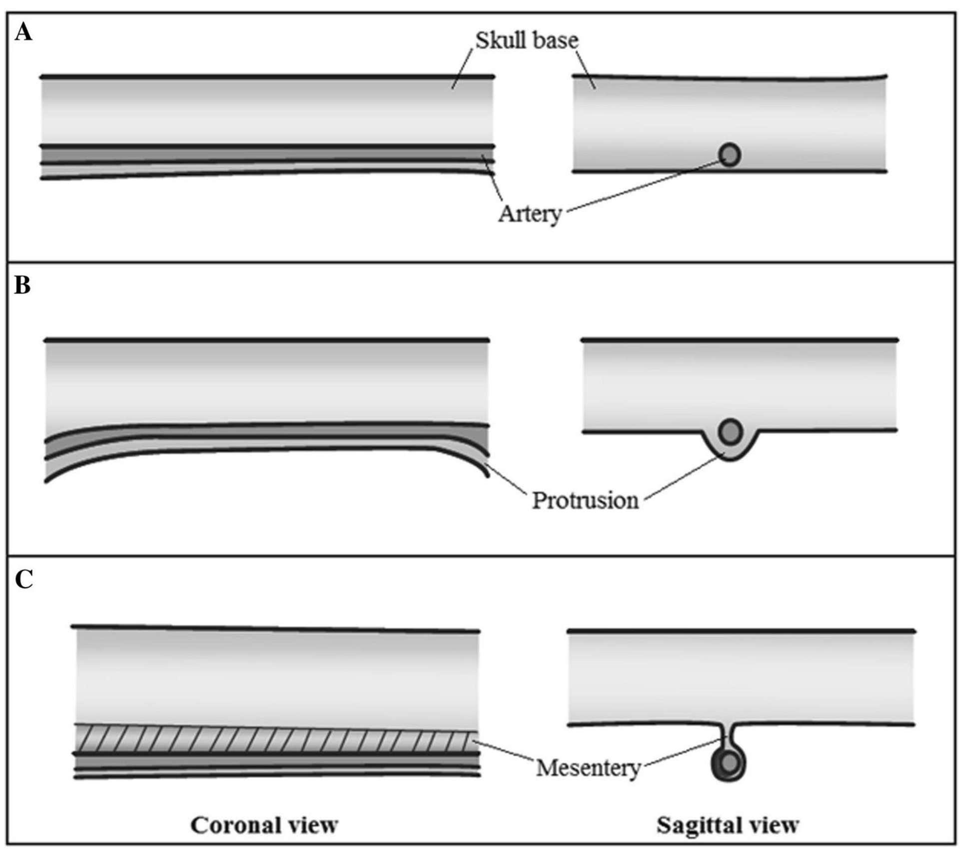

Fig. 1 The variable position of anterior ethmoidal artery at skull base in coronal view and corresponding sagittal view. **a** The anterior ethmoidal artery is within skull base. **b** The anterior ethmoidal artery courses at the level of skull base producing bony protrusion. **c** The anterior ethmoidal artery courses freely in the ethmoid sinus within a bony anterior ethmoidal canal and is connected to skull base by a thin bony mesentery

and only accessible to the research team members. Data were presented as grouped data and the responders were not identified individually.

The CT PNS was retrieved from radiology information system (RIS) and picture archive communication system (PACS). The CT PNS images were acquired from SOMATOM® Definition AS+ (Siemens Healthcare GmbH, Germany) which can produce 128 slices of images per rotation. The multiplanar CT images were reconstructed to axial, coronal and sagittal view at 1 mm slice thickness. CT images were interpreted by one radiologist (M.E.A), one otorhinolaryngologist (B.A) and the second author (E.H.L). All measurements were taken three times and the average was used in data analysis. When there was discordant opinion, further evaluation of the image was done by the specialists to obtain a mutual consensus. Inter-rater agreement was analysed using intraclass correlation coefficient (ICC). All data obtained were entered in the study proforma.

The CT image was evaluated on coronal and axial views for the presence of supraorbital ethmoid cell (Fig. 2) and then on sagittal view for the presence of suprabullar cell (Fig. 3). The AEA was identified on coronal view using the adjacent bony landmarks, namely AEF and anterior ethmoidal canal when present. Following the identification of AEA, the distances between AEA and skull base (Fig. 4), orbital floor (Fig. 5) and nasal floor (Fig. 6) were measured. The height of the lateral lamella of the cribriform plate was measured on coronal view that showed the lowest cribriform plate and classified according to the Keros classification [10] (Fig. 7). The anteroposterior dimension of the lateral lamella of the cribriform plate was measured by tracing it on the axial view with the endpoint of crista galli as the posterior boundary and classified according to the Yenigun classification [28].

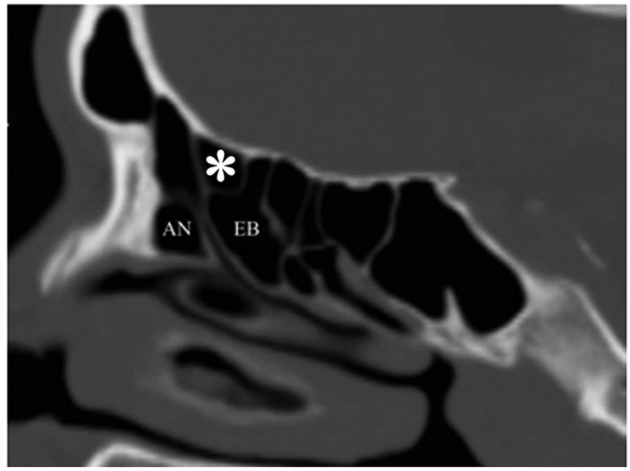

Fig. 3 The position of suprabullar cell (asterisk) above the ethmoid bulla is best seen by sagittal CT PNS scan. *AN* agger nasi cell, *EB* ethmoid bulla

All data obtained were transferred into the Statistical Package for Social Sciences (SPSS) software version 22.0. Descriptive analysis was used to calculate the prevalence of supraorbital ethmoid cell and suprabullar cell. Descriptive analysis was also used to analyse the distance of AEA from various anatomical reference points. Pearson's Chi-squared test was used to determine the association between the presence of supraorbital ethmoid cell and suprabullar cell with the position of AEA as well as the association between the height and the anteroposterior dimension of the lateral lamella of the cribriform plate with the position of AEA. A p value of <0.05 was considered statistically significant.

Fig. 2 The position of supraorbital ethmoid cell (asterisks) extending over the orbit is best seen by coronal CT PNS scan

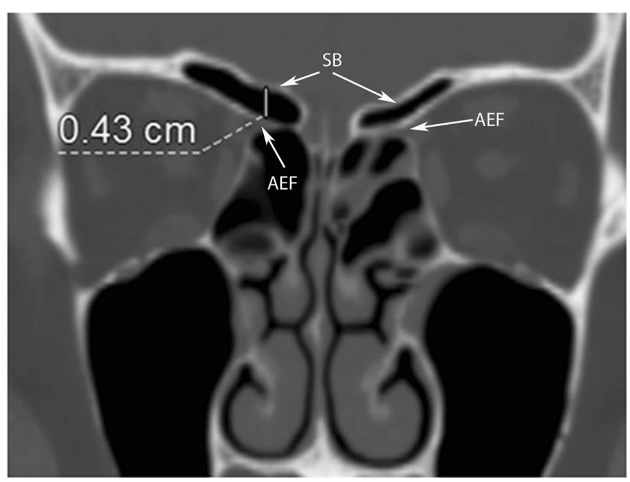

Fig. 4 The vertical distance from anterior ethmoidal foramen (AEF) to skull base (SB) was used to assess the distance of anterior ethmoidal artery from skull base

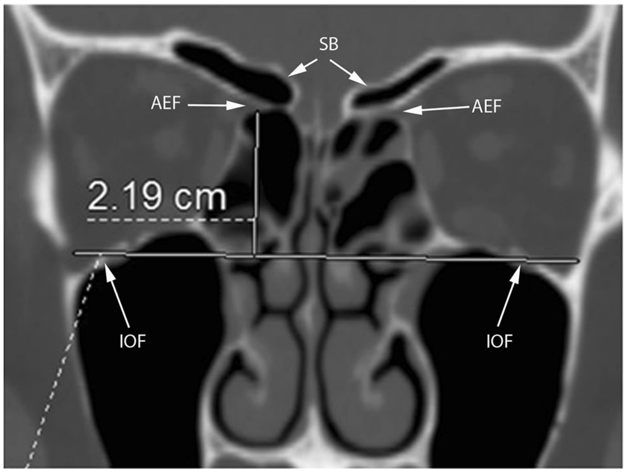

Fig. 5 The distance of anterior ethmoidal artery from orbital floor was assessed by measuring the vertical distance of anterior ethmoidal foramen (AEF) in relation to the horizontal plane drawn across both infraorbital foramen (IOF). *SB* skull base

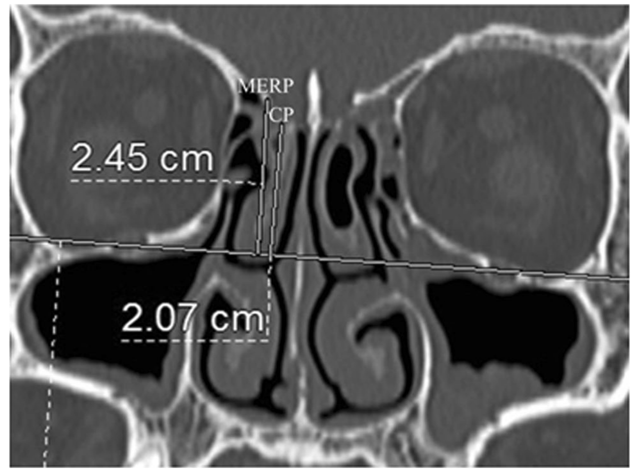

Fig. 7 The lateral lamella height was calculated by subtracting cribriform point (CP) height from medial ethmoid roof point (MERP)

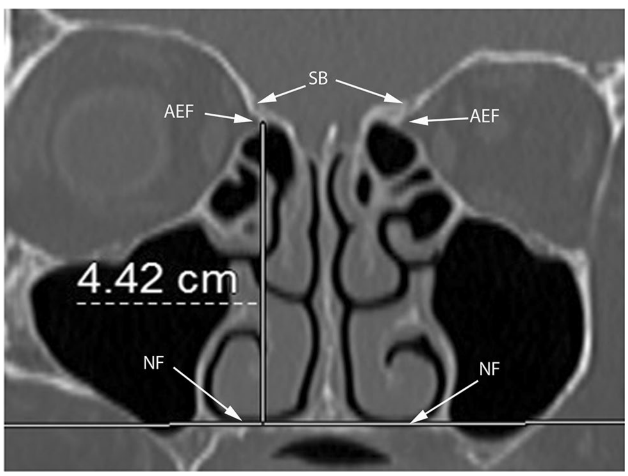

Fig. 6 The distance of anterior ethmoidal artery from nasal floor (NF) was assessed by measuring the vertical distance of anterior ethmoidal foramen (AEF) in relation to the horizontal line drawn across nasal floor. *SB* skull base

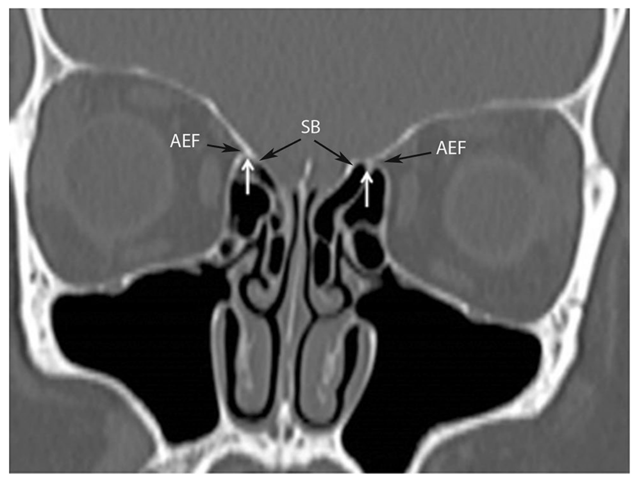

Fig. 8 Coronal CT PNS appearance when anterior ethmoidal artery (white arrows) courses within skull base (grade 1). *AEF* anterior ethmoidal foramen, *SB* skull base

Results

This study involved 126 subjects consisting of 72 males and 54 females. The age ranged from 18 to 86 years with mean age of 52.09 ± 18.48. In terms of ancestry, there were 106 Malays (84.1%), 15 Chinese (11.9%), 1 Indian (0.8%) and 4 (3.2%) others, representing the ethnic ratio of local population. A total of 252 anterior ethmoidal arteries were analysed. The AEF which was identified as the notch on the medial wall of the orbit was seen in 100% of cases, whereas the anterior ethmoidal canal was only seen in 34.1%. The supraorbital ethmoid cell and suprabullar cell were present in 29.8% and 48% of cases, respectively. 42.5% of AEA was found within skull base (grade I) (Fig. 8), 20.2% at skull base (grade II) (Fig. 9) and the remaining 37.3% coursed freely below skull base (grade III) (Fig. 10). In the presence of supraorbital ethmoid cell, AEA coursed freely in the ethmoid sinus in 81.3%, whereas this only occurred in 18.6% of AEA when the supraorbital ethmoid cell was absent ($p < 0.001$) (Table 1). However, there was no significant association between the presence of suprabullar cell and the position of AEA at the skull base ($p = 0.268$).

The mean height of the lateral lamella of the cribriform plate was 3.74 ± 1.01 mm (1.00–7.00 mm) with excellent inter-rater agreement (ICC of 0.905). The lateral lamella

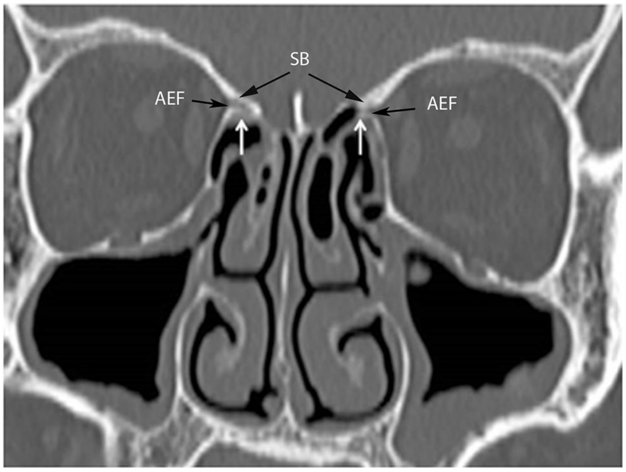

Fig. 9 Coronal CT PNS appearance when anterior ethmoidal artery (white arrows) courses within bony protrusion just below the level of skull base (grade 2). *AEF* anterior ethmoidal foramen, *SB* skull base

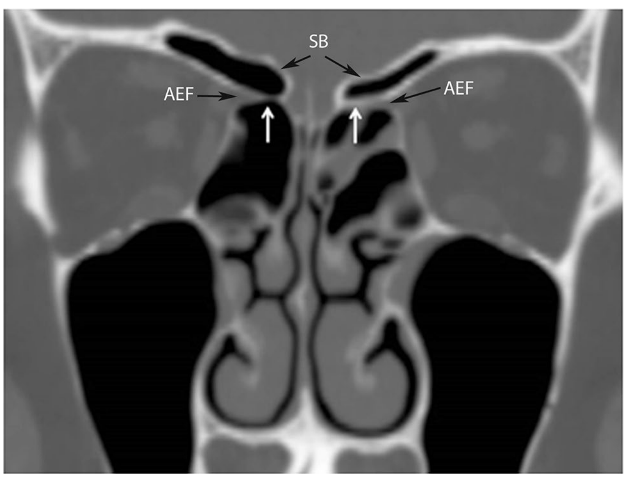

Fig. 10 Coronal CT PNS appearance when anterior ethmoidal artery (white arrows) coursed freely below skull base (grade 3). *AEF* anterior ethmoidal foramen, *SB* skull base

of the cribriform plate was 1–3 mm (Type I Keros) in 106 sides and 4–7 mm (Type II Keros) in 146 sides. There was no Type III Keros (LLCP of 8–16 mm) seen in our study. It was found that with the increase in height of the lateral lamella of the cribriform plate, the probability for the AEA to course freely within the ethmoid sinus increases and the association was significant ($p = 0.016$) (Table 2).

When comparing the height of both lateral lamella of the cribriform plate in the same person, asymmetry (≥ 1 mm) was found in 51 subjects. The lateral lamella was found lower on the right side for 25 subjects and lower on the left side for 26 subjects. The mean anteroposterior length of the lateral lamella of the cribriform plate was 7.44 ± 1.32 mm (4.00–12.00 mm) with a good inter-rater agreement (ICC = 0.72). The anteroposterior length of the lateral lamella of the cribriform plate was 6–10 mm (Type I Yenigun) on 246 sides and 11–15 mm (Type II Yenigun) on the remaining 6 sides. Our study did not show any significant association between the anteroposterior length of the lateral lamella of the cribriform plate and the position of AEA. The mean distance of AEA from skull base was 1.93 ± 2.03 mm (0–7.50 mm), from orbital floor 21.91 ± 2.47 mm (17.05–30.35 mm) and 49.01 ± 3.53 mm (40.90–57.90 mm) from nasal floor (Table 3). All these measurements showed excellent inter-rater agreement with ICC of 0.966, 0.943 and 0.962, respectively.

Discussion

Landmarks for identification of the anterior ethmoidal artery

Several studies had provided guidelines to improve the identification and localization of the artery during endoscopic sinus surgery [3, 4, 6, 17]. Indirect identification of AEA through adjacent bony landmarks has been widely applied with the use of CT scan as it depicts bony structures better compared to other imaging modalities. We found that AEF on the medial wall of orbit was a reliable reference to locate AEA since it was seen in 100% of cases in our study. Souza et al. [23] and Gotwald et al. [6] showed that AEF was found in 100% and 95% of cases, respectively. These findings were like that of ours.

Table 1 Association between supraorbital cell and position of anterior ethmoidal artery

Supraorbital cell	AEA position						*p* value[a]
	Within skull base		At skull base		On mesentery		
	Side	%	Side	%	Side	%	
Absent	105	59.3	39	22.0	33	18.6	< 0.001
Present	2	2.7	12	16.0	61	81.3	

[a]Pearson's Chi-squared test, $\chi^2(2) = 96.27$; association between supraorbital cell and anterior ethmoidal artery position was significant ($p < 0.001$)

Table 2 Association between Keros classification [10] and the position of anterior ethmoidal artery

Keros classification [10]	AEA position						p value[a]
	Within skull base		At skull base		On mesentery		
	Side	%	Side	%	Side	%	
Type I	56	52.8	19	17.9	31	29.2	0.016
Type II	51	39.4	32	21.9	63	43.2	
Type III	0	0.0	0	0.0	0	0.0	

[a]Pearson's chi-squared test, $\chi^2(2)=8.30$; association between Keros classification [10] and anterior ethmoidal artery position was significant ($p=0.016$)

Table 3 The distance of the AEA from the skull base, orbital floor and nasal floor

Distance (mm)	Minimum	Maximum	Mean	SD*
AEA-skull base	0	7.50	1.93	2.03
AEA-orbital floor	17.05	30.35	21.91	2.47
AEA-nasal Floor	40.90	57.90	49.01	3.53

**SD* standard deviation

The anterior ethmoidal artery and the skull base

In the ethmoid sinus, the course of AEA varies depending on its relation to skull base. In our study, we found that AEA was closely related to skull base in 62.7% of cases (grade I and II) and coursed freely in the ethmoid sinus below skull base in the remaining 37.3% (grade III). In the former group, 42.5% of the artery was completely within skull base (grade I) while another 20.2% coursed at the level of skull base with some degree of bony protrusion (grade II). These findings correspond to earlier studies done by Basak et al. [3], Moon et al. [16], Araujo et al. [2], Simmen et al. [20], Lannoy-Penisson et al. [11] and McDonald el al. [14], whereby the majority of the artery was found at the level of skull base. On the contrary, Kainz and Stammberger [9], Cankal et al. [4], Yang et al. [27] and Joshi et al. [8] reported that greater number of AEA was located below skull base with a mesentery connecting it to skull base. This discrepancy demonstrates the wide variations in the position of the artery. Recognition of these variations prior to surgery aids to minimize the risk of injuring the artery, especially when the position of the artery is below the skull base. If the AEA is not recognized as being on a mesentery, the artery might be accidentally injured while clearing septations at the skull base [21].

The anterior ethmoidal artery and the pneumatization of the ethmoid sinus

The prevalence of supraorbital ethmoid cell in our study was 29.8%. It corresponds to all previous studies done, which showed prevalence between 15.0 and 55.8% [7, 8, 15, 17, 20, 23, 28]. The wide range of prevalence is probably attributable to the difference in the sample size, methodology or ancestry. Supraorbital ethmoid cell refers to anterior ethmoid cell that arises from pneumatization of the orbital plate of frontal bone. It extends superolaterally over the orbit from frontal recess. There is a significant association between the presence of supraorbital ethmoid cell and the distance of AEA from skull base ($p<0.001$). When a supraorbital ethmoid cell was present, 81.3% of the AEA was located at a further distance below the skull base, whereas this was only seen in 18.6% when the supraorbital ethmoid cell was absent. Therefore, the presence of supraorbital ethmoid cell serves as a guide to indicate position of AEA is below the skull base and at risk of injury during surgery [8, 20].

Another pattern of pneumatization of the ethmoid sinus that is clinically important is the suprabullar cell. As the name implies, this cell lies above the ethmoid bulla just below the skull base. If a suprabullar cell is present, AEA may be found within it in 85.3% of cases [20]. However, we found the presence of suprabullar cell has no implication on the position of the AEA at the skull base ($p=0.268$) in our study.

The anterior ethmoidal artery and lateral lamella of the cribriform plate

The lateral lamella of the cribriform plate is part of ethmoid bone that constitutes the lateral border of the olfactory fossa, with the cribriform plate providing the floor. Keros classification [10] is used to classify the height of the lateral lamella of the cribriform plate. In Keros type I, the height of the lateral lamella of the cribriform plate is 1–3 mm, Keros type II is 4–7 mm and Keros type III is 8–16 mm. In the study by Keros [10], type I was found in 12%, type II in 70% and type III in 8% of cases. Our study found that type II Keros was the most common, seen in 57.9% and type I in 42.1%. When comparing the height of lateral lamella of the cribriform plate between both sides in the same subject, asymmetrical lateral lamella was found in 51 subjects. The usual observation was that the right lateral lamella of the cribriform plate was lower than the left [22]. However, our study found a slight preponderance of a lower left lateral lamella (51%)

than the right lateral lamella (49%). No type III Keros was found in our study consistent with another study done by Alazzawi et al. [1] that has similar finding in their patients.

The height of the lateral lamella of the cribriform plate was found to be a reliable predictor of the position of the AEA at the skull base [5, 18, 20, 23]. The AEA travels freely in the ethmoid sinus below the skull base in greater frequency if the lateral lamella of the cribriform plate is tall and the olfactory fossa is deep [25]. The association between the height of the lateral lamella of the cribriform plate and the position of AEA was found to be significant in our study ($p = 0.016$). Keros classification [10] was subsequently modified by Yenigun et al. [28] to include the measurement of the anteroposterior length of the lateral lamella of the cribriform plate when they discovered that the AEA is also more likely to run freely below the skull base with the increase in anteroposterior length of the lateral lamella of the cribriform plate. In contrast, our study did not show any association between anteroposterior length of the lateral lamella and the position of AEA.

The anterior ethmoidal artery, nasal floor and orbital floor

The mean distance between AEA and nasal floor was 49.01 ± 3.53 mm. Our result was very similar to the study done in the Korean population by Moon et al. [16], that found this distance was 49.0 ± 4.9 mm, while Araujo et al. [2] and Monjas-Cánovas et al. [15] found a slightly longer distance of 61.72 ± 4.18 mm and 55.51 ± 5.52 mm, respectively in European population. The difference could be due to population variations. The mean distance between AEA and orbital floor was 21.91 ± 2.47 mm. As the orbital floor is a fixed anatomical landmark that is rarely distorted by pathology or surgery, this distance may provide the surgeon useful information to locate AEA [26]. These measurements could also be useful references for surgeon to estimate the extent of space for manipulation during surgery.

Surgical technique for anterior ethmoidal artery protection

A prior identification of bulla and the presence of both suprabullar and supraorbital ethmoid cells will guide and assist surgeons to locate and identify the position of AEA intraoperatively. Surgeons should exercise extra caution in the presence of deep keros [10] as the skull base will be lower and the risk of injury to both skull base and AEA is higher. The ethmoid bulla basal lamella is an excellent anatomical reference point for the posterior wall of frontal recess. Therefore, preserving ethmoid bulla during frontal endoscopic surgical approach is advisable as it not only serves to identify the landmark for frontal recess but at the same time will also protect AEA [13]. Intact bulla dissection method is one of the techniques used to protect AEA from injury when access to frontal recess is required [19]. For beginners and surgeons not familiar with the frontal recess area, it is one of the safest techniques to adopt. It is also safer, in the presence of supraorbital ethmoid cells and deep keros [10], to use microinstruments such as angled curette or microforceps in place of powered microdebrider as such instruments when used near skull base are least damaging to AEA, especially when it is low-lying and unprotected under the skull base.

Conclusions

The position of AEA at the skull base in our study is defined by the presence of supraorbital cell and length of lateral lamella, but not with suprabullar cell. When compared to the European population, the mean distance between AEA and nasal floor is shorter in Asians. The variations of AEA in different populations should be recognized by surgeons to prevent unwarranted complications during endoscopic sinus surgery.

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

Compliance with ethical standards

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

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