IJAE
Vol. 123, n. 3: 248-256, 2018
ITALIAN JOURNAL OF ANATOMY AND EMBRYOLOGY

Research Article - Basic and Applied Anatomy

Morphological characterization of the posterior ethmoidal and additional ethmoidal canal in adult Croatian population

Marina Raguž[1,2,*], Ivan Bohaček[2,3], Dora Sedmak[2,4,5], Ana Hladnik[2,4,5], Dubravko Jalšovec[2,6]

[1] Department of Neurosurgery, University Hospital Dubrava, Zagreb, Croatia
[2] Department of Anatomy and Clinical Anatomy, School of Medicine, University of Zagreb, Zagreb, Croatia
[3] Department of Orthopedic Surgery, University Hospital Centre Zagreb, Zagreb, Croatia
[4] Department of Neuroscience, Croatian Institute for Brain Research, School of Medicine, University of Zagreb, Zagreb, Croatia
[5] Center for Excellence for Basic, Clinical and Translational Neuroscience, School of Medicine, University of Zagreb, Zagreb, Croatia
[6] Department of Thoracic Surgery, University Hospital Centre Zagreb, Zagreb, Croatia

Abstract

The anterior and posterior ethmoidal foramina that open into canals entering the cranial cavity are situated on the medial orbital wall. Since there may be a variable number of accessory ethmoidal foramina and their anatomy appears to be dependent on studied population, we are presenting a study of frequency and morphological characteristics of posterior and additional ethmoidal canals in adult Croatian population. In this study 439 skulls from the Zagreb skull collection were examined in order to confirm the existence of the posterior ethmoidal canal that opens in the anterior cranial fossa and the additional ethmoidal canal that opens in ethmoidal cells. Length and width of both canals were analyzed on computerized tomography scans using Analyze 8.1. software. The posterior ethmoidal canal was found in 86% of skulls. In 10% of skulls the posterior and the additional ethmoidal canals were found. In 4% of skulls we found only the additional ethmoidal canal. On skulls that had the additional ethmoidal canal the posterior ethmoidal canal was shorter and narrower. Variations in communications between orbital cavity and anterior cranial fossa, as well as ethmoidal and sphenoid sinuses could be related to increased need for vascular and nerve supply. Moreover, knowing anatomical variations of the posterior ethmoidal canal is crucial for development of safe surgical and therapeutic guidelines both in orbital and cranial regions. Based on observed communications, we suggest the revision of commonly used nomenclature for the anterior and posterior, as well as additional ethmoidal canals.

Key words

Posterior orbitocranial canal, orbitoethmoidal canal, dry skulls, CT, computerized tomography, orbital surgery.

Introduction

The floor of the anterior cranial fossa is composed of the orbital plates of the frontal bone, the cribriform plate of the ethmoid bone, and the small wings and anterior part of the body of the sphenoid bone. The central portion of the floor of the anterior fossa corresponds with the roof of the nasal cavity, and its lateral portions sup-

* Corresponding author. E-mail: marinaraguz@gmail.com

http://www.fupress.com/ijae
DOI: 10.13128/IJAE-25416

port the frontal lobes of the cerebrum and form the roof of the orbital cavities (Lewis, 1918). The floor of anterior cranial fossa ossifies during the 4th postconceptional month on the cartilaginous basis of the ethmoid, composed of medial and paired lateral portions. During the ossification process, several blood vessels and nerves pass through the new bone. As a consequence, several communications with anterior cranial fossa remain open (Patten, 1946). These important anatomical openings serve as a communication with orbital and nasal cavity.

Classical anatomy describes two openings on medial orbital wall that usually lie in the frontoethmoidal suture, the anterior and posterior ethmoidal foramina (AEF and PEF respectively; Lewis, 1918; Caliot et al., 1995; McQueen et al., 1995; Hayreh, 2006). The foramina open into canals that transmit homonymous vessels and nerves into the ethmoidal sinuses, anterior cranial fossa and nasal cavity. The anterior ethmoidal canal (AEC), widely referred to in literature as the orbitocranial canal (Weber, 1996), opens in the cribrofrontal suture behind the crista galli. It transmits the anterior ethmoidal nerve and vessels, which then run forward in a groove beneath the dura to descend through a slit-like foramen lateral to the crista galli into the nasal cavity. The posterior ethmoidal canal (PEC), widely referred to in literature as the orbitoethmoidal canal (Weber, 1996), opens at the posterolateral corner of the cribriform plate and is overhung by the sphenoid. Anterior ethmoidal artery supplies anterior and middle ethmoidal cells and frontal sinuses and entering the cranium gives a meningeal branch to the adjacent dura mater and nasal branches that descend into the nasal cavity with anterior ethmoidal nerve. Posterior ethmoidal artery and nerve supply the posterior ethmoidal cells and sphenoid sinuses. Entering the cranium, the artery sends a meningeal branch to the dura mater and nasal branches descending into the nasal cavity via the cribriform plate to anastomose with the sphenopalatine branches supplying bone.

Usually, the medial wall of the orbit contains the AEF and the PEF, but there may be a variable number of accessory ethmoidal foramina between the AEF and the PEF (Caliot et al., 1995; Takahashi et al., 2011b). Recent studies have been focused on the precise localization and the frequency of mentioned foramina on dry skull collections in order to provide reference data which can be used to guide the safe and precise surgical procedures and diagnostic/therapeutic interventions in the medial orbital wall with fewer complications minimizing injuries to the important neurovascular bundles. However, the anatomy of skull fossae and their foramina appears to be dependent on studied population and various studies showed different data even between body sides and genders (Rontal et al., 1979; Harrison, 1981; Caliot et al., 1995; McQueen et al., 1995; Hwang and Baik, 1999; Huanmanop et al., 2007; Piagkou et al., 2014). Despite the relatively large number of reports describing ethmoidal foramina, we could not find any report that included in-depth analysis with detailed radiological and morphometric analysis in a large population sample.

Our data present a study of frequency and morphological characteristics of the PEC when the additional ethmoidal canal is present in order to confirm morphological and clinical aspect of this communications in adult Croatian population.

Materials and methods

Morphological analysis of adult human skulls

Macerated skull collection on the Department of Anatomy and Clinical Anatomy, School of Medicine University of Zagreb (Judas et al., 2011) contains 562 dry adult human skulls that have been collected in the second half of 20th century (approximately from 1940s until 1970s). Damaged, fractured or in any kind deformed skulls were excluded from the study. A total number of 439 skulls were examined and included in study: 241 were male, and 198 female. Anterior and posterior ethmoidal foramina were identified on the medial orbital wall, while the AEC and PEC were identified if a probe (thickness 0.05 mm) passed from the medial orbital wall to the anterior cranial fossa through the AEF and PEF respectively. Additional ethmoidal foramen was also identified on the medial orbital wall as a third foramen, and additional ethmoidal canal (AdEC) was identified if a probe passed from the medial orbital wall to ethmoidal cells. The skulls with both PEC and AdEC were further characterized using computerized tomography (CT).

Morphological characterization of the posterior and the additional ethmoid canals using computerized tomography

High-resolution images were obtained using Siemens Somatom Sensation 16 CT Scanner. Distance between the PEF and additional ethmoidal foramen on the medial orbital wall was measured, as well as the length and width of the PEC and AdEC using Analyze 8.1 (Mayo Clinic, Rochester, MN) software. Each measurement was repeated three times, using the average value for further analysis. The length was measured from foramina in the medial orbital wall toward the anterior cranial fossa (PEC) and ethmoidal cells (AdEC). The canal surface was measured at the entrance, in the middle and at the exit of canal, and the widest measure was noted. Data from CT analysis are presented as mean and standard deviation. For statistical analysis, distribution was assessed by the Kolmogorov-Smirnov test, confirming normal distribution. We used t test for comparison between groups. Statistical analysis was performed using MedCalc Statistical Software version 12.5.0 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org). P values less than 0.05 and 0.005 were recorded separately and assumed as significant.

Results

Morphological characteristics of the posterior and the additional ethmoid canals

Macroscopical examination of 439 dry adult human skulls confirmed the existence of AEC and PEC. During the examination we observed skulls with more than two foramina on the medial orbital wall. Using both macroscopical examination and CT analysis we found that in the skulls with three foramina and associated canals the AEC and PEC opened in the anterior cranial fossa (correspond to classic anatomical description), while the additional ethmoidal foramen and its canal terminated in

Figure 1. Mediosagittal cross section of the skull with a clear display of the posterior ethmoidal canal, PEC (posterior orbitocranial) and additional ethmoidal canal, AdEC (orbitoethmoidal).

the ethmoidal cells (Figure 1). The AEF, PEF and additional ethmoidal foramen lied in the frontoethmoidal suture. The additional foramen was situated in 11% cases between PEF and optic canal, and in 89% cases between AEF and PEF.

The PEC was observed in total 379 skulls (86%), 203 males and 175 females. The PEC and the AdEC were found in 44 skulls (10%), 29 males and 15 females. In 16 skulls (4%), 9 males and 8 females, only the canal that terminated in the ethmoidal cells (AdEC) was observed, while the PEC was not observed. We also recorded unilateral or bilateral frequency of canals (Table 1).

Skulls with both the PEC and AdEC were further analyzed on CT. The length and width of the PEC and AdEC were measured. Also, the distance between PEF and additional ethmoidal foramen on the medial orbital wall was measured.

In male skulls the average length of the left PEC was 2.378±0.291 mm, and of the right PEC was 2.252±0.283. The average length of the left AdEC was 2.412±0.102 mm, and of the right AdEC was 2.418±0.216 mm. The mean surface of the PEC was 1.4±0.16 mm^2, while the mean surface of the AdEC was 1.5±0.29 mm^2 . The distance between the PEF and additional ethmoidal foramen on the left medial orbital wall was 21.03±2.78 mm, and on the right medial orbital wall was 20.89±1.99 mm (Table 2). None of these differences were significant.

In female skulls the average length of the left PEC was 2.028±0.205 mm, and of the right PEC was 2.031±0.143 mm. The average length of the left AdEC was 2.18±0.675 mm, and of the right AdEC was 2.21±0.131 mm . The mean surface of the PEC was 1.3±0.14 mm^2, while the mean surface of the AdEC was 1.4±0.87 mm^2. The distance between the PEF and additional ethmoidal foramen on the left medial orbit-

Table 1. Frequency of number of the posterior (PEC) and additional (AdEC) ethmoidal canals per skull, male and female: further classification on bilateral and unilateral canals was included.

	Total number	Male			Female		
		Total	Unilateral	Bilateral	Total	Unilateral	Bilateral
PEC	379 (86%)	203	12	191	175	14	161
AdEC	16 (4%)	9	2	7	8	3	5
Both canals	44 (10%)	29	13	16	15	10	5

Table 2. Morphological characterizations of the PEC and AdEC in male and female dry skulls. Data are from skull where both PEC and AdEC were found.

	male (N = 29)		female (N = 15)	
	length (mm)	surface (mm^2)	length (mm)	surface (mm^2)
PEC				
left	2.378±0.291	1.4±0.16	2.028±0.205	1.3±0.14
right	2.252±0.283		2.031±0.143	
AdEC				
left	2.412±0.102	1.5±0.29	2.18±0.675	1.4±0.87
right	2.418±0.216		2.21±0.131	

al wall was 19.01±1.64 mm, and on the right medial orbital wall 18.98±1.75 mm (Table 2). None of these differences were significant.

The length difference of both left and right PEC and AdEC between male and female skulls showed no statistical significance, as well as surface of PEC and AdEC. The distance from the PEF to additional ethmoidal foramen between male and female skulls showed statistical significance on both left and right medial orbital wall (*p<0.005*).

Discussion

Since anatomical variations are common and are possible cause of iatrogenic complications, detailed anatomical analysis of ethmoidal foramina is of a great importance for the development of safe surgical and therapeutic guidelines (Rontal et al., 1979; McQueen et al., 1995). These foramina and canals usually appear during prenatal development. A neurovascular bundle enters as a unit in the developing bone, forming a foramen and a canal with further growth through (Kirchner et al., 1961). Recent anatomical studies primarily focused on precise localization and the frequency of mentioned foramina and canals (Cankal et al., 2004; Celik et al., 2015; Kazak et al., 2015; Yoon and Pather, 2016). The studies have been conducted on dry skull collections on different populations and have described a wide variability in location of ethmoidal foramina using different methods, from caliper and flexible wire to computer software. Several distance measurements on the medial wall of the orbit, such as the distances between the anterior lacrimal crest and the ethmoidal foramen or interforamina distance, were determined in order to provide reference data which can be used to guide surgery involving orbit. However, variations were considerable and the only safe conclusion from these measurements is that undue reliance should not be placed on these landmarks, nor on "average" position (Rontal et al., 1979; Harrison, 1981; McQueen et al., 1995; Hwang and Baik, 1999; Berge and Bergman, 2001; Huanmanop et al., 2007; Takahashi et al., 2011a,b; Abed et al., 2012; Piagkou et al., 2014; Kazak et al., 2015).

Several authors described the existence of multiple entry points on the medial orbital wall, and number of openings also varied depending on the described population. Caliot et al (1995) reported the presence of middle ethmoidal foramina and a case of quadruple foramina. Abed et al (2012) reported a case of quintuple ethmoidal foramina as a possible combination of anterior ethmoidal foramina, middle ethmoidal foramina and three posterior ethmoidal foramina. Huanmanop et al (2007) noted the presence of multiple posterior ethmoidal foramina. Berge and Bergman (2001) presented skulls with double foramina in 28%, and triple in 2% of cases. However, these studies did not provide the morphological characteristics of the additional canals.

Data from previous studies showed that the mean length of the PEC is 7.1±1.02 mm (Monjas-Cánovas et al., 2011) and 2–13 mm, mean 7.6 mm (Cankal et al., 2004). Since to the best of our knowledge there is no study on measurement of the PEC when the AdEC is present, we measured the length of the PEC only when the AdEC was present and showed that the mean length of the PEC was approximately 2.3 mm in male skulls and 2.05 mm in female skulls. Thus, the PEC was shorter and narrower than usual when the AdEC was present. It is possible that, when neurovascular supply or innervation through the PEC is not sufficient due to its shortness and narrowness, there is an additional supply to the posterior ethmoid cells and sphenoid sinus through the AdEC that opens into sinuses, instead in the anterior cranial fossa. Previous reports from cadaveric studies (McQueen et al., 1995; Hwang and Baik, 1999; Abed et al., 2011; Yoon and Pather, 2016) showed no presence of additional ethmoidal canal, so further research on cadavers is needed to investigate and confirm the presence of neurovascular bundle in additional ethmoidal canal.

Data from our study showed that the presence of both PEC and AdEC in Croatian population is significantly more frequent in males then in females. Bilateral appearance is more common than unilateral appearance (Table 1). The length and surface differences in the PEC and AdEC present in males and females were expected, due to sex dimorphism (Keen, 1950). These variations could be related with an increased need for vascular and nerve supply in males. Similar studies were conducted on different populations, namely those of India (Rontal et al., 1979), USA (McQueen et al., 1995), Korea (Hwang and Baik, 1999), Southeast Asia (Huanmanop et al., 2007), Japan (Takahashi et al., 2011a,b), and in Greek Caucasian (Piagkou et al., 2014). Potential differences among measured values can be explained by variation among different population (Rontal et al., 1979; McQueen et al., 1995; Hwang and Baik, 1999; Huanmanop et al., 2007; Takahashi et al., 2011a,b; Piagkou et al., 2014).

In clinical practice, these findings are important for several reasons. Many disorders, such as trauma, infections, neoplasms and vascular aberrations affect the orbital region.

During surgery performed on the medial orbital wall, the surgeon should be aware of these variation and of possible complication such as bleeding or nerve damage. Injury to the ethmoidal arteries is very common and may result with several complications after surgery, such as massive hemorrhage, orbital hematoma and even optic neuropathy (Graham et al., 2003; Yeh et al., 2004; Han et al., 2008; Abuzayed et al., 2009). In order to control bleeding, such as epistaxis, it is very important to identify all ethmoidal vessels in additional canals (Kirchner et al., 1961; Piagkou et al., 2014), while skull fractures in this area could result in postnasal hemorrhage simulating sphenopalatine arterial bleeding but, unlike the latter, this could not be controlled by external carotid ligation. Possibility of ascending infection from the orbit to the anterior cranial fossa should be taken into account as well (Badilla and Dolman, 2007).

So, detailed knowledge of anatomy and possible variations in the location and number of individual foramina containing blood vessels and nerves can contribute reducing intra- and post-operative complications in the medial orbital wall, especially when existence of such anatomical variations is dependent on observed population.

Moreover, as the AEC retained the name orbitocranial canal and the PEC retained that of orbitoethmoidal canal, due to the observed opening and orientation of the AdEC and PEC we propose revision of this widely accepted terminology. Thus, as the AEC and PEC terminate in the anterior cranial fossa, they should be defined as anterior and posterior orbitocranial canal. As the AdEC terminates in ethmoidal cells, and in 4% is the only posterior canal, we suggest that it should be defined as orbitoethmoidal canal.

Acknowledgments

We wish to thank prof. Zdravko Petanjek, Head of the Department of Anatomy and Clinical Anatomy, for helpful comments on this manuscript and access to the macerated scull collection. This work was supported by the Croatian Science Foundation grant no. 5943 (Microcircuitry of higher cognitive functions).

This publication was co-financed by the Scientific Centre of Excellence for Basic, Clinical and Translational Neuroscience (project "Experimental and clinical research of hypoxic-ischemic damage in perinatal and adult brain"; GA KK01.1.1.01.0007 funded by the European Union through the European Regional Development Fund).

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