The Sinonasal Anatomy: Endoscopic Lacrimal and Orbital Perspectives

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Introduction

Basic knowledge of the sinonasal anatomy is required to safely perform lacrimal and orbital surgeries. We reviewed the anatomy of the nasal cavity (overview, nasal septum, lateral nasal wall including the lacrimal passage, inferior turbinate and meatus, middle turbinate and meatus, and superior and supreme turbinates and meatuses), ethmoid sinus (overview, agger nasi, uncinate process, fontanelle, ethmoid bulla, hiatus semilunaris, ethmoid infundibulum, and ostiomeatal complex), and sphenoid sinus.

Anatomy of the Nasal Cavity

Overview of the Nasal Cavity

The nares or nostrils are the two openings into the nasal cavity [1]. The nasal septum divides the nasal cavity into two sides [2]. The vestibule is the anterior, skin-lined portion containing nasal hairs (Fig. 5.1a) [1]. The junction of the skin and nasal mucosa occurs at a variable distance inside the nose and is usually clearly discernible by different colors between the skin and mucosa (Fig. 5.1a) [1]. The web-like structure at this junction corresponds to the base of the ala nasi (Fig. 5.1b–d).

The choanae, the round, larger posterior nares, are the spaces representing the posterior limits of the nasal cavities and divide the nose from the superior epipharynx (Fig. 5.2a, b). The choanae are clearly visible from the front using nasal endoscopy (Fig. 5.2a). The floor of the nasal cavity is bordered by the hard and soft palates (Fig. 5.3) [1].

The lateral wall of the nose is a complex structure [1]. There are three or four paired nasal turbinates with a corresponding meatus under each turbinate (Fig. 5.4) [1]. The most important paranasal structures are concentrated in the middle meatus, and the nasolacrimal duct empties into the inferior meatus [1–3].

The effect of the nasal conchae and meatuses on the inspired airstream sets the parameters for nasal breathing and treatment of air before it is directed down into the lungs [4]. The turbulent airflow caused by the conchae adds to the perceived resistance of nasal airflow and the sensation of adequate breathing [4]. Turbulent airflow allows for the wafting of molecules to the sensory cells of the olfactory system, aiding the senses of taste and smell [4].

The external proportions of the nose are expected to influence the internal anatomy, and thus cause differences in nasal physiology. Populations adapted to cold and dry environments tend to have large, protruding external noses,

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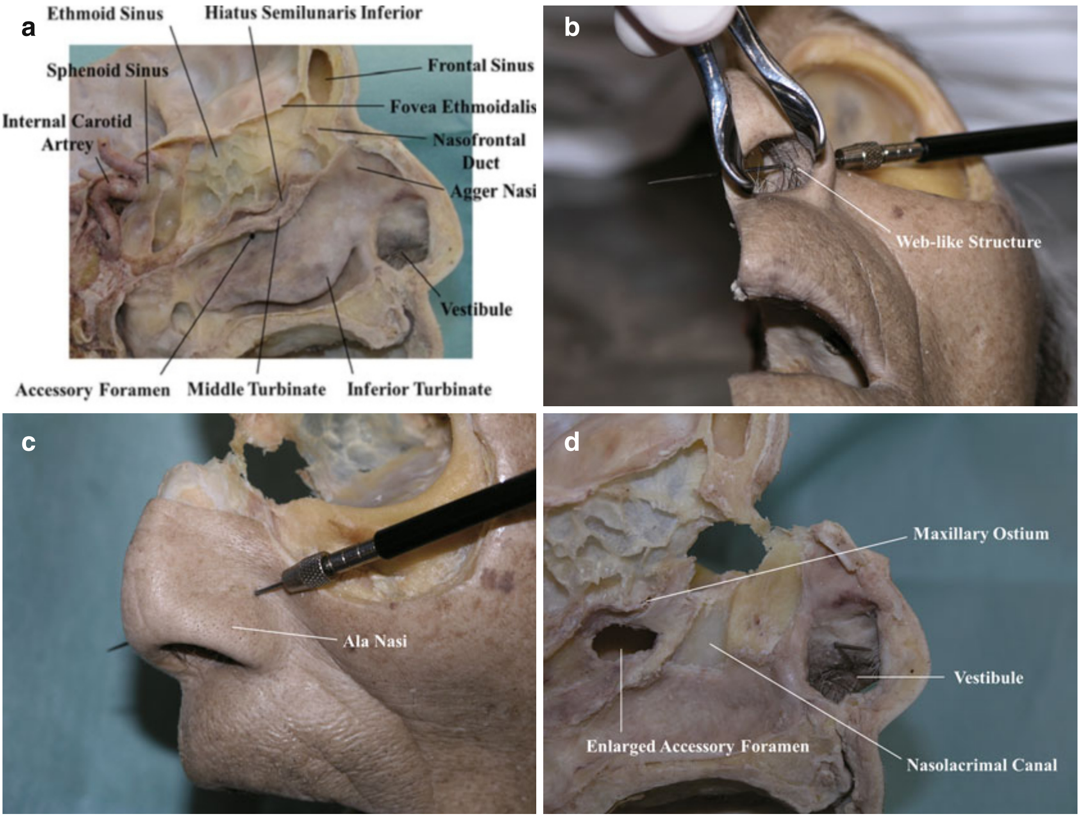

Fig. 5.1 (**a**) Anterior nasal space, lateral nasal space, and ethmoid and frontal sinuses. The middle turbinate is removed. (cadaver, 89-year-old male). (**b**) Web-like structure seen from the inferior aspect. (cadaver, 89-year-old male). (**c**) Pin piercing the base of the ala nasi. (cadaver, 89-year-old male). (**d**) Pin emerged at the superior border of the nasal vestibule. The nasolacrimal canal is directed posteriorly. (cadaver, 89-year-old male)

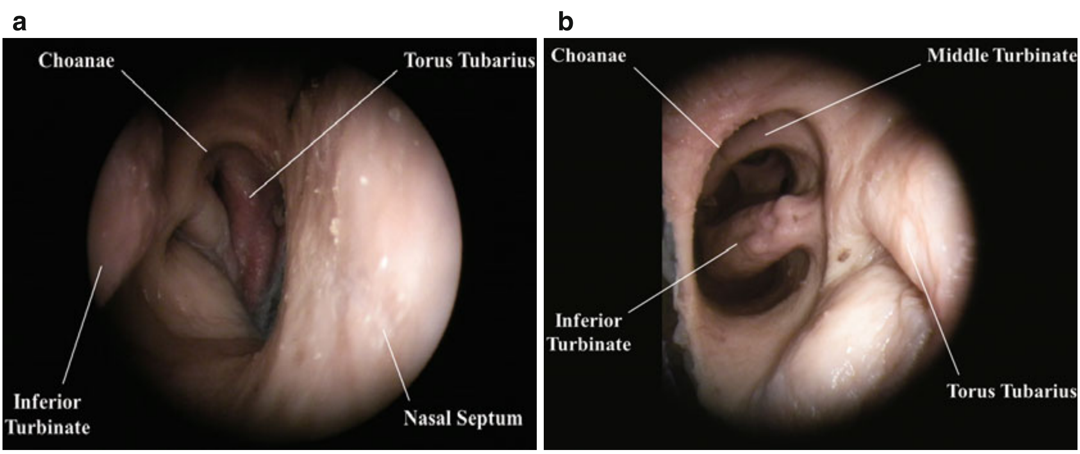

Fig. 5.2 (**a**) Appearance of the choanae seen from the front. (cadaver, 97-year-old female). (**b**) Appearance of the choanae seen from the back. (cadaver, 97-year-old female)

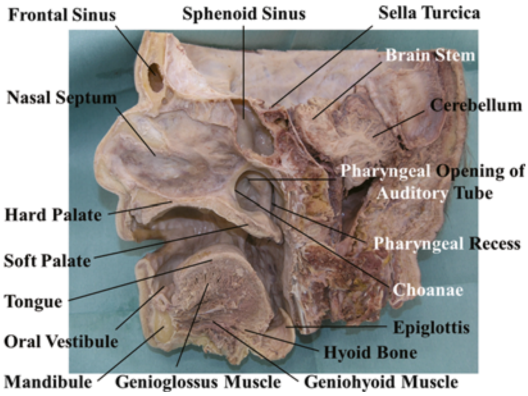

Fig. 5.3 Appearance of the facial half including the nasal septum. (cadaver, 89-year-old male)

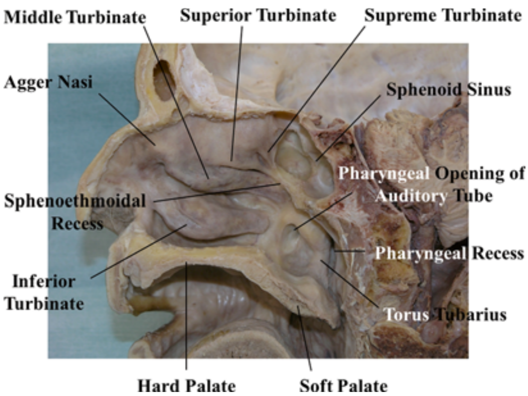

Fig. 5.4 Appearance of the lateral nasal wall with surrounding structures. (cadaver, 89-year-old male)

downwardly directed nostrils, and narrower skeletal nasal apertures [5]. These characteristics are thought to induce turbulence of nasal airflow, thereby maximizing filtration, heat, and humidification of air within the nasal passages [5–7]. Conversely, those with smaller, flatter external noses, more anteriorly directed nares, and shorter piriform apertures are better adapted to hot, humid environments. Because much of the energy required for breathing is expended in the nasal passages, a broader, flatter nasal structure favors less turbulent airflow, which is physiologically more economical because of the lower nasal airway resistance. In the platyrrhine nose, inspiratory airstreams passing through more horizontally

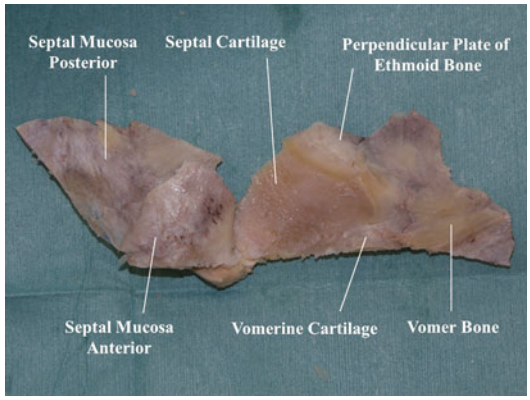

Fig. 5.5 Appearance of the nasal septum and mucosa. The septal mucosa has been placed inside out. (cadaver, 89-year-old male)

placed nostrils are directed toward the inferior portion of the nasal chamber to condition very warm air, and the region anterior to the turbinates typically plays a lesser role in black than in white individuals [5, 8].

Nasal Septum

The nasal septum comprises cartilage anteriorly (quadrilateral/septal cartilage) and bone posteriorly (vertical plate of the ethmoid bone posterosuperiorly and vomer bone posteroinferiorly) (Fig. 5.5) [1]. A membranous columella that divides the nares is present in the anteroinferior area [9], and the vomerine cartilage occupies the posteroinferior area [10]. The nasal septum divides the nasal cavity into two portions and forms most of the nasal bridge [2].

Although the vertical plate of the ethmoid bone and the nasal septum comprise hyaline cartilage in neonates, the vomer is already a bone [10]. From 1 or 2 months after birth, the hyaline cartilage begins to ossify posteriorly and forms the vertical plate of the ethmoid bone [10]. The nasal septum begins to grow rapidly from puberty and raises the external nose [10]. With its growth, the cartilage occasionally bends, forming protuberances and spurs at the junction with the vomer

[3, 10]. Approximately 90 % of adults show variable extents of septal bending that is directed both anteroposteriorly and transversely [3]. The nasal septum and bone continue to grow until the end of puberty [10]. The posterior edge of the cartilage grows posteriorly from puberty, resulting in formation of the sphenoid or vomerine processes [10].

The septal mucosa is thickest centrally in the superoinferior direction with a tendency to be thicker anteriorly in the anteroposterior direction (Fig. 5.5) [10]. The mucosa of the olfactory cleavage is comparatively thin [10]. Kiesselbach's area, a common site of nasal bleeding, is situated in the anteroinferior part of the septal mucosa [10].

Clinical Correlations

1. Nasal septal surgery should be performed after puberty because removal of the septal cartilage before puberty may prevent growth of the external nose [10]. For the same reason, it should be avoided or a minimal focal septoplasty should be done, if greatly needed in pediatric DCR.
2. Excessive removal of the anteriorly located septal cartilage occasionally causes ptosis of the nasal tip [10]. A saddle nose may occur by overharvesting the septal cartilage in the dorsum nasi [10]. Therefore, a 5- to 10-mm width of the dorsum nasi tissue should not to be removed. Incision of the nasal septum is usually performed 10 mm from the anterior tip of the septal cartilage, which approximately corresponds to the mucocutaneous junction. Incision of the cartilage is started approximately 3-mm posterior from the mucosal incision [3].
3. Endonasal dacryocystorhinostomy (DCR) occasionally requires a septoplasty, particularly if a Jones bypass tube is planned for insertion, because its aftercare requires easy endonasal access [2].

Lateral Nasal Wall

Lacrimal Passage

The anterior lacrimal crest, ridge, or maxillary line is formed by the underlying frontal process of the maxilla and corresponds to the anterior surface of the nasolacrimal duct [2].

The maxillary line is a curvilinear mucosal eminence projecting from the anterior middle turbinate attachment superiorly and extending inferiorly along the lateral nasal wall to the dorsum of the inferior turbinate (Fig. 5.6a, b) [11]. It corresponds intranasally to the junction of the maxilla and uncinate process and extranasally to the suture between the maxilla and lacrimal bone within the lacrimal fossa [11, 12]. A line drawn through the midpoint of the maxillary line is just inferior to the lacrimal sac–duct junction [11]. The thickness and proportion of the maxillary bone in the lacrimal sac fossa increases as the level increases from lower to upper [13]. When the height and length of the nasal bone are small, the frontal process of the maxilla is thick in the lacrimal fossa [13]. In this respect, Asians tend to have a thicker maxillary frontal process than that of Caucasians [13].

The lacrimal bone, which has a mean thickness of 0.057 [14] to 0.106 mm [15], is located posterior to the maxillary line. The lacrimal bone is also situated just anterior to the middle third of the uncinate process, which has an average length and width of 7.2 and 2.5 mm, respectively [14].

The nasolacrimal canal, which has an average length of 12 mm and drains into the inferior meatus (Figs. 5.1d and 5.6b) [9], originates at the base of the lacrimal fossa and is formed by the maxillary bone laterally and inferior turbinate bones medially [9]. The average width of the superior opening of the canal is 4.5–5.7 mm transversely [16–18] and 6.5–6.9 mm anteroposteriorly [17, 18]. The canal courses posteroinferiorly at an average of 12–27° (Fig. 5.1d) [17, 19–21] and almost parallel to the sagittal plane (Fig. 5.6c) [22]. However, in approximately half of individuals, the canal is directed inward against the sagittal line irrespective of the outward course of the lacrimal fossa [22, 23].

The nasolacrimal duct opening is present on the lateral nasal wall in the inferior meatus (Fig. 5.6b) [2]. The bony opening is most commonly located high up in the inferior meatus [2]. A duct orifice is present at this site in only about 10 % of individuals [24]. In most cases, a certain length of the mucosal duct extends anteroinferiorly from there

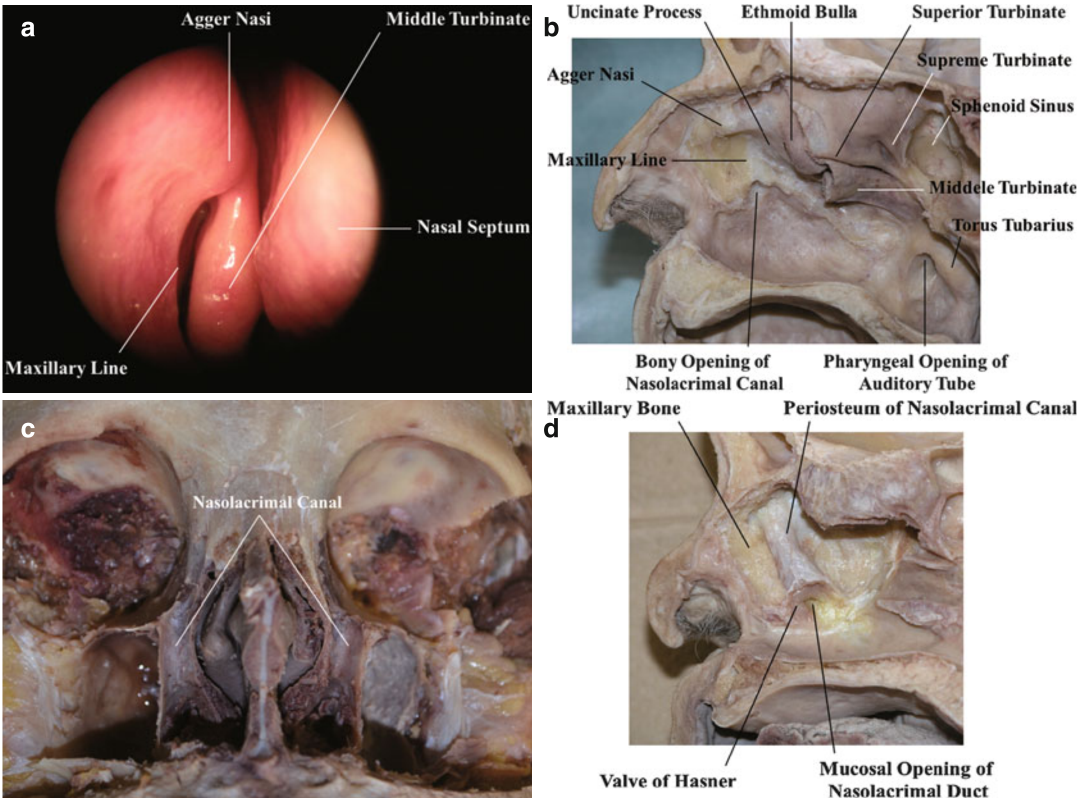

Fig. 5.6 (**a**) Maxillary line, agger nasi, and middle turbinate. (34-year-old female). (**b**). Appearance of the lateral nasal wall. The inferior turbinate and half of the middle and superior turbinates are removed. The bony opening of the nasolacrimal canal is seen. (cadaver, 89-year-old male). (**c**) The nasolacrimal canal courses almost parallel to the sagittal plane. (cadaver, 70-year-old male). (**d**) Certain length of mucosal duct, termed the valve of Hasner, extends from the bony opening of the nasolacrimal canal. (cadaver, 97-year-old female)

[24] and reaches approximately 1 cm posterior to the anterior tip of the inferior turbinate (Fig. 5.6d) [2]. This mucosal duct is often called the valve of Hasner [2]. The shape of the opening varies considerably from round to slit like or may simply be a pit or fold [2, 24].

The relationship between the lacrimal sac and lateral nasal wall is variable; the sac may be relatively high, normal, or low compared with the adjacent anterior nasal space (Fig. 5.7a, b) [2]. This may simply reflect differently sized nasal spaces and mid-face bony development [2]. Anterior ethmoid air cells are usually found between the lacrimal fossa and lateral nasal wall in most subjects [2]. These air cells are more common in the posterior superior lacrimal fossa [2].

The anterior end of the middle turbinate has been thought to be a constant anatomical landmark of the lacrimal sac [2, 25, 26]. However, whether this structure can serve as a useful landmark of the lacrimal sac fossa in the vertical or anteroposterior position is unclear [27]. Up to 20 % of the lacrimal sac was reported to be situated above the axilla of the middle turbinate [28, 29]. However, another study suggested that a large part of the lacrimal sac fossa was above the axilla of the middle turbinate [30–32]. In an Asian study, the axilla of the middle turbinate was attached to the lacrimal sac fossa in more than 90 % of cases and located above the lacrimal sac fossa in 4 % [13]. A wide positional variation was shown in relation to the lacrimal sac fossa.

The horizontal position of the axilla of the middle turbinate in Asians differs from that of Caucasians. A Caucasian study [33] demonstrated that in 53.2 % of cases, the axilla of the middle turbinate was located within the lacrimal sac fossa in contrast to the conventional notion

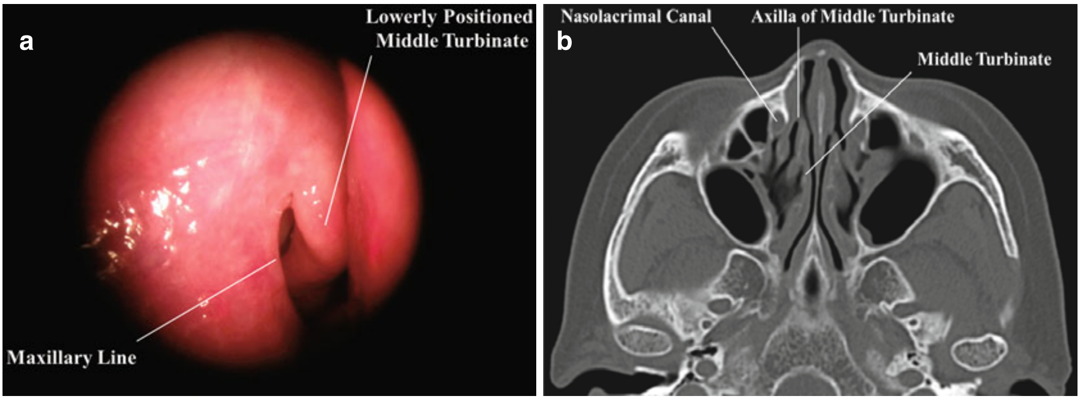

Fig. 5.7 (**a**, **b**) Relationship between the lacrimal sac and the middle turbinate is variable. These figures show high sac positions. (61-year-old female)

that the axilla of the middle turbinate is posterior to the lacrimal sac fossa. In an Asian study [13], the axilla of the middle turbinate was located posterior to the posterior lacrimal crest in only 2 % of cases.

More than 90 % of Caucasian specimens demonstrate the uncinate process extending beyond the posterior lacrimal crest [34]. However, in Asians, 100 % of the uncinate process reportedly attaches to the lacrimal fossa [13]. The ethmoid air cells are positioned more anteriorly in Asians than in Caucasians [13]. The anterior insertion of the uncinate process is oblique; the uncinate process generally attaches to the lacrimal bone at the lower level, becomes anterior to the maxillary bone–lacrimal bone at the middle level, and then joins the middle turbinate at the upper level [13]. The uncinate process is also helpful when approaching the lower portion of the lacrimal sac fossa [13].

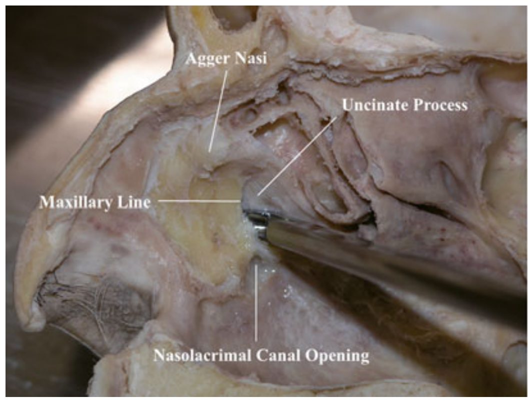

Fig. 5.8 Osteotomy during an endonasal dacryocystorhinostomy can be easily started at the lower portion of the lacrimal sac fossa, in which the lacrimal bone constitutes the lacrimal sac fossa in the highest proportion and the frontal process of the maxilla is thinnest. For ease of understanding, the rongeur is inserted into the nasolacrimal canal. (cadaver, 89-year-old male)

Clinical Correlations

(a) The lacrimal bone is very thin [14, 15] and easily penetrated for entrance into the nasal cavity during endonasal DCR [2]. In patients with a maxillary bone dominant fossa, the thicker bone makes it more difficult to create the osteotomy [2]. Special surgical techniques and instruments, such as a surgical drills or ultrasound aspirators, must be equipped for patients with a thick maxillary frontal process to expose the upper portion of the lacrimal sac fossa [13, 26]. In this respect, DCR for Caucasian patients with a thinner maxillary frontal process [13] may not require the use of such instruments.

(b) Osteotomy can be easily started at the lower portion of the lacrimal sac fossa, in which the lacrimal bone constitutes the lacrimal fossa in the highest proportion and the frontal process of the maxilla is thinnest (Fig. 5.8) [13].

(c) The uncinate process, which mostly extends beyond the posterior lacrimal crest, is an important factor to consider when creating an osteotomy during DCR [25, 34]. However, the sac and duct usually lie immediately anteriorly and laterally to the uncinate process, which does not need to be disturbed during surgery [2]. This notion is mostly applied to Caucasians, but not to Asians. Because the anterior ethmoid air cells always extend to the posterior lacrimal crest in Asians [2], an uncinectomy is recommended to clearly expose the lacrimal sac fossa to create a sufficient ostium.

(d) The nasolacrimal canal opening (bony opening) is located in the ceiling of the inferior meatus [2]. However, the nasolacrimal mucosal orifice empties fairly anteriorly [24]. Therefore, a specific technique is needed to clearly observe this mucosal orifice, such as preexamination fluorescein staining or putting the inferior turbinate aside.

(e) Because of variability in the relationship between the lacrimal sac and lateral nasal wall [2], and because of the thick maxillary frontal process in patients with a low nasal bridge [13], the precise position of the lacrimal sac is best to be confirmed by a transcanalicular illumination device during endonasal DCR [13]. The structures intervening between the lacrimal sac fossa and nasal cavity must be defined by moving the light device up and down and back and forth [13]. Diffuse light is expected in cases with an anteriorly displaced uncinate process or large agger nasi cell [13].

(f) Most Asians may sometimes need a partial middle turbinectomy for creation of a sufficient ostium because most of the posterior lacrimal crest is covered by the axilla of the middle turbinate [13].

(g) As described in the "Ethmoid Infundibulum" section, bone exposure after mucosal resection induces granulation [3]. Although anterior and posterior mucosal flaps are created during external DCR, bone in the upper and lower portions of the osteotomy is still exposed. These parts are at risk of granulation formation. Although the use of mitomycin C [35] or a stent [36] may prevent granulation to some extent, covering the whole osteotomy margin with the mucosal flap without bone exposure leads to a decreased risk of granulation.

Inferior Turbinate and Meatus

The inferior turbinate is the largest turbinate and occupies the lower third of the lateral nasal wall (Fig. 5.4) [2]. It arises from the medial wall of the maxillary sinus; the other turbinates arise from the ethmoid bone [9]. Its anterior tip is located 1.5–2.0 cm inside the nasal space in adults [2]. Its medial surface is usually concave, and its lateral surface is usually convex [2]. The inferior turbinate is covered by thick vascular mucosa, which often results in hypertrophy [2]. The nasolacrimal canal opening is located on the lateral nasal wall in the inferior meatus (Fig. 5.6b) [2].

The size of the meatus under each turbinate may be large or small, corresponding to the size of the bone making up the turbinate and varying with the state of mucosal and vascular engorgement of the overlying epithelium [1]. These anatomic and mucosal factors can dramatically influence the structures draining into each meatus [1].

Middle Turbinate and Meatus

The middle turbinate is part of the ethmoid bone (Fig. 5.4) [2]. When this turbinate is enlarged by air cells, it is called the "concha bullosa" (Fig. 5.9) [2] or sometimes the "interlamellar cell" [3]. The concha bullosa is classified into three types: pneumatization of the vertical lamella (lamellar type), pneumatization of the

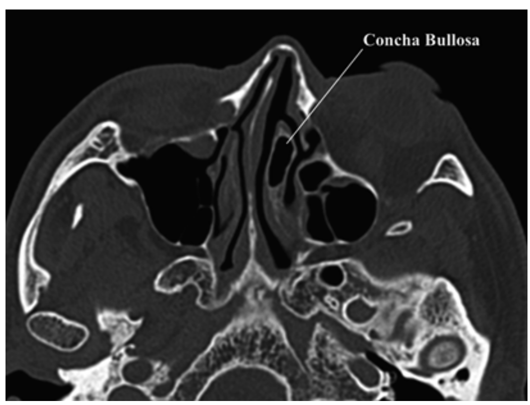

Fig. 5.9 Concha bullosa. (43-year-old male)

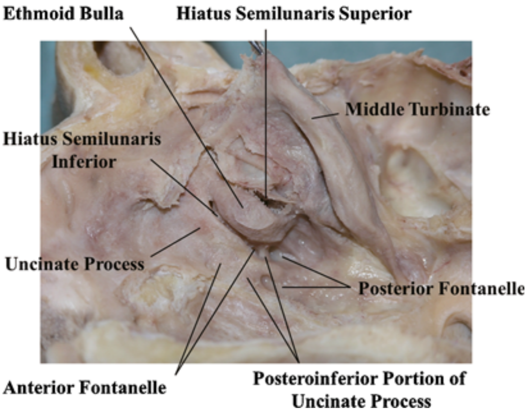

Fig. 5.10 Appearance of the middle meatus. This contains the uncinate process, hiatus semilunaris with the infundibulum, and ethmoid bulla and receives drainage from the frontal, anterior ethmoid, and maxillary sinuses. The posterior portion of the uncinate process divides the fontanelle into anterior and posterior parts. (cadaver, 89-year-old male)

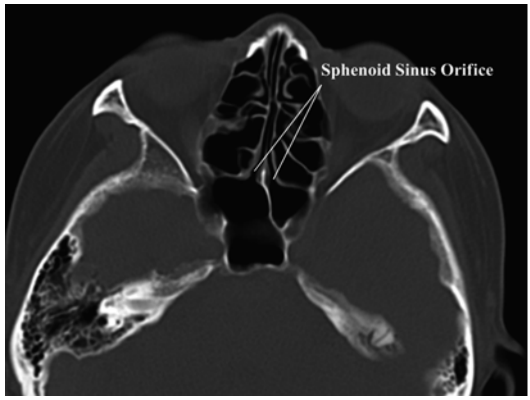

Fig. 5.11 Sphenoid sinus orifices. (38-year-old female)

inferior bulbous portion (bulbous type), and pneumatization of the entire turbinate (extensive type) [37, 38]. These air cells usually originate from the agger nasi [2]. Normally, its lateral wall is convex and its medial wall is concave. It protects the middle meatus and its important physiological structures [2].

The middle meatus contains the uncinate process, hiatus semilunaris with the infundibulum, and ethmoid bulla [2] and receives drainage from the frontal, anterior ethmoid, and maxillary sinuses (Fig. 5.10) [9]. This area is important pathophysiologically because it forms part of the ostiomeatal complex [2]. The detailed anatomy of this structure is described later [2].

The middle meatus divides the paranasal sinuses into anterior and posterior portions [3]. The anterior paranasal sinuses are the general term for the paranasal sinuses emptying into the middle meatus and comprise the frontal, anterior ethmoid, and maxillary sinuses [3]. The posterior paranasal sinuses are located posterior to the middle turbinate, the opening of which is around the ceiling of the posterior nasal cavity [3]. The posterior paranasal sinuses are constituted by the posterior ethmoid cells emptying into the superior meatus and the sphenoid sinus with its orifice opening to the sphenoethmoidal recess (Fig. 5.11) [3]. Conditions such as sinusitis are usually sectioned such as anterior or posterior types [3].

Superior and Supreme Turbinates and Meatuses

These structures and spaces are usually small and insignificant in size compared with the other two turbinates (Fig. 5.4) [1]. These turbinates originate from the ethmoid bone. The superior turbinate has the common attachment of the middle turbinate to the skull base [39]. The supreme turbinate may be found in up to 65 % of specimens [9]. The air cells forming the posterior ethmoid sinus drain into the superior meatus with two or three ducts and occasionally into the supreme meatus [1, 40]. The olfactory neuroepithelium, which is centered principally on the area of the cribriform plate, extends to the superior turbinate and superior part of the middle turbinate to varying degrees [41].

Anatomy of Ethmoid Sinus

Overview of the Ethmoid Sinus

The ethmoid air cells are cavities comprising various sizes of honeycomb-like air cells (Fig. 5.1a) [3, 42]. The superior border is the comparatively flat roof of the ethmoid, the lateral border is the lamina papyracea, and the medial

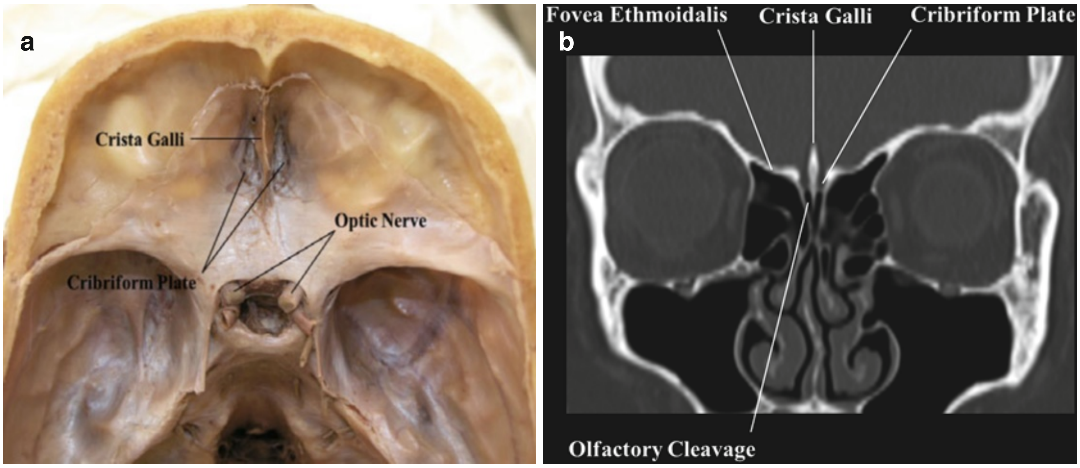

Fig. 5.12 (**a**) Appearance of the skull base with special features of the cribriform plate, crista galli, and optic nerve. (cadaver, 81-year-old male). (**b**) Cribriform plate separates the nose from the anterior cranial fossa. The cribriform plates are often located lower than the fovea ethmoidalis. (42-year-old male)

border is the lateral wall of the middle and superior meatuses and middle turbinate [3, 42]. The space is narrower anteriorly and becomes larger posteriorly, finally reaching the anterior wall of the sphenoid sinus (Fig. 5.11) [3, 42].

The cribriform plate is not a part of the ethmoid sinus, but is located medial to the attachment of the middle turbinate, separating the nose from the anterior cranial fossa (Fig. 5.12a) [1]. The two cribriform plates are separated from each other by the crista galli, and both plates lie posterior to the posterior table of the frontal sinus [1]. Each cribriform plate measures approximately 2 cm from anterior to posterior and 0.5 cm from medial to lateral [1]. The olfactory nerve endings traverse small openings in each cribriform plate to reach the olfactory bulb [1]. The narrow nasal cavity inferior to the cribriform plate is the olfactory cleavage [42]. The cribriform plates are often located lower than the roof of the ethmoid sinus, called the fovea ethmoidalis (Fig. 5.12b) [42].

Although the inside of the ethmoid sinus is complexly divided into many cells, there are several partitions dividing the sinus from anterior to posterior [3]. These are called the "basal lamellae" or "ground lamellae" [3]. When this is used in a singular form, it represents the "third basal lamella" [3]. Because the term "ground lamella" is not cited in Nomina Anatomica, the term "basal lamellae" is mainly used at present [3].

The basal lamellae of the ethmoid sinus are walls connecting the lateral nasal wall and the lamina papyracea [3]. However, only the third basal lamella clearly reaches the lamina papyracea from the lateral nasal wall [3]. Whether most of the other basal lamellae reach the lamina papyracea cannot be confirmed because of their complex structure [3]. Therefore, they are termed the "incomplete basal lamellae" [3].

The ethmoid sinus generally shows five basal lamellae that are numbered from anterior to posterior (Fig. 5.13) [3]. The first basal lamella continues to the uncinate process. The second generally originates from the anterior wall of the ethmoid bulla, occasionally including the whole ethmoid bulla with its posterior wall [43]. The third is the largest and most obvious lamella and hangs the middle turbinate [3]. This third basal lamella clearly divides the ethmoid sinus into anterior and posterior portions [3]. The fourth supports the superior turbinate, and the fifth originates at the supreme turbinate [3]. The central portion of the middle turbinate is all hung by the third basal lamella, but the anterior and posterior edges attach to the lateral nasal wall [3].

The three-dimensional positional relationship between the middle meatus and third basal lamella is similar to the relationship between the body of a pigeon and its half-opened wing when its body is regarded as the lamina papyracea [3]. That is to say, the portion of the body close to the half-opened wing is the third basal lamella, and the wing inferiorly hanging from that site is the suspended middle turbinate [3].

Haller cells (Fig. 5.14a) and Onodi cells (Fig. 5.14b) are known as special cells [3]. Haller cells, also called infraorbital cells, extend beneath the orbit and often narrow the ostiomeatal complex [3]. Onodi cells develop from the lateral wall of the ethmoid sinus and are specifically named when the optic canal protuberates into this sinus [3].

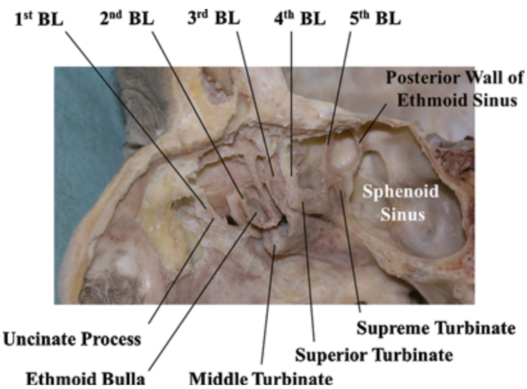

Fig. 5.13 Five basal lamellae of the ethmoid sinus. *BL* basal lamella. (cadaver, 89-year-old male)

Clinical Correlations

(a) Knowledge of the anatomy described herein is vital for the performance of endoscopic sinus surgery and endoscopic orbital surgeries such as orbitotomies or orbital and optic nerve decompression.

(b) Mucoceles and sinusitis in Onodi cells occasionally cause optic neuropathy because the optic nerve often runs close to the small cavities of Onodi cell [44–46]. Imaging studies are vital to detect these lesions, and endoscopic sinus surgery and antibiotic administration are effective treatments [44–46]. When operating in the vicinity of Onodi cells, optic nerve injury must be prevented [3].

Agger Nasi

The agger nasi is a mound situated above the axilla of the middle turbinate (Fig. 5.4). It is a remnant of the first ethmoturbinal region and is a pneumatized portion of the most anterior part of the ethmoid cell (Figs. 5.6b and 5.15a). The ascending portion of the first ethmoturbinal regresses as the agger nasi, and the descending portion remains as the uncinate process [12]. The agger nasi can lie within the lacrimal fossa, between the lacrimal bone and the nasofrontal fossa [2, 42]. It is present in 78–100 % of cases [13, 47]. When the axilla of the middle turbinate is situated lower, the agger nasi is also positioned

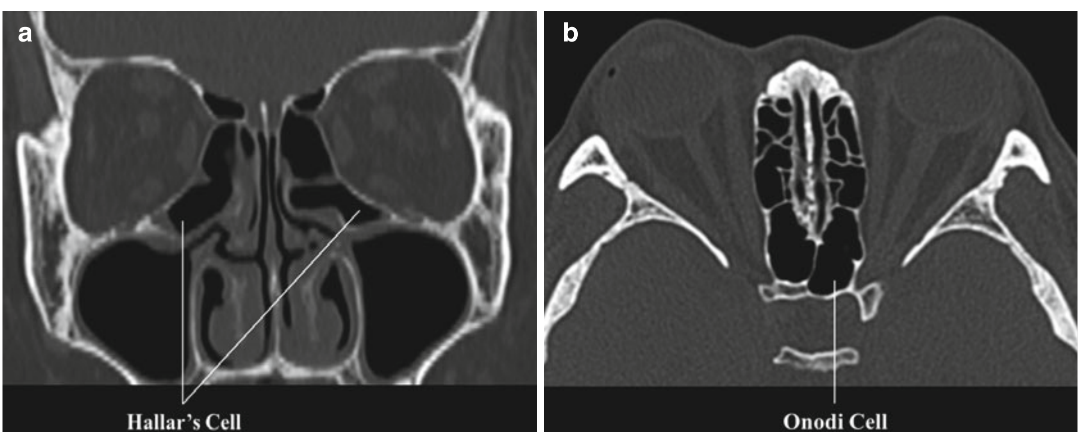

Fig. 5.14 (**a**) Haller cell. (49-year-old male). (**b**) Onodi cell. (52-year-old female)

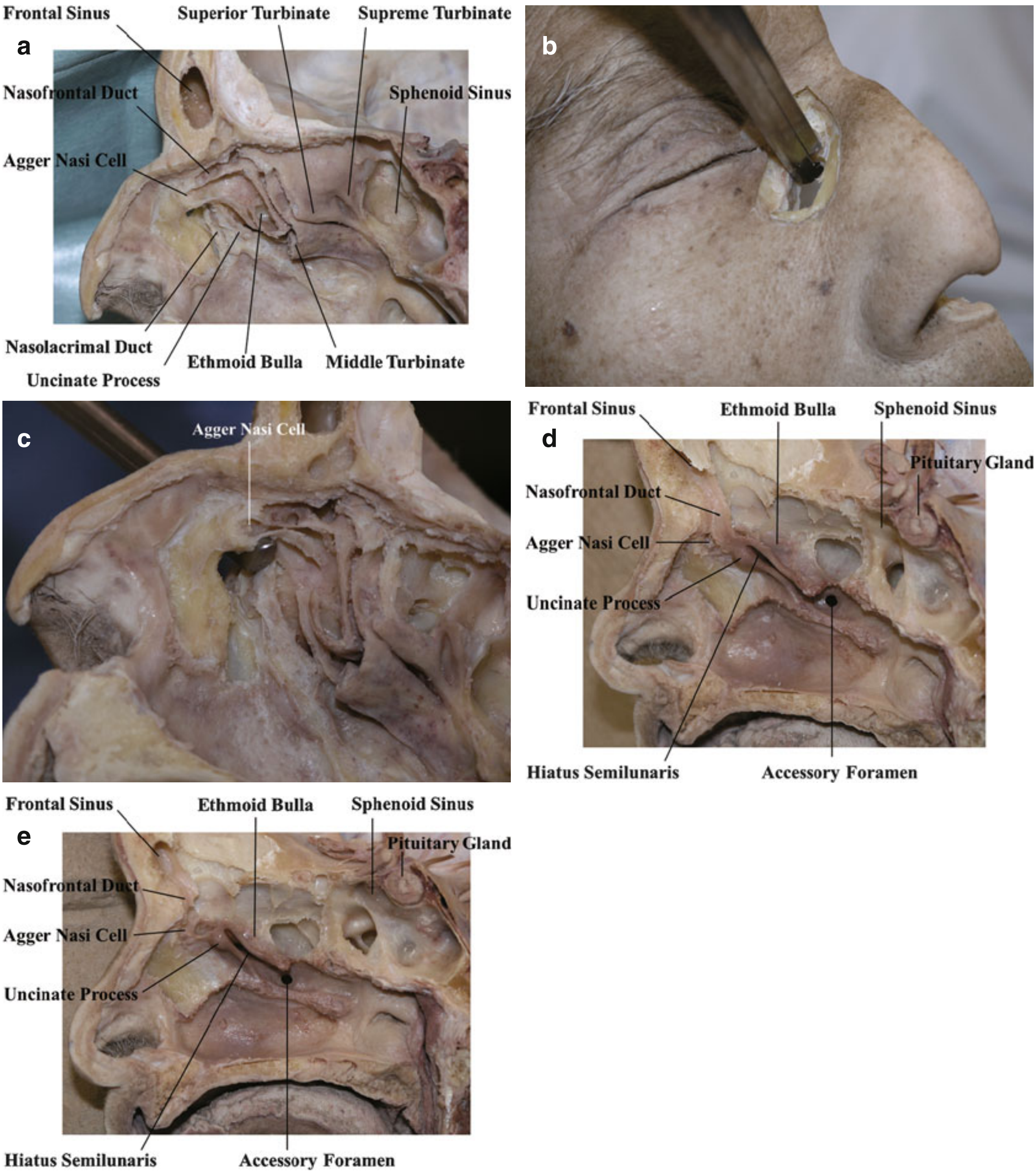

Fig. 5.15 (**a**) Agger nasi cell is a pneumatized part of the most anterior portion of the ethmoid air cell. (cadaver, 89-year-old male). (**b**, **c**) When the axilla of the middle turbinate is located lower than the lacrimal sac fossa, the agger nasi cell must be removed during dacryocystorhinostomy. (cadaver, 89-year-old male). (**d**) The agger nasi cell is situated in front of the nasofrontal duct. Accessory foramen is shown. The inferior and middle turbinates are removed. (cadaver, 97-year-old female). (**e**) Removing the lower part of the nasolacrimal duct, the agger nasi cell is situated is shown behind the nasofrontal duct. The maxillary ostium is shown through the hiatus semilunaris. (cadaver, 97-year-old female)

lower, with tendency to be adjacent to the lacrimal sac fossa [13]. This type is present in one-third to one-half of lacrimal sac fossas [13, 48]. The agger nasi cell is medially, superiorly, and inferiorly bound by the uncinate process [12]. Its anterior wall is the frontal process of the maxilla, and its lateral wall is the lacrimal bone [12]. Posterior pneumatization of the agger nasi cell

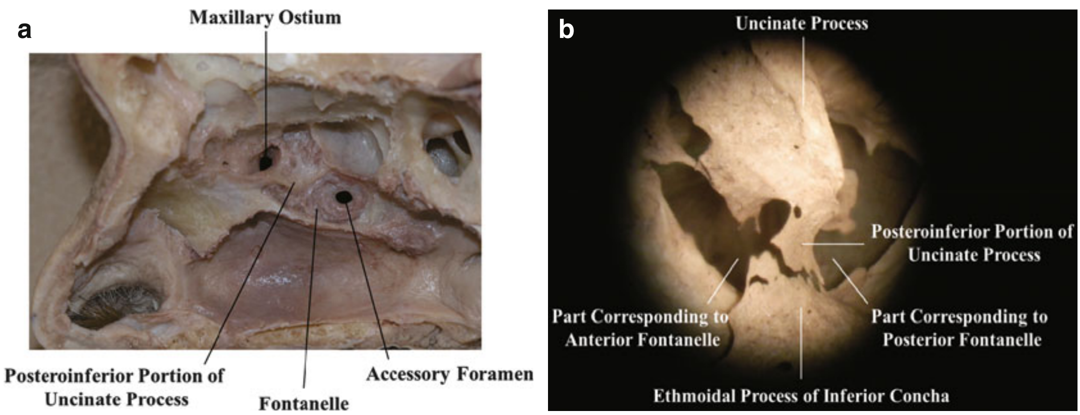

Fig. 5.16 (**a**) The hook part is covered by the fontanelle and located too posteroinferiorly. This figure shows a posteroinferior portion of the uncinate process with upward bending with attachment to only the lower portion of the ethmoid bulla. Accessory foramen opens at the fontanelle. The maxillary ostium is shown in front of the posteroinferior portion of the uncinate process. (97-year-old female). (**b**) The posteroinferior portion of the uncinate process comprises a plate of a cortical bone with no cells. (dry skull of unknown nationality, sex, and age)

pushes the posterosuperior attachment of the uncinate process backward to the lamina papyracea to form the terminal recess [12].

Clinical Correlation

(a) If the axilla of the middle turbinate is located lower than the lacrimal sac fossa, the agger nasi cell must be removed during DCR (Fig. 5.15b, c) [13].
(b) Because there is a close relationship between the agger nasi and the uncinate process, it is important to examine and analyze these structures as one unit.
(c) When confirmation of the frontonasal duct is difficult, removal of the agger nasi helps to detect it (Fig. 5.15d, e) [42]. In addition, the agger nasi cell is a key to understanding the anatomy of the frontal recess [49]. The frontal recess originally indicated a part of the ethmoid cells extending the frontal bone and clinically indicates a part of the anterior ethmoid cells around the frontonasal canal.

Uncinate Process

The uncinate process is a wing-like or boomerang-like structure covering the ethmoid infundibulum in the anterior part of the middle meatus (Fig. 5.10) [2, 42]. “Uncinate” is Latin for “hook” and refers to the shape of a thin leaf of bone lying almost parallel to the lateral nasal wall [2]. The hook part is covered by the fontanelle and located too posteroinferiorly (Fig. 5.16a) to see its shape [50, 51]. It comprises a plate of a cortical bone with no cells (Fig. 5.16b) [42].

The inferior border of the uncinate process is curvilinear and directed anterosuperiorly [48]. An anteriorly attached uncinate process covering at least 50 % of the lacrimal fossa is present in 63 % of individuals [48] and can be expected to totally obstruct the access to the lacrimal sac fossa [13]. Fifty percent of the uncinate process reaches anterior to the frontal process of the maxilla, and 40 % articulates on the lacrimal bone [52–54].

The uncinate process is divided into eight patterns based on the shape or articulation pattern of its posteroinferior portion: [50, 51] articulation only to the inferior concha (42 %); articulation to the inferior concha inferiorly with simultaneous attachment to the lower portion of the bulla ethmoidalis superiorly (24 %); a small or absent anterior fontanelle because of attachment of the lower margin of the posteroinferior portion of the uncinate process to the inferior concha in close proximity (11 %); attachment only to fibrous tissues without any bony attachment to the landmarks of the fontanelle such as the inferior concha, the perpendicular plate of the palatine bone, or the lower portion of the bulla ethmoidalis (10 %); articulation to the perpendicular plate of the palatine bone (5 %); complete ossification over the location of the posterior fontanelle (4 %); upward bending and attachment to only the lower portion of the bulla ethmoidalis (3 %); and simultaneous articulation to the lower portion of the bulla ethmoidalis, perpendicular process of the palatine bone, and inferior concha (1 %).

The superior attachment of the uncinate process is divided into three major variants: attachment to the lamina papyracea laterally, to the skull base centrally, and to the middle turbinate medially [12]. The single superior attachment of the uncinate process to the lamina papyracea shows the highest prevalence (33 %), followed by that to the skull base (10 %) [12]. Other specimens show more than one superior attachment (57 %) either to the lamina papyracea and skull base (31 %) or to the lamina papyracea and middle turbinate (21 %) [12]. Taken together, the uncinate process attaches to the lamina papyracea in 86 % of cases [12]. This rate of 86 % is close to the prevalence of the agger nasi cell (78–100 %) [12]. The two close rates indicate that most of the upper part of the uncinate process extends backward and laterally to further connect the agger nasi cell with the terminal recess [12]. The cells between the uncinate process and the lamina papyracea in the posterosuperior portion comprise the "terminal recess." [3, 12]

The site of attachment of the uncinate process determines the frontal sinus drainage pathway [42]. When the uncinate process attaches to the lamina papyracea inferolateral to the frontonasal fossa, the frontonasal duct drains into the nasal cavity, and when the uncinate process attaches to the roof of the ethmoid bone or middle turbinate medial to the nasofrontal fossa, the nasofrontal duct drains into the ethmoid infundibulum [42]. The frontal sinus empties via the nasofrontal duct into the nasal cavity in 86 % of cases and into the ethmoid infundibulum in 14 % [12, 42]. Because the nasofrontal duct threads the ethmoid cells, it is not actually a simple duct, but an irregular passway [3].

Fontanelle

The fontanelle, the membranous part of the maxillary sinus, must be described in relation to the uncinate process (Figs. 5.10 and 5.16a) [42]. The boundaries of the fontanelle were recently well described [50]. The anterior boundary is the lacrimal bone, and the posterior boundary is the perpendicular plate of the palatine bone [50]. The superior boundary comprises the orbital floor in the anterior one-fifth, the lower horizontal portion of the bulla ethmoidalis in the middle section, and the horizontal portion of the basal lamella of the middle turbinate in the last one-fifth [50]. Therefore, the superior margin of the fontanelle corresponds to the inferior margin of the orbital floor [42]. The inferior boundary is the superior border of the inferior turbinate [50]. In most cases, the posteroinferior portion of the uncinate process crosses the anterior portion of the fontanelle and is attached to the ethmoid process of the inferior concha [50]. The fontanelle is usually divided into anteroinferior and posterosuperior parts by the posteroinferior portion of the uncinate process (Fig. 5.10) [3, 50, 51].

The fontanelle shows three major shapes when observed from the medial to lateral aspects: triangular, pencil-like, and oval [50]. In the triangular type, the posterior height is higher than the anterior height, whereas the anterior and posterior heights of the pencil-like type are almost identical [50]. The pencil-like type has an anterior end that is similar in shape to the blunt tip of a pencil [50]. In the oval type, the midportion of the fontanelle is the highest, with less anterior and posterior height. [50] The triangular type is the most common (57.3 %), followed by the pencil-like type (25 %) and oval type (20 %) [51]. In one study, the anteroposterior length of the whole fontanelle was 18.1 ± 3.8 mm (mean ± SD), and the greatest height of the whole fontanelle was 9.2 ± 2.2 mm [50].

Clinical Correlation

It is important to know the anatomical landmarks of the fontanelle, since this is utilized as a landmark in sphenopalatine artery (SPA) ligation. The SPA ligation is one of the last resorts in the management of recalcitrant epistaxis and this is an important tool in the armamentarium of any nasal endoscopic surgeon.

Ethmoid Bulla

The ethmoid bulla is a thin-walled bony prominence representing the largest and most consistent air cell of the anterior ethmoid complex, like a bleb on the lamina papyracea (Figs. 5.10 and 5.17a) [2]. The orifice of this cell is located at a cavity in the back side facing the third basal lamella [3] called the lateral recess or retrobulbar recess (Fig. 5.17b, c) [3, 55]. When no air cell exists in the ethmoid bulla, it is termed the torus ethmoidalis or torus lateralis [3]. The part forming a dome in the roof of the anterior ethmoid cells is called the fovea ethmoidalis and is part of the skull base formed by the frontal bone [3].

The ethmoid bulla is classified into three types based on its development [56]. The simple bulla is a single cavity with one opening, generally to the hiatus semilunaris [56]. The compound bulla has two or three separate compartments that communicate with the hiatus semilunaris [56]. The complex bulla also has two or three compartments, each of which communicates with the hiatus

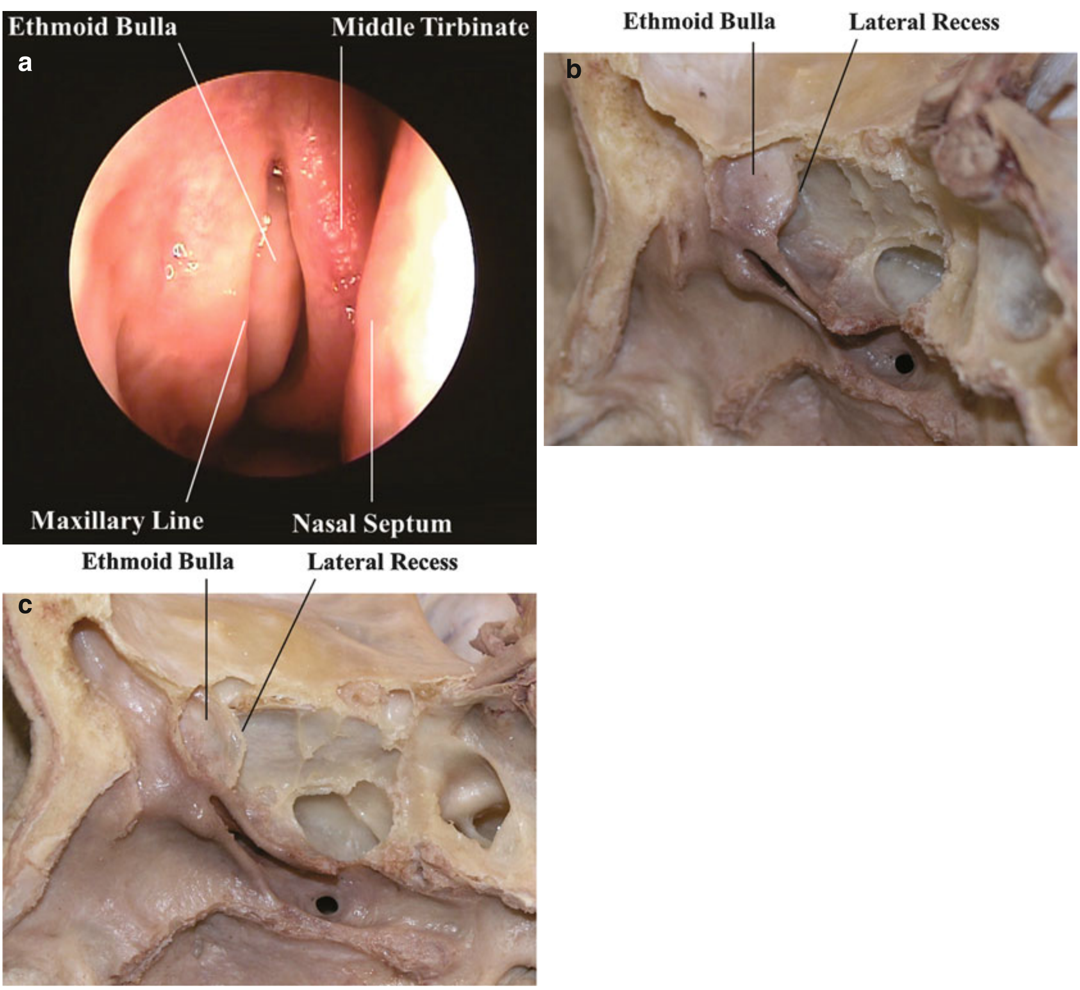

Fig. 5.17 (**a**) Ethmoid bulla occasionally bulges anteriorly (67-year-old female). (**b**) The lateral recess of the ethmoid bull is a cavity in the posterolateral side facing the third basal lamella. (cadaver, 97-year-old female). (**c**) The lateral recess of the ethmoid bulla. The medial aspect of the ethmoid bulla is removed. (cadaver, 97-year-old female)

semilunaris, ethmoid infundibulum, or superior meatus [56]. In individuals with compound and complex bullae, there is no communication between the compartments [56]. About 50, 25, and 25 % of ethmoid bullae are simple, compound, and complex bullae, respectively [56].

Hiatus Semilunaris

The superior posterior free margin borders of the uncinate process create the hiatus semilunaris with the ethmoid bulla (Figs. 5.10 and 5.15d, e), which is an important crescent-shaped cleft leading to the infundibulum and into which the frontal, anterior ethmoid, and maxillary sinuses drain [2]. In general, the cleft situated anteroinferior to the ethmoid bulla is known as the hiatus semilunaris. This is typically 1–2 mm wide, but can be up to 3 mm wide [57]. The posterosuperior cleft to the ethmoid bulla is occasionally called the hiatus semilunaris superior [3]. In this situation, the general hiatus semilunaris is called the hiatus semilunaris inferior [3]. The hiatus semilunaris superior is continuous with the lateral recess of the ethmoid bulla and third basal lamella (Fig. 5.17b, c) [3, 58]. Including the ethmoid infundibulum, the hiatus semilunaris is not a term describing a structure or a tissue, but a space encircled by tissues [3].

Ethmoid Infundibulum

The ethmoid infundibulum is a funnel-shaped space bordered medially by the hiatus semilunaris and laterally by the lamina papyracea (Figs. 5.1a, 5.9, and 5.14a) [2]. The maxillary sinus ostium is found at the floor and lateral aspect of the infundibulum, where is usually hidden by the uncinate process and cannot be observed by nasal endoscopy (Figs. 5.15d, e and 5.16a) [2, 42]. The ostium of the maxillary sinus lies in an approximate vertical line to the anterior ethmoid foramen [10]. In most specimens, the position of the maxillary ostium is situated on the second and half quarter of the anterior surface of the ethmoid bulla [59] with a 7- to 11-mm length and 2- to 6-mm width [60]. The average distance from the maxillary ostium to the nasolacrimal canal is 5.5 mm [59]. Ten to fifty percent of specimens show more than one accessory ostium opening at the anterior, posterior, or both fontanelles (Figs. 5.1a, 5.15d, e, and 5.16a) [3, 59, 61]. These accessory ostia can be observed by nasal endoscopy [3].

The anterior and posterior ethmoid air cells show several openings, respectively [3]. The ethmoid infundibular area is important pathophysiologically because it forms part of the ostiomeatal complex [2].

Clinical Correlations

(a) Silent sinus syndrome, also called imploding antrum syndrome [62], is a rare disorder characterized by unilateral or bilateral enophthalmos and hypoglobus caused by an alteration of the orbital architecture due to maxillary sinus collapse with chronic hypoventilation [62–64]. Its basic pathology involves negative maxillary antral pressure because of obstruction of the ethmoid infundibulum, which generates negative pressure over time [65]. This entity is idiopathic, occurs postoperatively following bony decompression for Graves' orbitopathy [66], or develops after facial trauma, especially orbital floor fracture [65]. The conditions after surgery and radiotherapy for sinonasal malignancy are excluded [64, 67]. Frontal silent sinus syndrome was recently reported as well [68].

(b) Bone exposure after mucosal resection induces granulation [3]. In medial orbital wall decompression, mucosal removal [69] may not cause granulation because the escaped orbital contents occupy the space. However, after surgery for smooth ventilation against sinusitis, mucosal removal may increase granulation to an extent that negates the surgical purpose [3]. In this kind of surgery, the intact mucosa must therefore be preserved as much as possible [3].

Ostiomeatal Complex

The ostiomeatal complex is also called the ostiomeatal unit [3]. This complex is considered to be a unified apparatus comprising the anterior ethmoid sinus openings and their passages [3]. It is a functional and conceptual unit containing the openings and passages of the frontal, anterior ethmoid, and maxillary sinuses [3]. Therefore, the ostiomeatal complex is not an anatomical term [3], but corresponds to the middle meatus, anterior ethmoid sinus, and orifices of each paranasal sinus emptying around them. Specifically, the ostiomeatal complex contains the agger nasi cells, frontal sinus orifice, nasofrontal duct, natural ostium of the maxillary sinus, ethmoid infundibulum, hiatus semilunaris, and middle meatus [3].

Ventilation and drainage of the frontal, ethmoid, and maxillary sinuses largely depend on the state of the ostiomeatal complex [3]. Functional deficiency of the ostiomeatal complex is mainly caused by anatomical disorders, obstructive lesions, and functional changes [3]. Anatomical disorders involve the concha bullosa, paradoxical middle nasal turbinate, paradoxical uncinate process, septal deviation, and distention of agger nasi cells and Haller cells [3]. Cilial disorders are enumerated as functional disorders [3]. These disorders do not always result in disorders of the ostiomeatal complex [3]

Anatomy of the Sphenoid Sinuses

The sphenoid sinuses are located at the most posterior part of all the paranasal sinuses (Figs. 5.1a, 5.3, 5.4, and 5.11) [42] and within the body of the sphenoid bone. They vary greatly in size and shape [1, 34]. The length from the nostril to the anterior wall of the sinus is about 7 cm [42]. They are commonly deep in their anteroposterior dimensions [1, 34]. Laterally, they may extend into various parts of the sphenoid bone, including the greater and lesser wings, pterygoid processes, and lateral pterygoid plates [1, 34]. The midline septum usually divides the two sinuses unequally (Fig. 5.11) [1, 34].

The sphenoid ostia are located superiorly and medially on the anterior wall and drain into the sphenoethmoidal recess [1, 34], the highest point of which is about the center between the choanae and the roof of the nasal cavity [42]. From an endoscopic viewpoint, the sphenoid ostium is located, in most cases, medial to the posterior part of the superior turbinate [40, 70, 71]. The lateral one-half to two-thirds of the anterior wall of the sphenoid sinus abuts against the posterior ethmoid air cells and is called the pars ethmoidalis [1, 34, 35]. The medial one-third to one-half faces the posterosuperior nasal cavity between the superior turbinate and the nasal septum and is called the pars nasalis [42].

The sphenoid sinuses have several important relationships with surrounding structures (Figs. 5.1a, 5.3, 5.4, and 5.15a) [1, 34]. The brain stem (pons, basilar artery) lies posterior to the ethmoid sinus (Figs. 5.3 and 5.4) [1, 34]. The optic chiasm and pituitary gland lie superior to the sinus, and the pituitary gland commonly bulges into the superior wall (Figs. 5.3, 5.4 and 5.15d, e) [1, 34]. The optic nerves, carotid artery, and cavernous sinus are important lateral relationships (Figs. 5.1a and 5.12a) [1, 34]. The nasopharynx is inferior to the sphenoid sinus (Figs. 5.3 and 5.4) [1, 34].

Clinical Tips

(a) When the sphenoid sinus is pneumatized to a large extent, only a thin wall of bone and mucoperiosteum separate it from the surrounding tissue [34]. In such a situation, serious cases of sphenoid sinusitis may compromise the optic nerve [34].
(b) Invasive fungal sphenoiditis is an ophthalmic emergency. Fungal elements penetrate the sinus mucosa, submucosa, blood vessels, or bone in invasive sphenoiditis [72], often causing an orbital apex syndrome and further extending to the meninges, cavernous sinus, and cavernous carotid artery [73]. Early treatment including aggressive surgical debridement and antimycotic drugs is essential to preserve vision and life [73].
(c) An injury to the head, especially to the brow, may result in an optic canal fracture [74, 75]. Causes of vision loss include bone fracture or tissue swelling within the optic canal that compresses the optic nerve or a bone fragment penetrating into the optic nerve [76]. Optic nerve decompression via the sphenoid sinus may result in vision improvement in

patients with light perception [76]. On the other hand, this procedure may not be indicated for patients with no light perception who have a lateral wall fracture of the optic canal or a bone fragment penetrating the optic nerve [76].

Conclusion

The sinonasal anatomy was illustrated in detail with the use of cadaver specimens, CT, and nasal endoscopic figures. Although each lacrimal or orbital surgery requires different portions of the knowledge presented in this chapter, we believe that these surgeries can be performed safely and with confidence endoscopically by understanding each surgical field as a part of the whole.

References

1. Witterick IJ, Hurwitz JJ. Anatomy of the nose and sinuses. In: Hurwits JJ, editor. The lacrimal system'. Philadelphia: Lippincott-Raven; 1996. p. 31–7.
2. Olver J. Colour atlas of lacrimal surgery. Oxford: Butterworth & Heinemann; 2002. p. 14–8.
3. Ohnishi T, Ozawa M, Kasahara Y, et al. Endoscopic sinus surgery. Tokyo Med View. 1995; 32–104. (Japanese)
4. Mirante JP. Nasal anatomy and evaluation. In: Cohen AJ, Mercandetti M, Brazzo BJ, editors. The lacrimal system: diagnosis, management, and surgery. New York: Springer; 2006. p. 25–32.
5. Leong SC, Eccles R. A systematic review of the nasal index and the significance of the shape and size of the nose in rhinology. Clin Otolaryngol. 2009;34:191–8.
6. Elad D, Wolf M, Keck T. Air-conditioning in the human nasal cavity. Respir Physiol Neurobiol. 2008;163:121–7.
7. Wolf M, Naftali S, Schroter RC. Air-conditioning characteristics of the human nose. J Laryngol Otol. 2004;118:87–92.
8. Cottle MH. The structure and function of the nasal vestibule. In: Maurice H, Cottle MD, Barelli PA, editors. Rhinology. Philadelphia: American Rhinologic Society; 1987. p. 74–86.
9. Burkat CN, Lucareli MJ. Anatomy of the lacrimal system. In: Cohen AJ, Mercandetti M, Brazzo BJ, editors. The lacrimal system: diagnosis, management, and surgery. New York: Springer; 2006. p. 3–19.
10. Haruna S. Clinical anatomy for endoscopic endonasal surgery. In: Kishimoto S, editor. Practical otolaryngology: clinical anatomy for otolaryngology, and head & neck surgery. Tokyo: Bunkodo Publishers; 2002. p. 120–5. (Japanese).
11. Chastain JB, Cooper MH, Sindwani R. The maxillary line: anatomic characterization and clinical utility of an important surgical landmark. Laryngoscope. 2005;115:990–2.
12. Zhang L, Han D, Ge W, et al. Anatomical and computed tomographic analysis of the interaction between the uncinate process and the agger nasi cell. Acta Otolaryngol. 2006;126:845–52.
13. Woo KI, Maeng HS, Kim YD. Characteristics of intranasal structures for endonasal dacryocystorhinostomy in Asians. Am J Ophthalmol. 2011;152:491–8.
14. Yung MW, Logan BM. The anatomy of the lacrimal bone at the lateral wall of the nose: its significance to the lacrimal surgeon. Clin Otolaryngol Allied Sci. 1999;24:262–5.
15. Hartikainen J, Aho HJ, Seppa H, Grenman R. Lacrimal bone thickness at the lacrimal sac fossa. Ophthalmic Surg Lasers. 1996;27:679–84.
16. Duke-Elder S. The development, form and function of the visual apparatus. In: Elder S, editor. Textbook of ophthalmology, vol. 1. London: Henry Kimpton Publisher; 1932. p. 235–9.
17. Lee H, Ha S, Lee Y, et al. Anatomical and morphometric study of the bony nasolacrimal canal using computed tomography. Ophthalmologica. 2012;227:153–9.
18. Takahashi Y, Kakizaki H, Nakano T. Bony nasolacrimal duct entrance diameter: gender difference in cadaveric study. Ophthal Plast Reconstr Surg. 2011;27:204–5.
19. Janssen AG, Mansour K, Bos JJ, et al. Diameter of the bony lacrimal canal: normal values and values related to nasolacrimal duct obstruction: assessment with CT. AJNR Am J Neuroradiol. 2001;22:845–50.
20. Shigeta K, Takegoshi H, Kikuchi S. Sex and age differences in the bony nasolacrimal canal: an anatomical study. Arch Ophthalmol. 2007;125:1677–81.
21. Park J, Takahashi Y, Nakano T, et al. The orientation of the lacrimal fossa to the bony nasolacrimal canal: an anatomical study. Ophthal Plast Reconstr Surg. 2012;28:463–6.
22. Takahashi Y, Nakamura Y, Nakano T, et al. Horizontal orientation of the bony lacrimal passage: an anatomical study. Ophthal Plast Reconstr Surg. 2013;29:128–30.
23. Narioka J, Matsuda S, Ohashi Y. Correlation between anthropometric facial features and characteristics of nasolacrimal drainage system in connection to false passage. Clin Experiment Ophthalmol. 2007;35:651–6.
24. Ohnogi J. Endoscopic observation of inferior aperture of the nasolacrimal duct. Jpn J Clin Ophthalmol. 2001;55:650–4. (Japanese).
25. Fayet B, Racy E, Assouline M. Systematic unciformectomy for a standardized endonasal dacryocystorhinostomy. Ophthalmology. 2002;109:530–6.
26. Wormald PJ. Powered endoscopic dacryocystorhinostomy. Otolaryngol Clin North Am. 2006;39:539–49.
27. Tsirbas A, Davis G, Wormald PJ. Mechanical endonasal dacryocystorhinostomy versus external dacryocystorhinostomy. Ophthal Plast Reconstr Surg. 2004;20:50–6.
28. Steadman MG. Transnasal dacryocystorhinostomy. Otolaryngol Clin North Am. 1985;18:107–11.
29. McDonogh M, Meiring JH. Endoscopic transnasal dacryocystorhinostomy. J Laryngol Otol. 1989;103:585–7.

30. Whittet HB, Shun-Shin GA, Awdry P. Functional endoscopic transnasal dacryocystorhinostomy. Eye. 1993;7:545–9.
31. Pearlman SJ, Michalos P, Leib ML, et al. Translacrimal transnasal laser-assisted dacryocystorhinostomy. Laryngoscope. 1997;107:1362–5.
32. Wormald PJ, Kew J, Van Hasselt A. Intranasal anatomy of the nasolacrimal sac in endoscopic dacryocystorhinostomy. Otolaryngol Head Neck Surg. 2000;123:307–10.
33. Fayet B, Racy E, Assouline M, et al. Surgical anatomy of the lacrimal fossa a prospective computed tomography densitometry scans analysis. Ophthalmology. 2005;112:1119–28.
34. Rose Jr JG, Lucarelli MJ, Lemke BN. Lacrimal, orbital and sinus anatomy. In: Woog JJ, editor. Manual of endoscopic lacrimal and orbital surgery. Philadelphia: Butterworth & Heinemann; 2004. p. 1–16.
35. Henson RD, Cruz HL, Henson Jr RG, et al. Postoperative application of mitomycin-C in endocanalicular laser dacryocystorhinostomy. Ophthal Plast Reconstr Surg. 2012;28:192–5.
36. Callejas CA, Tewfik MA, Wormald PJ. Powered endoscopic dacryocystorhinostomy with selective stenting. Laryngoscope. 2010;120:1449–52.
37. Hatipoğlu HG, Çetin MA, Yüksel E. Concha bullosa types: their relationship with sinusitis, ostiomeatal and frontal recess disease. Diagn Interv Radiol. 2005;11:145–9.
38. Bolger WE, Butzin CA, Parsons DS. Paranasal sinus bony anatomic variations and mucosal abnormalities: CT analysis for endoscopic sinus surgery. Laryngoscope. 1991;101:56–64.
39. Orlandi RR, Lanza DC, Bolger WE, et al. The forgotten turbinate: the role of the superior turbinate in endoscopic sinus surgery. Am J Rhinol. 1999;13:251–9.
40. Eweiss AZ, Ibrahim AA, Khalil HS. The safe gate to the posterior paranasal sinuses: reassessing the role of the superior turbinate. Eur Arch Otorhinolaryngol. 2012;269:1451–6.
41. Lane AP, Gomez G, Dankulich T, et al. The superior turbinate as a source of functional human olfactory receptor neurons. Laryngoscope. 2002;112:1183–9.
42. Ikeda K. Clinical anatomy for endoscopic sinus surgery. In: Kishimoto S, editor. Practical otolaryngology 8: clinical anatomy for otolaryngology, and head & neck surgery. Tokyo: Bunkodo Publishers; 2002. p. 126–31. (Japanese).
43. Wormald PJ. Three-dimensional reconstruction and surgery of the bulla ethmoidalis, middle turbinate, posterior ethmoid and sphenoid. In: Wormald PJ, editor. Endoscopic sinus surgery: anatomy, three-dimensional reconstruction, and surgical technique. 3rd ed. New York: Thieme; 2013. p. 103–16.
44. Chee E, Looi A. Onodi sinusitis presenting with orbital apex syndrome. Orbit. 2009;28:422–4.
45. Kitagawa K, Hayasaka S, Shimizu K, Nagaki Y. Optic neuropathy produced by a compressed mucocele in an Onodi cell. Am J Ophthalmol. 2003;135:253–4.
46. Klink T, Pahnke J, Hoppe F, Lieb W. Acute visual loss by an Onodi cell. Br J Ophthalmol. 2000;84:801–2.
47. Ercan I, Cakir BO, Sayin I, et al. Relationship between the superior attachment type of uncinate process and presence of agger nasi cell: a computer-assisted anatomic study. Otolaryngol Head Neck Surg. 2006;134:1010–4.
48. Soyka MB, Treumann T, Schlegel CT. The Agger Nasi cell and uncinate process, the keys to proper access to the nasolacrimal drainage system. Rhinology. 2010;48:364–7.
49. Wormald PJ. The agger nasi cell: the key to understanding the anatomy of the frontal recess. Otolaryngol Head Neck Surg. 2003;129:497–507.
50. Yoon JH, Kim KS, Jung DH, et al. Fontanelle and uncinate process in the lateral wall of the human nasal cavity. Laryngoscope. 2000;110:281–5.
51. Isobe M, Murakami G, Kataura A. Variations of the uncinate process of the lateral nasal wall with clinical implications. Clin Anat. 1998;11:295–303.
52. Whitnall SE. The relations of the lacrimal fossa to the ethmoid cells. Ophthalmic Rev. 1911;30:321–5.
53. Blaylock WK, Moor CA, Linberg JV. Anterior ethmoid anatomy facilitates dacryocystorhinostomy. Arch Ophthalmol. 1990;108:1774–7.
54. Tsirbus A. Lacrimal fossa anatomy. Ophthalmology. 2006;113:1475–6.
55. Simmen D, Jones N. Manual of endoscopic sinus surgery and its extended application. Stuttgart/New York: Thieme; 2005. p. 66.
56. Setliff RC, Catalano PJ, Catalano LA, et al. An anatomic classification of the ethmoidal bulla. Otolaryngol Head Neck Surg. 2001;125:598–602.
57. Yanagisawa E, Weaver EM. Endoscopic view of the hiatus semilunaris superior and inferior. Ear Nose Throat J. 1996;75:460–2.
58. Iinuma T. History of infundibulum. Jibiinkoukatembo. 2001;44:168–73. (Japanese).
59. Unlü HH, Gövsa F, Mutlu C, et al. Anatomical guidelines for intranasal surgery of the lacrimal drainage system. Rhinology. 1997;35:11–5.
60. Rice DH. Management of the middle turbinate in endoscopic surgery. Op Tech Otolaryngol Head Neck Surg. 1995;6:144–8.
61. Prasanna LC, Mamatha H. The location of maxillary sinus ostium and its clinical application. Indian J Otolaryngol Head Neck Surg. 2010;62:335–7.
62. Gaudino S, Di Lella GM, Piludu F, et al. CT and MRI diagnosis of silent sinus syndrome. Radiol Med. 2013;118:265–75.
63. Soparker CNS, Patrinely JR, Cuaycong MJ, et al. The silent sinus syndrome: a cause of spontaneous enophthalmos. Ophthalmology. 1994;101:772–8.
64. Ferri A, Ferri T, Sesenna E. Bilateral silent sinus syndrome: case report and surgical solution. J Oral Maxillofac Surg. 2012;70:e103–6.
65. Cobb AR, Murthy R, Cousin GC, et al. Silent sinus syndrome. Br J Oral Maxillofac Surg. 2012;50:e81–5.
66. Rose GE, Lund VJ. Clinical features and treatment of late enophthalmos after orbital decompression: a

condition suggesting cause for idiopathic "imploding antrum" (silent sinus) syndrome. Ophthalmology. 2003;110:819–26.
67. Brandt MG, Wright ED. The silent sinus syndrome is a form of chronic maxillary atelectasis: a systemic review of all reported cases. Am J Rhinol. 2008;22:68–73.
68. Naik RM, Khemani S, Saleh HA. Frontal silent sinus syndrome. Otolaryngol Head Neck Surg. 2013;148:354–5.
69. Leone Jr CR, Piest KL, Newman RJ. Medial and lateral wall decompression for thyroid ophthalmopathy. Am J Ophthalmol. 1989;108:160–6.
70. Gupta T, Aggarwal A, Sahni D. Anatomical landmarks for locating the sphenoid ostium during endoscopic endonasal approach: a cadaveric study. Surg Radiol Anat. 2013;35:137–42.
71. Millar DA, Orlandi RR. The sphenoid sinus natural ostium is consistently medial to the superior turbinate. Am J Rhinol. 2006;20:180–1.
72. Deshazo RD. Syndromes of invasive fungal sinusitis. Med Mycol. 2009;47:S309–14.
73. Thurtell MJ, Chiu ALS, Goold LA, et al. Neuro-ophthalmology of invasive fungal sinusitis: 14 consecutive patients and a review of the literature. Clin Experiment Ophthalmol. 2013;41:567–76.
74. Duke-Elder S, MacFaul PA. Indirect orbital fractures associated with head injury. In: Duke-Elder S, editor. System of ophthalmology, Injury. Part 1. Mechanical injuries, vol. XIV. London: Henry Kimpton Publisher; 1972. p. 265–8.
75. Guyon JJ, Brant-Zawadzki M, Seiff SR. CT demonstration of optic canal fractures. AJR Am J Roentgenol. 1984;143:1031–4.
76. Yang QT, Zhang GH, Liu X, et al. The therapeutic efficacy of endoscopic optic nerve decompression and its effects on the prognosis of 96 cases of traumatic optic neuropathy. J Trauma. 2012;72:1350–5.