Scientific contribution

The Ethmoid Labyrinth, Point of Entry to Diseases of the Nasal Cavity, Paranasal Sinuses, the Orbit and Skull Base

Bogataj Jan[1*], Tancer Ivana

[1] University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia
*Correspondence: Bogataj Jan, bogataj.jan@gmail.com

Abstract:

Endoscopic endonasal surgery developed as a logical consequence of more sophisticated knowledge of the pathophysiology of the paranasal sinuses. Also endoscopic treatment of various diseases of the nasal cavity and paranasal sinuses proved to be as effective as classical methods. Ethmoidal bone is a basic anatomic area, where pathologic activities are formed or the natural extension for a minimally invasive approach from the natural nasal opening to the brain, so the knowledge of its anatomy and development is of the paramount significance. Ethmoid labyrinth starts to develop in the third week of gestation from the pharyngeal apparatus, and reach its full size only at age 12. From a surgical point of view, the most interesting are the medial turbinates, the roof of the nasal cavity, the uncinate process and the bulla ethmoidalis. Through the transethmoidal approach we can access all the cells in the ethmoid sinuses, the frontal sinus, the anterior skull base, the orbital walls and its contents. The awareness that there might be anatomical variations also carries great importance. The central location of the ethmoid bone is actually an intersection inside the nasal cavity and the basic component for understanding the anatomical relationships and the physiology of the paranasal sinuses.

Keywords: ethmoid labyrinth, embryology, anatomy, endoscopic endonasal surgery

Citation: Bogataj J, Tancer I. The ethmoid labyrinth, point of entry to diseases of the nasal cavity, paranasal sinuses, the orbit and skull base. Proceedings of Socratic Lectures. **2024**, 9, 1-7. https://doi.org/10.55295/PSL.2024.D1

Publisher's Note: UL ZF stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

The surgery of the nasal cavities experienced an unexpected development in the late 1970s when Messerklinger and Wigand changed the understanding of the anatomical characteristics, pathophysiology, and treatment of nasal cavity diseases. Over time, the name functional endoscopic sinus surgery (FESS) was established for the then new surgical approach to the disease, now known as chronic rhinosinusitis with nasal polyposis (CRSwNP) and chronic rhinosinusitis without nasal polyposis (CRSsNP) (Messerklinger,1978; Wigand, 1981; Wigand et al., 1978). The use of an endoscope allowed for a natural nasal opening to be used for access (Stammberger ,1986). The perspective and understanding of the surgical anatomy of the nasal cavity became completely different compared to external approaches. The key to understanding the complex anatomical relationships of the space between the middle turbinate and the posterior wall of the ethmoid sinus, the roof of the nasal cavity, and the roof of the sphenoid sinus is understanding the development and anatomy of the ethmoid sinus.

2. Embryology of the ethmoid sinus

The development of the head and neck, face, nose, and paranasal sinuses occurs simultaneously in a short period of time. By the end of the fourth embryonic week, the branchial arches, pouches, and clefts appear. In the fifth week, five protuberances form on the embryo from the mesenchyme. One of these is the frontonasal prominence, around which the nasal placodes develop. The deepening of the nasal placodes forms the nasal cavity. Between the seventh and ninth weeks of embryonic development, several bony protuberances of ectodermal origin develop on the lateral nasal wall, specifically from cells of the neural crest (Petrovič, 2002). Six bony ridges form and reduce or fuse until there are 3 to 5 of them. Each ridge has an anterior ascending and a posterior descending part. The ascending and descending parts of the first ridge will form the agger nasi cells and the uncinate process. The second and third ridges give rise to the middle and superior nasal turbinates. While the bony outgrowths form the bony structures, the spaces between them, called grooves, form the hollow spaces and openings of the sinus drainage pathways. Grooves can be divided into primary and secondary. The primary grooves give rise to the semilunar space, infundibulum, middle meatus (opening below the middle turbinate), and frontal sinus opening. The second primary groove gives rise to the superior meatus (opening below the superior turbinate). Secondary grooves form the ethmoid air cells (Petrovič, 2002; Suh, 2009). Sinuses begin to develop in the third month of embryonic development, and at birth, only the maxillary and ethmoid sinuses are present. A newborn has the same number of ethmoid air cells as an adult, but they are smaller. The ethmoid sinus reaches its final shape at 12 years of age (Elwany et al.,2013).

3. Anatomy of the ethmoid sinus

The ethmoid sinus is located between the forehead anteriorly and the sphenoid sinus posteriorly. It comprises a large part of the nasal cavity and forms the inner wall of the orbit. Its basic structure consists of four interconnected plates. The largest plate is the vertical perpendicular plate (lamina perpendicularis), which constitutes part of the bony nasal septum. On top of this plate lies the horizontally positioned cribriform plate, which forms the nasal vault and a portion of the skull base. Vertically downward from each side of the cribriform plate hang the ethmoidal labyrinth, which consists of numerous cells surrounded by thin bony walls. These cells are separated from the orbit by an extremely thin bony plate that also forms part of the orbit, known as the orbital lamina (lamina papyracea). The medial side of the labyrinth forms the upper part of the lateral nasal wall. Protruding from it are the superior and middle nasal conchae, which are curved bony structures extending downward and laterally (see **Figure 1**). The ethmoid sinus cells are divided into the anterior and posterior ethmoid sinuses by the attachment of the middle nasal concha. The superior meatus, where the posterior ethmoid cells open, is located below the superior nasal concha. The middle meatus is located below the middle nasal concha and receives openings from the anterior ethmoid cells, the maxillary sinus, and the frontal sinus (Casiano, 1997; Duncavage and Becker, 2011; Kobe et al.,2007).

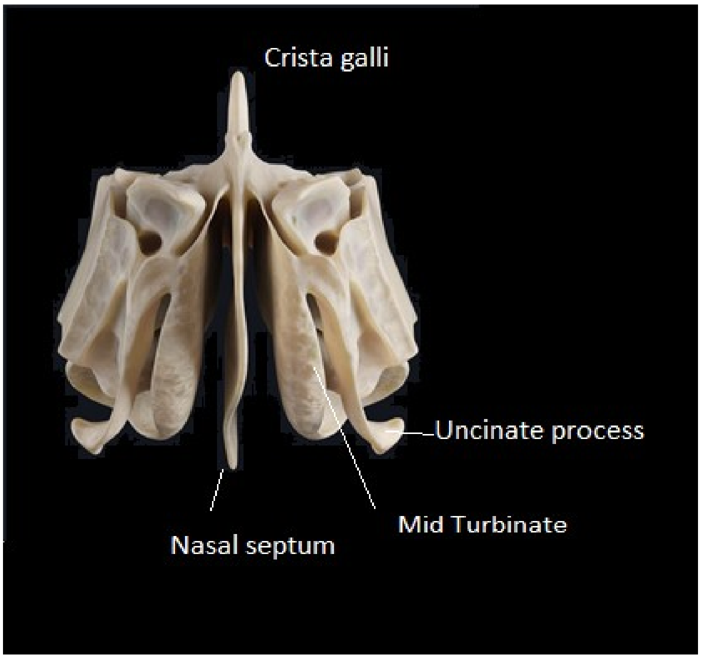

Figure 1. View of the ethmoid bone from the front. Nasal septum, middle nasal conchae, uncinate process, and cells of the ethmoid labyrinth are visible (From: https://3d4medical.com/blog/ethmoid-bone. Sneak peek from our Head & Neck update: The ethmoid bone. Complete Anatomy. 2020).

The largest of the ethmoid cells is the ethmoid bulla, which belongs to the anterior cells. Between the bulla and the middle nasal concha, there is a narrow, thin, backward and downward curved bony ridge called the uncinate process, which surrounds the semilunar hiatus. Within the hiatus, lateral and inferior to the bulla, is the entrance to the maxillary sinus. The posterior wall of the ethmoid bulla serves as a passage, through the basal lamella, into the posterior ethmoid sinus. Within it, we first find the ethmoid crest, followed by the entrance to the sphenopalatine foramen (through which the sphenopalatine artery passes). Just before the anterior wall of the bulla, there is a natural drainage pathway of the frontal sinus (frontal recess), which is surrounded by agger nasi cells on the anterior or anterolateral wall. The orbital lamina forms the bony boundary between the nasal cavity and the contents of the orbit, which are further separated by the dense connective tissue of the periorbita. Laterally to the periorbita, at the level of the anterior part of the ethmoid sinus, there is adipose tissue, followed by the medial rectus muscle of the eye. Posteriorly, there is progressively less orbital fat, and the muscle is closer to the periorbita. Two important arteries, both branches of the ophthalmic artery, traverse the ethmoid complex: the anterior and posterior ethmoidal arteries. The anterior ethmoidal artery typically courses within the roof of the ethmoid sinus. However, if there is a cell that extends above the roof of the orbit (supraorbital cell or recess), the artery may course within a bony or connective tissue mesentery. This course makes the artery more vulnerable to injury during surgical procedures. The posterior ethmoidal artery always courses within the orbital lamina. They accompany the nerves of the same name. Occasionally, a third intermediate artery may also be present (Katić and Prgomet, 2009).

4. Anatomical Variations

Knowledge of various anatomical variations of the paranasal sinuses is crucial for endoscopic surgical approaches through the nasal cavity. Onodi or sphenoethmoid cells are posterior ethmoid air cells that extend laterally and slightly superiorly around the sphenoid sinus. They are closely related to the optic nerve, which increases the risk of injury during surgery when these cells are present. The incidence of Onodi cells ranges from 8% to 14% (Kantarci et al., 2004; Stammberger and Kennedy, 1995). Agger nasi cells are the most anteriorly located cells, situated anteriorly, laterally, and inferiorly to the frontal recess. They usually develop through the pneumatisation of the agger nasi, often via the recess. The reported incidence varies widely, ranging from 10% to 89% (Kantarci et al., 2004; Messerklinger, 1967). When these cells are large, they can alter the position of the middle nasal turbinate medially and superiorly, mechanically narrowing the frontal recess. Haller cells are ethmoid air cells that grow into the floor of the orbit, directly above and below the natural drainage pathway of the maxillary sinus. If enlarged, they can significantly narrow the ethmoid infundibulum and the opening of the maxillary sinus. The incidence of Haller cells is between 10% and 18% (Kantarci et al., 2004). Concha bullosa is a pneumatized middle nasal turbinate, occasionally involving the superior or inferior turbinate. It can cause functional narrowing of the nasal cavity due to its size. Uncinate bulla is a pneumatization of the uncinate process and is a rare anatomical variation. According to various studies, its incidence ranges from 0.4% to 5% (Kantarci et al., 2004; Rao and el-Noueam, 1998). It can significantly narrow the drainage pathways of the sinuses.

5. Modern surgical therapy of chronic inflammatory diseases, tumors of the nose, paranasal sinuses, orbit, and anterior skull base

The indications for endoscopic endonasal surgery include CRSwNP (chronic rhinosinusitis with nasal polyps), CRSsNP (chronic rhinosinusitis without nasal polyps), all intraorbital complications of acute rhinosinusitis, and other complications of acute and chronic rhinosinusitis. Furhermore, drainage of mucoceles, pyoceles, and pneumocele, resection of the tumors of the lateral wall of the nasal cavity and paranasal sinuses, and surgical access to the orbit (anterior part, including lacrimal duct surgery, extending to the cone of the orbit and optic nerve decompression) (Wilson, 2012).

Approaches to individual paranasal sinuses can vary. Previously, classical approaches involving facial incisions are mostly unsuitable for benign pathologies. However, they can be useful in cases of extensive malignancies. Endoscopic approaches through the natural openings, such as the nostrils, are now equally effective. Moreover, the boundaries of endoscopic access can extend far beyond the nose and paranasal sinuses, including the anterior skull base, orbit, retrosphenoid space, clivus, pterygopalatine fossa, and infratemporal fossa (Simmen and Jones, 2014; Wormald, 2017).

The unoperated (non-opened) labyrinth of the ethmoid bone is covered by mucosa. Imagine a coronal section through the nose (paranasal sinuses) in front of you. This provides the closest approximation to the actual endoscopic view that a surgeon sees (**Figure 2**). During a standard endoscopy, we can only see the anterior and medial surfaces of the middle turbinate, roof of the nose, uncinate process, and sometimes the ethmoid bulla. We also discuss important orientation (navigation) points that lead towards the maxillary sinus and orbit (uncinate process), towards the posterior part of the ethmoid (bulla), intracranially (roof of the nasal cavity). After removing the uncinate process, we reveal the entrance to the maxillary sinus. Moving upward, we continue into the area of the agger nasi and behind it, into the frontal recess. In this area, the ethmoid labyrinth can be composed of heterogeneous structures, which contributes to the relative complexity of the natural drainage pathway of the frontal sinus and its surgical management. By maintaining the concept of a coronal section, only the orbital wall remains laterally, while the middle turbinate remains medially. A wide surgical passage through the ethmoid into the frontal sinus represents a frontotomy. Emptying the ethmoid labyrinth behind the posterior wall of the ethmoid bulla leads us through the basal lamella into the posterior ethmoid and ultimately into the sphenoid sinus. We return along the roof, which naturally rises forward. Usually, just before transitioning back into the frontal recess, we encounter the anterior ethmoidal artery. This emptied ethmoid labyrinth forms the basis of a complete anterior and posterior ethmoidectomy, the most commonly performed procedure in CRSwNP, where the disease affects practically all nasal cavities.

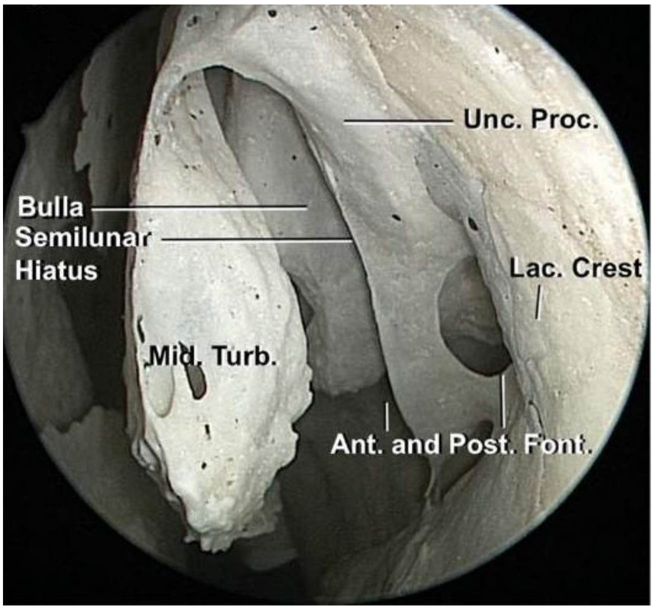

Figure 2. Endoscopic view of the parts of the ethmoid. We can see the middle nasal turbinate, uncinate process, middle nasal meatus, ethmoid bulla, and cells of the anterior ethmoid extending towards the frontal recess. Mid. Turb. – middle turbinate, Bulla – ethmoid bulla, Unc. Proc. - uncinate process, Lac. Crest – lacrimal crest, Ant. and Post. Font. – anterior and posterior fontanelle. (From: https://www.neurosurgicalatlas.com/neuroanatomy/endoscopic-view-through-the-anterior-nasal-aperture. Endoscopic View Through the Anterior Nasal Aperture.)

CRSwNP and CRSsNP are etiologically related diseases of the nasal and paranasal sinus mucosa, best defined by a yet to be precisely determined pathological inflammatory response of the mucosa to an unidentified external factor or multiple factors (Fokkens et al., 2012). The therapeutic goal in CRSsNP is to establish sinus drainage and preserve most of the natural anatomical relationships. In CRSwNP, it also involves the removal of all diseased or polypoid-transformed mucosa. In doing so, the intimate relationships of vascular and nerve structures, proximity to orbital contents, and the anatomy of the anterior cranial base must be considered (Simmen and Jones, 2014). Surgical intervention allows for the application of local medications that effectively reduce the chances of disease recurrence (Fokkens et al., 2012).

Functionally, the maxillary sinus, frontal sinus, and ethmoid sinus preserve most of their drainage capacity, provided by the active functioning of cilia in the mucosa (Duncavage and Becker, 2011). Endoscopic endonasal surgery has emerged as an equally successful and less invasive method of surgical treatment for certain benign and malignant tumors, including tumors that involve or even extend beyond the anterior cranial base intracranially (Lund et al., 2014).

In cases of malignancies in the nasal cavities, our boundaries are even broader. We aim to remove the malignant tumor in healthy tissues either in one block or in multiple divided, oriented blocks. The principles of oncologic surgery also apply to endoscopic endonasal surgery for tumors. Planning and executing the surgery in layers without tumor presence is a fundamental requirement for ensuring radicality (Lund et al., 2014).

In such cases, the lateral surface is typically the periorbita, which comparably effectively halts the local progression of the disease. This continues until reaching the optic nerve canal, which is already located in the sphenoid sinus. Moving upward in the periorbital plane, we find duplicatures for the anterior and posterior ethmoidal arteries. When viewing the roof of the ethmoid, the anterior ethmoidal artery courses lateroposteriorly to medioanteriorly, while the posterior ethmoidal artery courses lateroanteriorly to medioposteriorly. The posterior artery is in direct proximity to the optic nerve. When removing the superior orbital lamella, we start grinding the superiomedial wall of the orbit, and we can enter the most superior (frontal recess) and superoinferior (supraorbital recess) parts of the ethmoid. The roof of the ethmoid borders the dura of the cranial fossae and is considerably higher than the roof of the nasal cavity. Hence the classification according to Keros, which divides the ratio of both roofs into more or less dangerous categories from an endoscopic surgical perspective (Elwany et al.,2013; Keros, 1962).

For diseases that extend intracranially and transnasally-transethmoidally accessible diseases, the mentioned corridor can be advantageously used for successful, less invasive neurosurgical interventions (Zanation et al., 2012). The ethmoid labyrinth leads into the anterior cranial fossa. The area of the posterior wall of the frontal sinus, roof of the nose, and roof of the ethmoid is also referred to as the anterior cranial base. In a transcribriform approach, intracranially, we see the space that is laterally bounded by the left and right periorbita, with the entrance into both frontal sinuses extending intracranially with the frontal lobes of the brain and the anterior vascular network, usually after removing the cribriform plate along with both olfactory bulbs and tracts (following dural removal).

Conclusion

The ethmoid bone represents the anatomical and functional center of the nasal cavity. Various changes occur on its mucosa, leading to pathological processes of benign or malignant nature. With the advent of endoscopic nasal surgery, the ethmoid bone has become even more important, subjected to detailed surgical study, and a key aspect of surgical management for significant nasal and sinus diseases. Furthermore, corridors through the ethmoid bone have been created for accessing the anterior skull base, including intracranial regions, becoming of interest in the treatment of brain and cerebrovascular diseases.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Casiano RR. Correlation of clinical examination with computer tomography in paranasal sinus disease. Am J Rhinol. 1997; 11:193-196. DOI:10.2500/105065897781751848
2. Duncavage JA, Becker SS. The Maxillary Sinus. GeorgThieme Verlag KG. 2011. DOI: 10.1055/b-002-80418
3. Elwany S. Kennedy D, Hwang P. Rhinology: Diseases of the Nose, Sinuses, and Skull Base. Eur Arch Otorhinolaryngol. 2013; 270:387. DOI: https://doi.org/10.1007/s00405-012-2206-1Jan 1;270.
4. Fokkens WJ, Lund VJ, Mullol J, et al. EPOS 2012: European position paper on rhinosinusitis and nasal polyps 2012. A summary for otorhinolaryngologists. Rhinology. 2012; 50:1-12. DOI:10.4193/Rhino12.000
5. Kantarci M, Karasen RM, Alper F, Onbas O, Okur A, Karaman A. Remarkable anatomic variations in paranasal sinus region and their clinical importance. Eur J Radiol. 2004; 50:296-302. DOI:10.1016/j.ejrad.2003.08.012
6. Katić V, Prgomet D. Otorinolaringologija i kirurgija glave i vrata. 2009 [cited 2023 May 19]; Available from: https://www.bib.irb.hr/461823
7. Keros P. [On the practical value of differences in the level of the lamina cribrosa of the ethmoid]. Z Laryngol Rhinol Otol. 1962 Nov; 41:809–13.
8. Kobe V, Dekleva A, Lenart IF, et al. Anatomija: skripta za študente medicine. Del 1, kosti, sklepi, mišice. University of Ljubljana, Faculty of Medicine; 2007
9. Lund VJ, Howard DJ, Wei WI, Ang K, Aygun N, Chua DTT, et al. Tumors of the Nose, Sinuses and Nasopharynx. 2014th ed. Geoge Thieme Verlag KG, Stuttgart. 2014. DOI: 10.1055/b-002-91652

10. Messerklinger W. On the drainage of the normal frontal sinus of man. Acta Otolaryngol. 1967; 63:176-181. DOI:10.3109/00016486709128748
11. Messerklinger W. Endoscopy of the Nose. Urban & Schwarzenberg; 1978.
12. Petrovič D. Razvoj škržnih (branhialnih) organov. Med Razgl. 2002; 41: 63–74.
13. Rao VM, el-Noueam KI. Sinonasal imaging. Anatomy and pathology. Radiol Clin North Am. 1998; 36:921-vi. DOI:10.1016/s0033-8389(05)70069-5
14. Simmen D, Jones N. Manual of Endoscopic Sinus and Skull Base Surgery. Secon edition. Thieme Medical Publishers, Inc, New York. 2014
15. Stammberger H. Endoscopic endonasal surgery--concepts in treatment of recurring rhinosinusitis. Part II. Surgical technique. Otolaryngol Head Neck Surg. 1986; 94:147-156. DOI:10.1177/019459988609400203
16. Stammberger HR, Kennedy DW. Anatomic Terminology Group. Paranasal sinuses:anatomic terminology and nomenclature. Ann Otol Rhinol Laryngol Suppl. 1995;167:7–16.
17. Suh J. Rhinology: Sinus Anatomy and Embryology. UCLA Head and Neck Surgery. 2009. Available from: http://headandnecksurgery.ucla.edu/workfiles/Academics/Lectures/Endoscopic_Sinus_Surgery_JSuh_3-25-09.pdf
18. Sneak peek from our Head & Neck update: The ethmoid bone. Complete Anatomy . 2020. Available from: https://3d4medical.com/blog/ethmoid-bone
19. Wigand ME. Transnasal ethmoidectomy under endoscopical control. Rhinology. 1981;19:7–15.
20. Wilson M. ENT–HEAD AND NECK SURGERY: ESSENTIAL PROCEDURES. The Journal of Laryngology & Otology. 2012; 126:1084. DOI:10.1017/S0022215112001946
21. Wormald PJ. Endoscopic sinus surgery: anatomy, three-dimensional reconstruction, and surgical technique. 4th Edition. New York: Thieme. 2017. DOI:10.1055/b-006-149762
22. Zanation AM, Carrau RL, Snyderman CH, Kassam AB, Gardner PA, Prevedello DM, et al. Endoscopic Reconstruction of Anterior Skull Base Defects. In *Endoscopic Approaches to the Skull Base*, 2012; Vol.26,pp.168-181. Karger Publishers.