REVIEW

10.2478/AMB-2026-0025

ANATOMICAL VARIANTS OF THE NASAL CAVITY AND PARANASAL SINUSES IN CLINICAL AND SURGICAL PRACTICE

K. Bechev[1,3*], N. Yotova[2], D. Markov[1,4], A. Fasova[2], S. Markov[5,6]

[1]Department of General and Clinical Pathology, Faculty of Medicine, Medical University – Plovdiv, Bulgaria
[2]Department of Anatomy, Histology and Cytology, Faculty of Medicine, Medical University – Plovdiv, Bulgaria
[3]Neurological Surgery, Pulmed University Hospital – Plovdiv, Bulgaria
[4]Department of Clinical Pathology, Pulmed University Hospital – Plovdiv, Bulgaria
[5]Department of Otorhinolaryngology, Medical University – Plovdiv, Bulgaria
[6]Department of Otorhinolaryngology, University Hospital "Sv. George" – Plovdiv, Bulgaria

Abstract. *The nasal cavity and paranasal sinuses form an anatomically intricate and highly variable region that plays a vital role in the physiological functions of the upper respiratory tract and is intimately associated with a wide range of pathological and surgical considerations. Anatomical variations in this area – such as concha bullosa, septal deviation, Haller and Onodi cells – are frequently linked to impaired mucociliary clearance, obstruction of natural drainage pathways, and an increased risk for the development of chronic rhinosinusitis. Moreover, the presence of such variations significantly influences the planning and execution of functional endoscopic sinus surgery (FESS) and transnasal approaches to the skull base, increasing the likelihood of complications involving the optic nerve, internal carotid artery, or orbital structures. This review aims to provide a structured analysis of the most clinically relevant anatomical variants of the nasal cavity and paranasal sinuses, grounded in contemporary literature from the past decade across radiological imaging, anatomical studies, and skull base surgery. It explores the relationship between structural anomalies and the frequency and severity of sinonasal pathology, as well as their implications for endoscopic surgical practice. Special attention is given to surgical hazards posed by variations such as dehiscent lamina papyracea, accessory maxillary ostia, and pneumatization of the anterior clinoid process. The review includes tabular and graphical representations illustrating the associations between specific anatomical features and their related clinical and surgical risks. This integrative approach is intended to support clinicians in enhancing diagnostic accuracy, optimizing preoperative planning, and minimizing intraoperative complications through a personalized anatomical understanding of this region.*

Key words: *nasal cavity, paranasal sinuses, anatomical variations, functional endoscopic sinus surgery (FESS), radiological imaging, surgical risks, skull base*

Corresponding author: *Kristian Bechev, Department of General and Clinical Pathology, Faculty of Medicine, Medical University of Plovdiv, 4002 Plovdiv, Bulgaria tel.: +359 88344621, e-mail: kristian_bechev@abv.bg*

ORCID: *0009-0007-1460-3522*

Received: *24 June 2025;* ***Revised/Accepted:*** *18 August 2025*

INTRODUCTION

The nasal cavity and paranasal sinuses form a functionally and anatomically integrated system that plays a pivotal role in respiration, air humidification and filtration, as well as resonance in phonation [1, 2]. These structures exhibit considerable anatomical variability, and such individual differences are well – documented contributors to inflammatory and obstructive upper airway conditions. Furthermore, they serve as essential surgical corridors for accessing the skull base [3-5]. Modern imaging modalities, particularly high – resolution computed tomography (CT), have significantly advanced the ability to visualize both normal and variant anatomy. Frequently encountered variations include concha bullosa, nasal septal deviation, Haller cells, Onodi cells, and agger nasi cells [6-9].

The clinical relevance of these variants extends beyond their role in increasing the incidence of acute and chronic rhinosinusitis. They also represent significant risk factors during endoscopic surgical interventions, including FESS and transnasal skull base procedures [10-13]. Anatomical variants can alter the configuration of the osteomeatal complex, impair mucociliary function, and hinder sinus drainage, thereby creating a substrate for persistent inflammation [14-17]. Particularly high – risk variations – such as pneumatization of the anterior clinoid process, accessory maxillary ostia, paradoxical middle turbinates, and dehiscent lamina papyracea – may complicate intraoperative orientation and increase the likelihood of injury to critical neurovascular structures [18-22].

Comprehensive anatomical knowledge of these features is crucial for all surgical interventions in the sinonasal region. A failure to account for such individual variations may result in serious intraoperative or postoperative complications, including orbital hematomas, optic nerve damage, cerebrospinal fluid leaks, and rupture of the internal carotid artery [23-26]. This review article presents a systematic and critical examination of key anatomical variants of the nasal cavity and paranasal sinuses, their clinical relevance, and the associated risks in the context of surgical management.

MATERIALS AND METHODS

This article was developed as a systematic literature review focused on anatomical features of the nasal cavity and paranasal sinuses, and their clinical significance in sinus and skull base surgery. The selection and critical interpretation of sources adhered to established methodological standards for scientific medical reviews.

A targeted search of English-language literature published between 2013 and 2024 was conducted. The primary data sources included: databases – PubMed, ScienceDirect, Google Scholar, and Scopus, peer-reviewed journals in the fields of otorhinolaryngology, anatomy, neurosurgery, and radiology, review articles, meta-analyses, original clinical studies, and anatomical investigations describing the prevalence, clinical relevance, and surgical risks associated with various anatomical variations.

The search strategy used a range of relevant keywords, including: nasal cavity, paranasal sinuses, anatomical variations, concha bullosa, Onodi cell, functional endoscopic sinus surgery, CT anatomy of sinuses, surgical risk, skull base access, among others.

Over 100 scientific sources were initially reviewed. Of these, 73 articles were selected for inclusion in the final analysis based on criteria such as scientific rigor, originality, methodological quality, and practical applicability.

Inclusion criteria were as follows:

- Anatomical and clinical studies involving human subjects (adults and adolescents);
- Clearly defined morphological variations of the nasal cavity and paranasal sinuses;
- Assessment of clinical implications, surgical access, or radiological evaluation;
- Availability of data on prevalence, associated risks, or relevance in surgical procedures.

Exclusion criteria included:

- Articles lacking full-text access;
- Non-peer-reviewed publications;
- Brief communications or isolated case reports without a broader literature context.

Each study underwent a critical qualitative appraisal. When feasible, comparative data were extracted regarding the frequency, anatomical localization, and surgical implications of the reported variations. The findings were subsequently organized into tables and graphical formats to facilitate interpretation of the relationships between anatomical variants and their clinical consequences (Table 1).

The purpose of this methodological approach is to provide a synthesized and practically applicable review of the available literature in the last 10 years, to summarize the data from the literature, which will serve for clinical and surgical practice.

Table 1. Key anatomical variations and their clinical significance

Anatomical variation	Related complications	Surgical risk	Clinical interpretation
Onodi cell	Damage to the optic nerve, loss of vision	High	Requires accurate CT localization
Haller cells	Obstruction of the infundibulum	Moderate	Increased attention when accessing the maxillary sinus
Concha bullosa	Chronic rhinosinusitis	Moderate	To decompress if necessary
Septal deviation	Nasal obstruction, chronic inflammation	Low to moderate	A common cause of chronic nasal symptoms
Agger nasi cells	Frontal sinusitis	Low	Limited surgical field in the frontal sinus
Paradoxical middle turbinate	Osteomeatal complex compression	Moderate	To be identified on a CT scan before FESS
Frontal cells type III/IV	Frontal mucocele, obstruction	Low to moderate	Increased risk in frontal surgery
Accessory maxillary sinus ostia	Secretion retention, recurrent infections	Moderate	Requires tracking of drainage
Pneumatized anterior clinoid process	Optic nerve damage during transsphenoidal surgery	High	Critical area in transsphenoidal surgery
Supraorbital ethmoid cells	Frontal sinusitis	Moderate	To be included in a preoperative assessment
Dehiscent lamina papyracea	Orbital cellulitis, hematoma	High	Requires precise navigation
Retained uncinate process	Failed FESS	Moderate	To be resected during revision surgery
Hypertrophic bulla ethmoidalis	Obstruction of the middle meatus	Moderate	An extended ethmoidectomy may be required
Multiple maxillary ostia	Maxillary rhinosinusitis recurrence	Moderate	Be aware of clinical manifestations to avoid treatment failure

RESULTS

Analysis of 73 full-text peer-reviewed sources, including anatomical, radiological, and clinical-surgical publications from the past 10 years, allowed the identification of major patterns regarding the frequency, clinical significance, and surgical risk associated with variations of the nasal cavity and paranasal sinuses, which are of key importance for surgery of the paranasal sinuses and skull base.

The distribution of the most frequently encountered anatomical variations from the literature data showed the following summary:

- Concha bullosa – in 34-68% of the examined individuals;
- Septum deviation – in 48-80% of the population, with a prevalence in men;
- Haller cells – between 20 and 45%;
- Onodi cells – ranging from 7 to 25%, more common in Asians;
- Agger nasi cells – reported in over 75-80% of Europeans;
- Paradoxical middle turbinate and accessory maxillary sinus ostia – with a frequency of 10-22% and 20-30%, respectively.

The graphically described anatomical variations can be represented in Fig. 1:

The graph presents the minimum and maximum reported frequencies of the most common anatomical variations of the nasal cavity and paranasal sinuses, based on data from peer-reviewed anatomical, radiological and clinical publications. The data show that concha bullosa and septal deviation are among the most commonly observed variations in the general population, with a frequency of up to 68% and 80%, respectively.

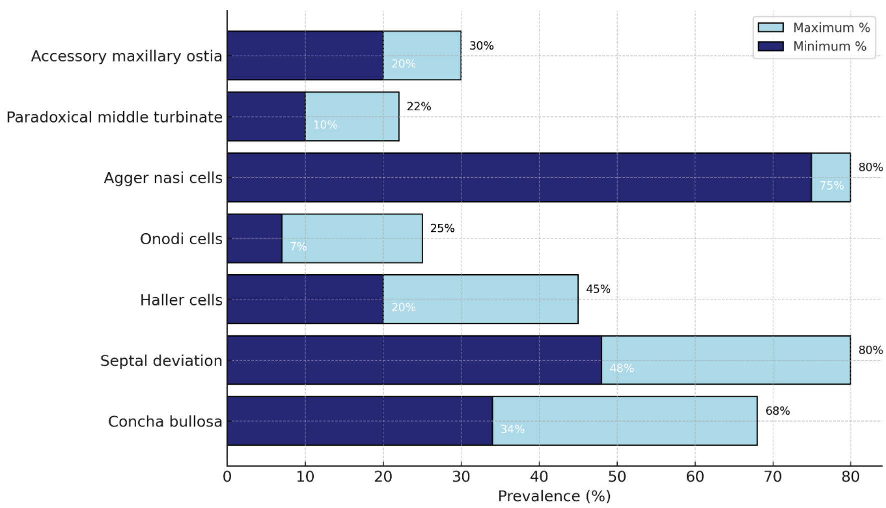

Fig. 1. Distribution of anatomical variations

Agger nasi cells are found with the highest frequency in the European population (up to 80%), while Onodi cells are significantly more common in the Asian population. The significant amplitude in the values reflects ethnic, demographic and methodological differences in the published studies.

The key clinical and pathological correlations related to the anatomical variations, after a review of the literature and analysis of the data can be summarized as follows:

- Concha bullosa, Haller cells and septal deviation are associated with chronic rhinosinusitis and obstruction of the osteomeatal complex;
- Agger nasi and frontal cells – increased risk of frontal rhinosinusitis and mucocele;
- Onodi cells – risk of orbital and neurological complications due to proximity to the optic nerve.

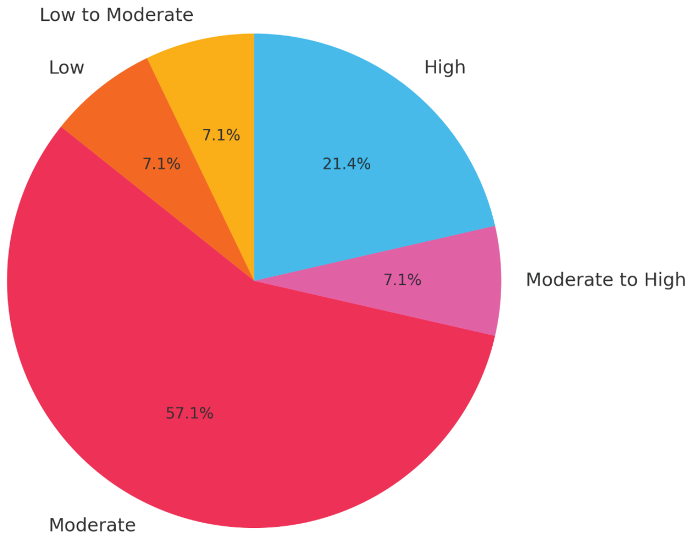

Fig. 2. Percentage ratio of surgical risk according to the presence of anatomical variations

The surgical risks associated with anatomical variations of the paranasal sinuses, after a systematic review, are distributed as follows:

- Onodi cells;
- Pneumatization of the anterior clinoid process;
- Dehiscence of the lamina papyracea;
- Frontal cells type III/IV.

Surgical risk in functional endoscopic sinus surgery (FESS) and transsphenoidal surgical approaches to the skull base can be graphically represented by a pie chart illustrating the relationship between anatomic variations and subsequent surgical complications, with data extracted from Table 1, presented in the Materials and Methods section (Fig. 2).

The results of the literature review showed population and ethnic differences that can be systematized as follows:

- Onodi cells are more common in the Asian population (up to 25%) compared to the European population (15%);
- Agger nasi cells and frontal cells are prevalent in the European population (up to 80%);
- Septal deviation and Concha bullosa are widespread in all groups, but with a higher frequency in Middle Eastern populations.

These differences are summarized graphically in Fig. 3, which presents a comparative analysis between the Asian, the European and the Middle Eastern populations across five key anatomical variations.

The results related to imaging diagnostics, based on the reviewed literature, yielded the following conclusions: Computed tomography (CT), especially with high-resolution scans (slice thickness <1 mm), remains the gold standard for detecting anatomical variations. Magnetic resonance imaging (MRI) serves as a valuable complementary tool, particularly in cases involving soft tissue masses, orbital extension, or intracranial involvement.

The summarized data can be effectively visualized through a composite chart comparing the three main imaging modalities – CT, MRI, and intraoperative navigation – based on two parameters: their operative value (assessed on a ten-point scale) and their frequency of use in peer-reviewed publications within the analyzed time frame (Fig. 4).

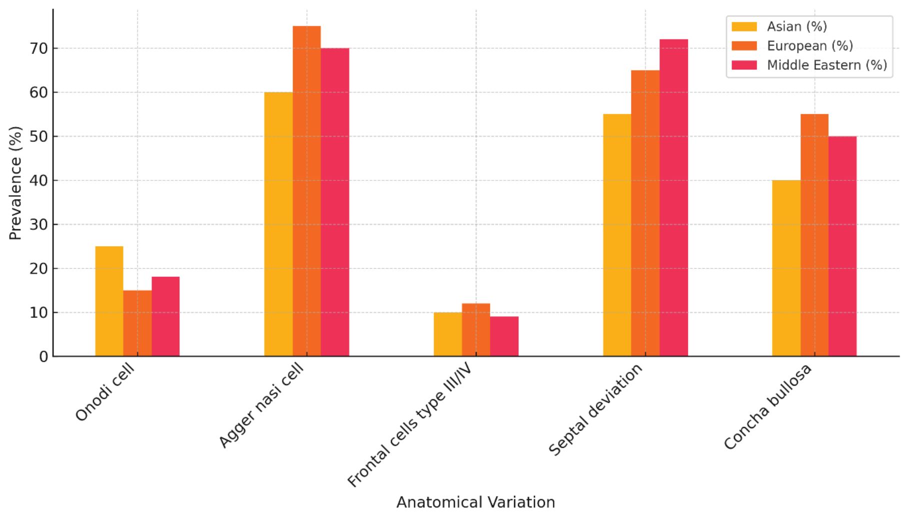

Fig. 3. Population and ethnic differences in the most common anatomical variations

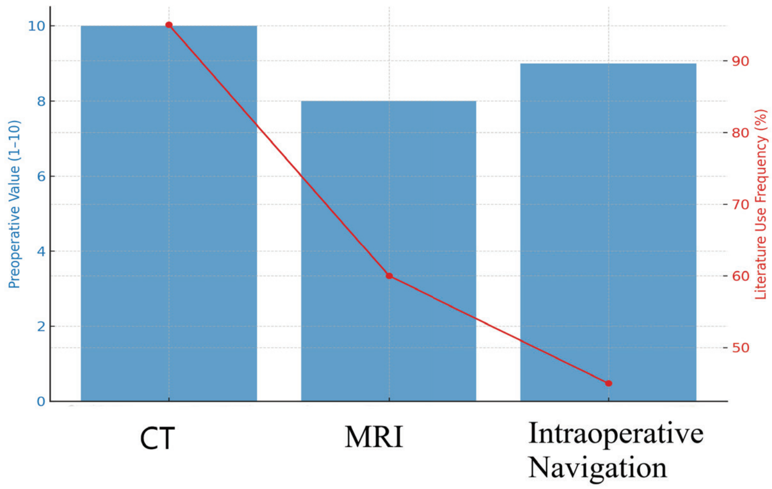

Fig. 4. Chart showing the comparative evaluation of CT, MRI and intraoperative navigation in terms of operational value

The data show that CAT remains the gold standard for anatomical visualization and was used in over 90% of the analyzed studies. MRI is used in cases with suspected soft-tissue lesions or intracranial spread, while intraoperative navigation demonstrates high clinical value in surgical planning in complex, high-risk cases, despite its more limited presence in the literature. In conclusion, the analyzed anatomical variations have an important clinical significance in surgical approaches in the considered anatomical area, and preoperative imaging and intraoperative navigation are the gold standard in modern surgery of the paranasal sinuses and skull base.

DISCUSSION

The anatomy of the nasal cavity and paranasal sinuses is one of the most complex and variable regions in the human body. A precise knowledge of this anatomical area is essential not only for anatomical specialties but also for clinical specialties such as ENT and neurosurgery. The nasal cavity is one of the cavities of the facial cranium. It is located between the oral cavity and the base of the skull. The entrance to the nasal cavity is the apertura piriformis, and the exit is the choanae. Its size depends on the age, gender and ethnicity of the individual. Its final formation ends around the age of 16. Its dimensions are quite variable, both in height and in width. It is widest and highest in its central part. The width in the lower part of the cavity is always greater than the upper. The nasal cavity is divided by a septum, which has a bony, cartilaginous and membranous part. The septum is usually not centrally located, but is deviated to the left or right. Severe deviation can cause obstruction of the upper airway and create conditions for various disorders and pathological processes of the surrounding structures [1, 2, 3, 8, 10].

Each half of the nasal cavity has a vestibule, floor, roof, lateral wall and medial wall. The paranasal sinuses also open in the nasal cavity, which are: frontal, maxillary, ethmoid and sphenoid. They open into the lateral wall through small openings through which the aeration of the sinuses and the cleaning of mucus takes place. The exact position of the openings and their shape is highly variable in different individuals. Through these holes, the respiratory epithelium of the nasal cavity passes into the sinuses and creates a path for inflammatory and other pathological processes. The most common variations leading to clinical complications are: agger nasi cells, nasal septum deviation and concha bullosa [22]. Other less significant changes are: uncinate process variation, paradoxical middle turbinate, Haller cells, Onodi cells, supraorbital ethmoid cells, accessory ostia of maxillary sinus. The least common are: sinus aplasia, crista galli pneumatization, dehiscence of the optic or maxillary nerve, internal carotid artery and lamina papyracea [1-30].

In this discussion, we will systematically review anatomical variations, their role in pathological processes, the importance of imaging, ethnic and population differences, and the impact of anatomical variations on surgical interventions performed in the paranasal sinuses. They are also used as surgical corridors for pathological processes affecting the skull base and intracranial brain tissue.

Anatomical variations

Nasal septum deviation

Deviation of the nasal septum can be genetically determined or due to trauma. Nasal deviation can be divided into 7 types. They include the S-shaped shape of the septum, the presence of horizontal and transverse ridges, which, depending on their degree of appearance, prevent normal aeration and are a significant obstacle in endoscopic operations [1-15]. Correction of the deviation of the nasal septum is a common procedure in rhinoplasty, due to the fact that it creates not only functional, but also aesthetic problems. Sarah Braga Sayao et al. reported a relationship between the degree of nasal deviation and asymmetry of the bony components of the palate. The team of Rao N, Datta G, Singh G. reported that 85% of individuals with a deviation of the nasal septum develop rhinosinusitis [16, 17, 20, 21].

Frontal sinus

The frontal sinuses are paired cavities located posterior to the arcus superciliaris of the frontal bone. The two sinuses are typically asymmetrical due to the lateral deviation of the intersinus septum. Additionally, incomplete accessory septa are sometimes present, forming small sub-compartments within the sinus. In adults, the average dimensions of the frontal sinus are: height – 3.2 cm, width – 2.6 cm, and depth – 1.8 cm. Each sinus consists of a frontal and an orbital part and drains via the ethmoidal infundibulum into the frontonasal recess.

At birth, the frontal sinus is absent. It develops in conjunction with the frontal bone and becomes radiologically visible around the age of six. The two sinuses develop independently, which accounts for the notable variations in their shape and size. Bent and Kuhn have described four types of frontal cells. Lack of familiarity with these anatomical variants can lead to misdiagnosis and may complicate surgical access to the anterior cranial fossa.

The literature reports varying rates of frontal sinus agenesis. The team of B. Cakur, M.A. Sumbullu, and N.B. Durma documented bilateral agenesis in 0.73% and unilateral agenesis in 1.22% of cases [39]. In a study of 565 Iranian patients, Danesh-Sani, Bavandi, and colleagues found bilateral agenesis in 8.32% and unilateral absence in 5.66% of cases. These discrepancies in prevalence are likely attributable to the differing ethnic backgrounds of the studied populations.

Maxillary sinus

The maxillary sinus is the largest of the paranasal sinuses. It has a pyramidal shape and is located within the body of the maxilla. The base of the pyramid faces medially towards the lateral wall of the nasal cavity. The floor of the sinus is formed by the alveolar and palatine processes of the maxilla and typically lies below the inferior wall of the nasal cavity. It is in close proximity to the roots of the teeth, especially the second premolar and first molar, but it may extend posteriorly to the third molar and anteriorly to the first premolar, and occasionally to the canine teeth. The roof of the sinus forms the floor of the orbit and contains the infraorbital canal, which may sometimes become dehiscent. The facial surface of the maxilla forms the anterior wall of the sinus. On its internal aspect, a very thin canal (canalis sinuosus) runs that transmits the anterior alveolar vessels and nerves.

The prelacrimal recess is the most anterior portion of the maxillary sinus and may extend towards the nasolacrimal canal. The posterior wall is formed by the infratemporal surface of the maxilla and contains the alveolar canals for the posterior alveolar arteries and nerves. These canals can produce various protrusions and irregularities on the inner wall of the sinus [25-40].

The medial wall is incomplete and houses the maxillary hiatus, which is partially closed off by the perpendicular plate of the palatine bone, the uncinate process, the inferior nasal concha, the lacrimal bone, and is covered by the nasal mucosa. The opening typically drains into the lower part of the ethmoidal infundibulum and subsequently into the middle nasal meatus via the hiatus semilunaris. During examination of the nasal cavity, the opening becomes visible after resection of the uncinate process. Additional accessory openings may also be observed, and these, like the main opening, are located closer to the roof than to the floor of the nasal cavity [25-40].

The maxillary sinus may be partially divided by septa; complete septation is extremely rare. Tumors developing in the sinus may protrude towards the orbital floor, displacing the eyeball, extend into the nasal cavity and obstruct the nasal passages, or cause epistaxis. They may spread into the infratemporal fossa or facially, damaging the infraorbital nerves. Involvement of the pterygoid muscles can lead to pain and limited mouth opening. If the disease propagates into the oral cavity, it may result in tooth loss and malocclusion. Altered normal anatomy in such cases complicates tooth extraction and can lead to fractures of the sinus wall. Hypoplasia of the maxillary sinus is rare [30-40].

Alveolar, zygomatic (infraorbital), and palatine recesses have been described within the maxillary sinus. The ostiomeatal complex includes the maxillary sinus ostium, the ethmoid infundibulum, and the hiatus semilunaris. This functional complex serves as a common pathway for the drainage of secretions from the maxillary sinus and the anterior ethmoidal cells. When the uncinate process is attached abnormally to the lateral nasal wall, the complex also drains the frontal sinus. The middle nasal meatus drains the frontal, maxillary, and anterior ethmoidal sinuses. The sphenoidal and posterior ethmoidal sinuses drain into the superior nasal meatus and the spheno-ethmoidal recess.

The walls of all paranasal sinuses are quite thin, and in some places, the bony wall may even be absent. This most commonly occurs in the lamina papyracea, lamina cribrosa, the lateral wall of the sphenoidal sinus, and the orbital and posterior walls of the frontal sinus. Such defects may lead to meningitis or frontal lobe brain abscess [25-40].

Selcuk A et al., after examining 330 CT scans of the paranasal sinuses, reported septa in the anterior part of the maxillary sinus in 20.3% of cases and in the posterior part in 2.5%. They observed that septa in the anterior sinus were predominantly vertical, while those in the posterior part were mainly horizontal. Their team also reported a 4.6% incidence of maxillary sinus hypoplasia [43].

Cakur, Sumbullu, and Durma reported agenesis of the maxillary sinus in 5-6% of cases [39]. The team of A. Yenigun et al. studied the existence of accessory openings in the maxillary sinus and found that in their presence, 29.1% had maxillary sinusitis, 43.0% showed mucosal thickening, and 48.6% had retention cysts [44].

In a study of 5,832 patients, Turna and Aybar found maxillary sinus aplasia in only 0.05%. Lantos, Pearlman et al., in a review of 500 CT scans, observed unilateral protrusion of the infraorbital canal into the maxillary sinus in 10.8% of cases and bilateral protrusion in 5.6% [50].

Sphenoidal sinus

The sphenoidal sinuses are two large cavities of different sizes located in the body of the os sphenoidale. Most often, the openings of the sphenoidal sinuses are located behind the upper part of the nasal cavity and medial to the superior nasal concha. The dimensions in adults are: vertical height – 2 cm, transverse breadth – 1.8 cm, anteroposterior depth – 2.1 cm. Usually the sinus is divided by a septum that is deviated to the left or to the right. Additional septa can also be observed in this sinus. A. carotis interna, canalis pterygoideus, n. maxillaris and sometimes n. opticus can protrude in its walls. The sphenoidal sinuses are in close connection with the pituitary gland and chiasma opticum. Laterally, the sinus cavernosus and the elements located in it are located. The pneumatization of the sinus is very variable. Depending on the direction in which it spreads, 6 types of sphenoid sinus have been described: sphenoid body type, lateral type, clival type, lesser wing type, anterior type and combined type. Excessive posterior displacement of the Onodi cell may affect the optic nerve and internal carotid artery. Transsphenoidal access to the pituitary gland also carries a risk of damage to adjacent structures. The sphenoethmoidal cell (Onodi cell) is rarely visualized on CT. This fact may complicate the preliminary planning of surgical interventions. According to D. Yazici, the most frequent deviations in this sinus are the pneumatization of the anterior clinoid processes, of the large wings and the violation of the integrity of the canal of a. internal carotid [41]. The team of Turna Aybar et al. in a study of 5832 adult patients reported a 0.5% dehiscence of the internal carotid artery [10]. Darsar et Gokce found a significant relationship between pneumatization of the sphenoid processes and protrusion of the internal carotid artery and optic nerve into the sphenoid sinus [22]. Shpilberg et al. reported that the third most common variation in this sinus was its extension to the posterior part of the nasal septum. The extension of the sellar pneumatization to the dorsum sellae was found in 13.4% [23].

Ethmoidal Sinus

The ethmoidal sinuses differ structurally from other paranasal sinuses. Rather than forming a single cavity, they consist of numerous thin-walled air cells, known as ethmoidal cells, with their number varying from 3 to 18 on each side. These sinuses are located between the upper part of the nasal cavity and the orbit. They are separated from the orbits by a very thin bony plate called lamina papyracea. Pneumatization of the ethmoidal sinuses may proceed in various directions – toward the body and wings of the sphenoid bone or the inferior nasal concha. Based on their embryological development and drainage location within the nasal cavity, the ethmoidal cells are classified into anterior and posterior groups. These groups are separated by the basal lamella, a bony plate that appears in various folded shapes. Approximately 11 anterior ethmoidal cells drain into the ethmoidal infundibulum. These are in close proximity to the lacrimal sac and nasolacrimal duct. About 7 posterior ethmoidal cells drain via individual openings into the superior nasal meatus. The posterior cells are located close to the optic canal and optic nerve, and may drain into the sphenoidal sinus or into the highest nasal meatus, if present.

The uncinate process is a thin, hook-shaped bony plate. Its posterior margin defines the hiatus semilunaris. The attachment of this process to adjacent bones can vary. In some cases, it may project into the middle nasal meatus and nearly obscure the maxillary sinus ostium, which may impair drainage and aeration of the sinus and complicate surgical interventions.

The lamina papyracea lies lateral to the ethmoidal cells, forming the boundary between them and the orbit. Small defects in its integrity have been reported in the literature, with frequencies ranging from 0.5% to 10%. Any disproportion in the size or shape of the ethmoidal sinuses can create difficulties during endoscopic procedures.

The Agger nasi cell is the most anterior ethmoidal cell. Due to its location above the frontal sinus and near the lacrimal fossa and nasolacrimal duct, precise preoperative planning is essential to avoid severe complications. Baharudin Abdullah et al. found a correlation between the position and course of the anterior ethmoidal artery and the development and size of the supraorbital ethmoidal cell [1-28].

Clinical significance of the anatomical characteristics of the paranasal sinuses

The nasal cavity and paranasal sinuses have important functional roles in human physiology, including participation in filtration, humidification and warming of air, resonant function of the voice, as well as protection against pathogenic microorganisms through mucociliary clearance. Any anatomical variation that leads to disruption of these processes can create prerequisites for the development of pathological conditions such as chronic rhinosinusitis, obstruction of sinus drainage, increased risk of infections and complications of surgical interventions [3-6]. One of the most common anatomical features of clinical importance is the deviation of the nasal septum. It occurs in 20% to 80% of people, with severe forms leading to unilateral obstruction, turbulent airflow and compensatory hypertrophy of the contralateral nasal concha [7, 8]. These changes disrupt the normal airflow in the nasal cavity, which facilitates the retention of secretions and creates conditions for inflammation. Multiple studies have established a direct relationship between nasal septal deviation and an increased incidence of chronic rhinosinusitis [9, 10].

Concha bullosa (pneumatization of the middle turbinate) is another common variation that can lead to compression of the osteomeatal complex. Large conchae bullosae are associated with an increased incidence of sinusitis and difficulty in endoscopic surgical access [11-13]. A systematic review by Lee et al. (2018) confirmed a significant association between the presence of concha bullosa and symptomatic chronic rhinosinusitis [14]. Haller cells, located in the infraorbital region, are also of significant clinical importance. They can cause stenosis of the infundibulum and osteum of the maxillary sinus, leading to impaired drainage and the occurrence of chronic infections. Their presence significantly complicates surgical manipulations in the medial orbital wall [15, 16].

Onodi cells are of particular importance due to their proximity to the optic nerve and internal carotid artery. The presence of such cells increases the risk of orbital and intracranial complications during FESS or transsphenoidal access [17-19]. In the absence of prior CT diagnosis, there is a real risk of damage to the optic nerve or even hemorrhage during manipulations in this area [20, 21]. Additional anatomical variations, such as pneumatization of the anterior clinoid process, deviations in the lamina papyracea, supraorbital ethmoid cells, accessory openings of the maxillary sinus, and others, also have their relevance to clinical practice. They can cause direct compression, difficult access or increased risk of injury to adjacent structures [22-25]. These data emphasize the need for systematic anatomical analysis before any endoscopic or transnasal surgery, especially in areas of increased anatomical density and the presence of multiple neurovascular elements.

The role of anatomical variations in pathological processes

Anatomical variations of the nasal cavity and paranasal sinuses can significantly impact pathological processes in the upper respiratory tract. These structural differences often result in mechanical disruption of the normal drainage and ventilation functions of the paranasal sinuses, creating favorable conditions for the development of acute and chronic inflammatory diseases [26, 27]. Furthermore, certain variations predispose individuals to recurrent infections, mucus retention, and, in more severe cases, orbital or intracranial inflammatory complications.

For instance, the presence of Haller cells can narrow the infundibulum and lateralize the uncinate process, thereby impairing the physiological drainage of the maxillary sinus. This anatomical alteration increases the risk of localized inflammation and mucocele formation in the region [28, 29]. Similarly, an extensively pneumatized concha bullosa may act as an obstructive mass within the middle meatus, functionally blocking the osteomeatal complex. Numerous clinical observations have demonstrated that patients with large concha bullosa exhibit a higher incidence of recurrent rhinosinusitis [30, 31].

Onodi cells, due to their posterior and superior anatomical position, pose a particular clinical concern as they may exert pressure on the optic nerve or serve as a source of inflammation that can extend into the orbit or anterior cranial fossa. The literature describes cases of orbital abscess, retrobulbar neuritis, and even vision loss associated with inflammatory processes originating in Onodi cells [32-34].

Although accessory ostia of the maxillary sinus are often considered benign in some reports, they may change the direction of mucosal drainage and cause mucus stagnation by disrupting the normal mucociliary clearance. This situation contributes to the persistence and chronicity of the infection and complicates effective therapeutic management [35, 36].

Certain anatomical configurations, such as type III and IV frontal cells according to the Kuhn classification, are associated with complete obstruction of the frontal sinus – a condition recognized as one of the most challenging forms of frontal sinusitis to treat

[37]. Patients with such variations often require revision surgeries, and the absence of adequate intraoperative visualization substantially increases the risk of anterior cranial fossa perforation [38].

Moreover, emerging evidence suggests that anatomical variations may not only cause mechanical obstruction but also affect local hemodynamics and mucosal oxygenation. This results in impaired local immune responses, thereby promoting colonization by pathogenic microorganisms [39, 40]. Recognizing these pathophysiological mechanisms is crucial for choosing an appropriate therapeutic strategy. Patients whose symptoms are driven by anatomical obstruction typically exhibit suboptimal response to pharmacological treatment and often require surgical decompression [41, 42]. Accurate identification of the variation using computed tomography, followed by targeted surgical correction when necessary, leads to substantial symptom relief and improved quality of life.

Significance of imaging in anatomical variations of the paranasal sinuses and its application in clinical practice

Imaging is the basis as a tool in the assessment of the anatomical features of the nasal cavity and paranasal sinuses. It is not only a diagnostic tool, but also an unchanging reference point in the planning and implementation of surgical interventions. The most widely used method is computed axial tomography (CT), which provides high spatial orientation and the possibility of three-dimensional reconstruction of anatomical structures [43]. Coronal CT slices, performed in a plane perpendicular to the hard palate, provide excellent visualization of the osteomeatal complex, infundibulum, and ethmoidal cells. They allow the detection of Haller and Onodi cells, as well as variations in the lamina papyracea, which can affect both drainage function and surgical access [44, 45]. Spiral CT with thin slices (less than 1 mm) and high resolution is considered the gold standard in the preoperative evaluation of patients undergoing FESS. It provides reliable identification of anatomical variations and pathological changes such as mucoceles, polyps, chronic mucosal hyperplasia, and osteomyelitis [46, 47]. Magnetic resonance imaging (MRI) is complementary to CT, especially in the evaluation of soft tissue structures, tumors, inflammation with intracranial extension, or orbital involvement. Although MRI does not provide sufficient bone resolution, it is superior to CT in distinguishing between inflammatory secretions and pathologic tissue formations, as well as in evaluating complications such as cavernous sinus thrombosis due to inflammatory processes [48, 49]. One of the modern directions in imaging diagnostics is the use of intraoperative CT navigation system. Navigation surgery allows real tracking of instruments in a three-dimensional anatomical map, directly on the patient and significantly increases the safety of interventions, especially near the orbit and anterior cranial fossa [50-52]. Numerous systematic analyses have shown that the use of navigation technique in complex clinical cases reduces the frequency of intraoperative complications and subsequently required revision surgeries [53].

However, there are some limitations of imaging diagnostics. Some ethmoidal cell variations remain difficult to distinguish even with high-resolution CT devices. Also, the interpretation of the images depends on the experience of the imaging diagnostician and the knowledge of the anatomical structures. Incorrect evaluation of anatomical variations can lead to serious consequences during operative intervention [54, 55]. For this reason, modern imaging is an indispensable component in the diagnostic and surgical behavior of patients with diseases of the nasal cavity and paranasal sinuses. The combined use of CT, MRI, and intraoperative navigation ensures a high degree of precision, safety and an individualized approach to each patient.

Surgical importance of anatomic variations

Surgical procedures involving the nasal cavity and paranasal sinuses require a thorough understanding of the regional anatomy and its potential variations. This is especially true for Functional Endoscopic Sinus Surgery (FESS), a technique that relies on access through natural anatomical pathways and is highly dependent on individual morphological characteristics [56, 57]. One of the primary objectives of FESS is to restore normal sinus ventilation and drainage by removing obstructive factors and re-establishing optimal physiological conditions.

In this context, anatomical variations may significantly complicate the surgical access and increase the risk of intraoperative complications. For instance, the presence of concha bullosa – a pneumatized middle nasal turbinate – can lead to lateral displacement, reducing working space within the nasal cavity, hindering endoscope maneuverability, and increasing the likelihood of injury to adjacent structures [58]. Similarly, well-developed Haller cells may be misinterpreted as pathological masses or impede access to the maxillary sinus [59].

Onodi cells represent an especially critical variation due to their close proximity to the optic nerve and internal carotid artery. Inaccurate interpretation of CT scans in such cases can result in direct injury to these vital structures. There have been reports of postoperative blindness and severe hemorrhage associated with unrecognized Onodi cells [60, 61].

The lamina papyracea, which forms the medial wall of the orbit, often exhibits variable thickness or even dehiscences. Even slight lateral deviation of instruments during FESS can lead to orbital penetration and complications such as emphysema, hematoma, or trauma to the extraocular muscles [62].

Another key anatomical landmark is the skull base. Surgical procedures involving the frontal sinuses or posterior ethmoidal cells carry the risk of lamina cribrosa perforation, which may result in cerebrospinal fluid (CSF) leakage. Such complications increase the risk of meningitis and other intracranial infections [63, 64]. With the growing use of endoscopic approaches to skull base surgery – such as transsphenoidal pituitary resections or excision of skull base tumors – preoperative anatomical assessment becomes even more crucial. In these cases, detailed knowledge of the sphenoidal sinus pneumatization and the positional variations of the optic canal, carotid artery, and optic chiasm is essential [65, 66].

Studies have shown that the use of intraoperative navigation systems and stereotactic technologies significantly reduces the risk of surgical complications. These advanced tools enable real-time recognition and avoidance of critical structures, shorten operative time, and enhance surgical precision [67-69].

However, even with the most advanced equipment, the ultimate safeguard for patient safety remains the surgeon's anatomical knowledge and experience. A lack of awareness or underestimation of anatomical variations is a major contributor to mistakes in paranasal sinus and skull base surgery [70]. Comprehensive training and preoperative planning should always include a systematic review of individual anatomy using CT imaging, and in high-risk cases, incorporation of navigation systems. Only through the integration of theoretical knowledge, radiological assessment, and refined surgical skills can optimal safety and effectiveness be achieved in this anatomically complex and demanding region.

Ethnic and demographic differences

The anatomical variability of the nasal cavity and paranasal sinuses is not limited to individual differences, but often reflects the ethnicity of the patients. Different populations demonstrate different frequencies and types of anatomical variation, which has important implications for clinical and surgical practice, especially in a globalized world with increasing population mobility. Studies have shown that the frequency of certain anatomical structures, such as Onodi cells, is significantly higher in Asian populations compared to European and North American groups. Lien et al. reported a frequency of 39.3% in the Japanese population, while in European populations it varies between 8% and 20% [71, 72]. This means that surgeons working with patients of different ethnic origins should adapt their preoperative assessment and surgical strategy to the likely anatomical configuration. Other anatomic variations include differences in the incidence of concha bullosa. A study by Al-Qudah et al., comparing patients from the Middle East and Central Europe, found that this variation was significantly more common in people of Arab origin (up to 72%) than in Europeans (about 49%) [73]. Similar observations exist for the deviation of the nasal septum, which in the Indian population shows a predominant left position, while in Caucasian populations the right side dominates [74].

Variations in ethmoidal and frontal cell architectonics also show ethnic dependence. A higher incidence of Kuhn type III and IV frontal cells has been observed in the Chinese population, creating serious challenges for surgical access to the frontal sinus [71, 73]. Likewise, pneumatization of the anterior clinoid process complicates transsphenoidal access to the pituitary gland and is more common in South Asian populations [58, 70, 71].

These differences are important not only for surgical management, but also for the interpretation of imaging studies. Imaging diagnosticians must be aware of the possible occurrence of rare or more frequent variations depending on the patient's background, so as not to interpret anatomical variations as pathological findings. Ethnic differences in the anatomical architectonics of the paranasal sinuses highlight the need for an individualized approach in the evaluation and treatment of patients with paranasal sinus and skull base pathology.

Summary and clinical recommendations

The anatomical features and variations of the nasal cavity and paranasal sinuses represent both scientific interest and a significant clinical challenge. The present literature review shows that variations such as concha bullosa, nasal septal deviations, Haller and Onodi cells, accessory foramina, and sphenoidal sinus pneumatizations should not be underestimated. They not only predispose to chronic infection, but also greatly complicate surgical access, increase the risk of damage to adjacent structures and require careful planning.

The narrow specialization of medical specialists in otolaryngology, maxillofacial surgery, and neurosurgery must include a thorough knowledge of anatomical variability, imaging interpretation, and safe intervention skills. This includes not only academic training, but also practical courses in surgical anatomy, use of simulators and navigation systems. It is also recommended that local protocols be drawn up to evaluate anatomical areas at risk, including the lamina papyracea, ethmoid roof, canalis opticus, and sinus cavernosus, in order to avoid complications with FESS and transnasal approaches. Through the integration of anatomical knowledge with clinical experience, modern imaging diagnostics and technological solutions, safe and effective treatment of diseases of the nasal cavity and sinuses can be ensured. An individualized approach and knowledge of anatomical variations are the key to modern endoscopic surgery. In Table 2, we summarize the anatomical variations and present their clinical significance.

Table 2. The most common anatomical variations and their clinical significance

Anatomical variation	Frequency (%)	Clinical significance
Nasal septum deviation	20-80%	Leads to unilateral obstruction, hypoventilation, predisposes to chronic rhinosinusitis
Concha bullosa	30-70%	Compresses the osteomeatal complex, associated with chronic sinusitis and difficult access during FESS
Haller cells	20-45%	Obstruction of the infundibulum, complicating the access to the maxillary sinus, possible lateralization
Onodi cell	8-30%	Risk of optic nerve and internal carotid artery damage during surgery
Accessory maxillary sinus ostia	30-40%	Disrupted mucociliary clearance, predispose to chronic inflammatory processes
Frontal cells type III/IV	10-25%	Complete obstruction of the frontal sinus, technically difficult access and high surgical risk
Pneumatized anterior clinoid process	5-15%	Makes transsphenoidal access difficult, increased risk in skull base interventions
Dehiscent lamina papyracea	5-10%	Increased risk of orbital complications (emphysema, hematoma, muscle damage)
Supraorbital ethmoid cells	10-20%	Restrict access to the frontal sinus, predispose to frontal sinusitis

CONCLUSIONS

Anatomical variations of the nasal cavity and paranasal sinuses represent an essential factor that affects both the physiology of breathing and the clinical course of various sinonasal diseases. Accumulating data over the past decade highlights that such variations are not simply anatomic findings, but have real clinical implications for diagnosis, therapy, and surgical management in patients with upper airway disease. The most common variations – such as concha bullosa, nasal septal deviation, Haller and Onodi cells – can impair sinus drainage and increase the risk of chronic rhinosinusitis. At the same time, some variations show a high surgical risk, especially in transnasal and craniobasal interventions, such as damage to the optic nerve or the internal carotid artery in the presence of Onodi cells or pneumatization of the anterior clinoid process. Modern imaging techniques, especially high-resolution computed tomography (CT) with intraoperative navigation, are essential for preoperative mapping of these structures and for minimizing intraoperative complications. Additional attention should be paid to population differences in the frequency of variations, which may determine an individualized surgical approach.

The presented review article provides a systematic and visually supported review of clinically relevant anatomical variations, aiming to assist clinicians, surgeons and imaging diagnosticians in the practical application of anatomically oriented medicine based on precise knowledge of individual patient characteristics.

__Supplementary Materials:__ All graphics and tables are included in the text.

__Author Contributions:__ Conceptualization, K.B. and N.Y.; methodology, K.B.; software, N.Y.; validation, D.M., N.Y. and A.F.; formal analysis, D.M.; investigation, S.M.; resources, N.Y.; data curation, K.B.; writing – original draft preparation, S.M.; writing – review and editing, A.F., D.M.; visualization, K.B.; supervision, D.M.; project administration, D.M.; funding acquisition, K.B. All authors have read and agreed to the published version of the manuscript.

__Funding:__ This research received no external funding.

__Institutional Review Board Statement:__ Not applicable.

__Informed Consent Statement:__ Not applicable.

__Conflicts of Interest:__ The authors declare no conflicts of interest.

REFERENCES

1. Stammberger HR, Kennedy DW. Anatomic Terminology Group. Paranasal sinuses:anatomic terminology and nomenclature. Ann Otol Rhinol Laryngol Suppl. 1995;167:7-16.
2. Kantarci M, Karasen RM, Alper F, et al. Remarkable anatomic variations in paranasal sinus region and their clinical importance. Eur J Radiol. 2004;50(3):296-302.

3. Fadda GL, Rosso S, Aversa S, et al. Multiparametric statistical correlations between paranasal sinus anatomic variations and chronic rhinosinusitis. Acta Otorhinolaryngol Ital. 2012;32(4):244-51.
4. Arslan H, Aydinlioğlu A, Bozkurt M, Egeli E. Anatomic variations of the paranasal sinuses: CT examination for endoscopic sinus surgery. Auris Nasus Larynx. 1999;26(1):39-48.
5. Wormald PJ. The agger nasi cell: the key to understanding the anatomy of the frontal recess. Otolaryngol Head Neck Surg. 2003;129(5):497-507.
6. Yüksel NG, Karabay N, Zeybek G, et al. Computed Tomographic Analysis: The Effects of Frontal Recess Morphology and the Presence of Anatomical Variations on Frontal Sinus Pneumatization. J Craniofac Surg. 2017;28(1):256-261.
7. Lee HY, Kim CH, Kim JY, et al. Surgical anatomy of the middle turbinate. Clin Anat. 2006;19(6):493-6.
8. Al-Abri R, Bhargava D, Al-Bassam W, et al. Clinically significant anatomical variants of the paranasal sinuses. Oman Med J. 2014;29(2):110-3.
9. Jones NS, Strobl A, Holland I. A study of the CT findings in 100 patients with rhinosinusitis and 100 controls. Clin Otolaryngol Allied Sci. 1997;22(1):47-51.
10. Bolger WE, Butzin CA, Parsons DS. Paranasal sinus bony anatomic variations and mucosal abnormalities: CT analysis for endoscopic sinus surgery. Laryngoscope. 1991;101(1 Pt 1):56-64.
11. Kennedy DW, Zinreich SJ, Rosenbaum AE, Johns ME. Functional endoscopic sinus surgery. Theory and diagnostic evaluation. Arch Otolaryngol. 1985;111(9):576-82.
12. Cherla DV, Tomovic S, Liu JK, Eloy JA. The central Onodi cell: A previously unreported anatomic variation. Allergy Rhinol (Providence). 2013;4(1):e49-51.
13. Devaraja K, Doreswamy SM, Pujary K, et al. Anatomical Variations of the Nose and Paranasal Sinuses: A Computed Tomographic Study. Indian J Otolaryngol Head Neck Surg. 2019;71(Suppl 3):2231-2240.
14. Meloni F, Mini R, Rovasio S, et al. Anatomic variations of surgical importance in ethmoid labyrinth and sphenoid sinus. A study of radiological anatomy. Surg Radiol Anat. 1992;14(1):65-70.
15. Scribano E, Ascenti G, Loria G, et al. The role of the ostiomeatal unit anatomic variations in inflammatory disease of the maxillary sinuses. Eur J Radiol. 1997;24(3):172-4.
16. Badia L, Lund VJ, Wei W, Ho WK. Ethnic variation in sinonasal anatomy on CT-scanning. Rhinology. 2005;43(3):210-4.
17. Kubota K, Takeno S, Hirakawa K. Frontal recess anatomy in Japanese subjects and its effect on the development of frontal sinusitis: computed tomography analysis. J Otolaryngol Head Neck Surg. 2015;44(1):21.
18. Hurley DB, Javer AR, Kuhn FA, Citardi MJ. The endoscopic management of chronic frontal sinusitis associated with frontal sinus posterior table erosion. Am J Rhinol. 2000;14(2):113-20.
19. Askar MH, Gamea A, Tomoum MO, et al. Endoscopic Management of Chronic Frontal Sinusitis: Prospective Quality of Life Analysis. Ann Otol Rhinol Laryngol. 2015;124(8):638-48.
20. Ramadan HH. Surgical causes of failure in endoscopic sinus surgery. Laryngoscope. 1999;109(1):27-9.
21. Bewick J, Egro FM, Masterson L, et al. Anatomic findings in revision endoscopic sinus surgery: Case series and review of contributory factors. Allergy Rhinol (Providence). 2016;7(3):151-157.
22. Papadopoulou AM, Bakogiannis N, et al. Anatomical Variations of the Sinonasal Area and Their Clinical Impact on Sinus Pathology: A Systematic Review. Int Arch Otorhinolaryngol. 2022;26(3):e491-e498.
23. Stammberger H, Posawetz W. Functional endoscopic sinus surgery. Concept, indications and results of the Messerklinger technique. Eur Arch Otorhinolaryngol. 1990;247(2):63-76.
24. Nouraei SA, Elisay AR, Dimarco A, et al. Variations in paranasal sinus anatomy: implications for the pathophysiology of chronic rhinosinusitis and safety of endoscopic sinus surgery. J Otolaryngol Head Neck Surg. 2009;38(1):32-7.
25. Midilli R, Aladağ G, Erginöz E, et al. Paranazal sinüslerin anatomik varyasyonlarinin bilgisayarli tomografi ile değerlendirilmesi ve bunlarin cinsiyetle ilişkisi [Anatomic variations of the paranasal sinuses detected by computed tomography and the relationship between variations and sex]. Kulak Burun Bogaz Ihtis Derg. 2005;14(3-4):49-56.
26. Sirikci A, Bayazit YA, Bayram M, et al. Variations of sphenoid and related structures. Eur Radiol. 2000;10(5):844-8.
27. Budu V, Mogoantă CA, Fănuţă B, Bulescu I. The anatomical relations of the sphenoid sinus and their implications in sphenoid endoscopic surgery. Rom J Morphol Embryol. 2013;54(1):13-6.
28. Aktas D, Kalcioglu MT, Kutlu R, et al. The relationship between the concha bullosa, nasal septal deviation and sinusitis. Rhinology. 2003;41(2):103-6.
29. Kaygusuz A, Haksever M, Akduman D, et al. Sinonasal anatomical variations: their relationship with chronic rhinosinusitis and effect on the severity of disease-a computerized tomography assisted anatomical and clinical study. Indian J Otolaryngol Head Neck Surg. 2014;66(3):260-6.
30. Sireci F, Cascio F, Lorusso Fet al. Correlation Between Nasal Anatomical Variants and SNOT-22 in Patients Affected by Odontogenic Sinusitis: A Retrospective Study. J. Clin. Med. 2025;14:2337.
31. Aramani A, Karadi RN, Kumar S. A Study of Anatomical Variations of Osteomeatal Complex in Chronic Rhinosinusitis Patients-CT Findings. J Clin Diagn Res. 2014;8(10):KC01-4.
32. Iturralde-Garrote A, Sanz JL, Forner L, et al. Volumetric Changes of the Paranasal Sinuses with Age: A Systematic Review. J. Clin. Med. 2023;12;3355.
33. Unal B, Bademci G, Bilgili YK, et al. Risky anatomic variations of sphenoid sinus for surgery. Surg Radiol Anat. 2006 May;(2):195-201.
34. Ramadan HH, Allen GC. Complications of endoscopic sinus surgery in a residency training program. Laryngoscope. 1995;105(4 Pt 1):376-9.
35. Orlandi RR, Kingdom TT, Hwang PH, et al. International Consensus Statement on Allergy and Rhinology: Rhinosinusitis. Int Forum Allergy Rhinol. 2016;6 Suppl 1:S22-209.
36. Orlandi RR, Kingdom TT, Smith TL, et al. International consensus statement on allergy and rhinology: rhinosinusitis 2021. Int Forum Allergy Rhinol. 2021;11(3):213-739. Erratum in: Int Forum Allergy Rhinol. 2022;12(7):974.
37. Kantarci M, Karasen RM, Alper F, et al. Remarkable anatomic variations in paranasal sinus region and their clinical importance. Eur J Radiol. 2004;50(3):296-302.
38. Sapçi T, Derin E, Almaç S, et al. The relationship between the sphenoid and the posterior ethmoid sinuses and the optic nerves in Turkish patients. Rhinology. 2004;42(1):30-4.
39. Ali IK, Sansare K, Karjodkar F, Saalim M. Imaging Analysis of Onodi Cells on Cone-Beam Computed Tomography. Int Arch Otorhinolaryngol. 2020;24(3):e319-e322.
40. Chmielik LP, Chmielik A. The prevalence of the Onodi cell – Most suitable method of CT evaluation in its detection. Int J Pediatr Otorhinolaryngol. 2017;97:202-205.
41. Carrau RL, Snyderman CH, Curtin HD, et al. Computer-assisted intraoperative navigation during skull base surgery. Am J Otolaryngol. 1996;17(2):95-101.

42. Hosemann W, Scotti O, Bentzien S. Evaluation of telescopes and forceps for endoscopic transnasal surgery on the maxillary sinus. Am J Rhinol. 2003;17(5):311-6.
43. Strauss G, Koulechov K, Röttger S, et al. Evaluation of a navigation system for ENT with surgical efficiency criteria. Laryngoscope. 2006 Apr;116(4):564-72.
44. Chaaban MR, Walsh EM, Woodworth BA. Epidemiology and differential diagnosis of nasal polyps. Am J Rhinol Allergy. 2013;27(6):473-8.
45. Batra PS. Radiologic imaging in rhinosinusitis. Cleve Clin J Med. 2004;71(11):886-8.
46. Choby G, Thamboo A, Won TB, et al. Computed tomography analysis of frontal cell prevalence according to the International Frontal Sinus Anatomy Classification. Int Forum Allergy Rhinol. 2018;8(7):825-830.
47. Kalaiarasi R, Ramakrishnan V, Poyyamoli S. Anatomical Variations of the Middle Turbinate Concha Bullosa and its Relationship with Chronic Sinusitis: A Prospective Radiologic Study. Int Arch Otorhinolaryngol. 2018;22(3):297-302.
48. Shirama YB, Adamu A, Ahmed SS, et al. Relationship between Sinonasal Anatomical Variations and Symptom Severity in Patients with Chronic Rhinosinusitis. J West Afr Coll Surg. 2020;10(1):20-25.
49. Srinivas CV, Kauser S. Anatomy and Variations of Onodi Cells and Haller Cells: A HRCT Cum Clinical Analysis in Sinonasal Disease and Polyposis. Indian J Otolaryngol Head Neck Surg. 2022;74(Suppl 2):1683-1689.
50. Al-Qudah M. The relationship between anatomical variations of the sino-nasal region and chronic sinusitis extension in children. Int J Pediatr Otorhinolaryngol. 2008;72(6):817-21.
51. Eloy JA, Friedel ME, Murray KP, Liu JK. Modified hemi-Lothrop procedure for supraorbital frontal sinus access: a cadaveric feasibility study. Otolaryngol Head Neck Surg. 2011;145(3):489-93.
52. McLaughlin RB Jr, Rehl RM, Lanza DC. Clinically relevant frontal sinus anatomy and physiology. Otolaryngol Clin North Am. 2001;34(1):1-22.
53. Dalgorf DM, Sacks R, Wormald PJ, et al. Image-guided surgery influences perioperative morbidity from endoscopic sinus surgery: a systematic review and meta-analysis. Otolaryngol Head Neck Surg. 2013;149(1):17-29.
54. Siedek V, Stelter K, Betz CS, et al. Functional endoscopic sinus surgery – a retrospective analysis of 115 children and adolescents with chronic rhinosinusitis. Int J Pediatr Otorhinolaryngol. 2009;73(5):741-5.
55. Akbar Ali M, Manish Jaiswal D, Sameer Ahamed DB, Kumari V, Alam S. A Study of Anatomical Variations of Sphenoid Sinus on CT PNS: Our Experience. Indian J Otolaryngol Head Neck Surg. 2022;74(Suppl 2):1690-1693.
56. Senturk M, Guler I, Azgin I, et al. The role of Onodi cells in sphenoiditis: results of multiplanar reconstruction of computed tomography scanning. Braz J Otorhinolaryngol. 2017;83(1):88-93.
57. Shin JH, Kim SW, Hong YK, et al. The Onodi cell: an obstacle to sellar lesions with a transsphenoidal approach. Otolaryngol Head Neck Surg. 2011;145(6):1040-2.
58. Bhattacharyya N. Do maxillary sinus retention cysts reflect obstructive sinus phenomena? Arch Otolaryngol Head Neck Surg. 2000;126(11):1369-71.
59. Wang JH, Jang YJ, Lee BJ. Natural course of retention cysts of the maxillary sinus: long-term follow-up results. Laryngoscope. 2007;117(2):341-4.
60. Fadda GL, Petrelli A, Martino F, et al. Anatomic Variations of Ethmoid Roof and Risk of Skull Base Injury in Endoscopic Sinus Surgery: Statistical Correlations. Am J Rhinol Allergy. 2021;35(6):871-878.
61. Bayram M, Sirikci A, Bayazit YA. Important anatomic variations of the sinonasal anatomy in light of endoscopic surgery: a pictorial review. Eur Radiol. 2001;11(10):1991-7.
62. Javadrashid R, Naderpour M, Asghari S, et al. Concha bullosa, nasal septal deviation and paranasal sinusitis; a computed tomographic evaluation. B-ENT. 2014;10(4):291-8.
63. Stallman JS, Lobo JN, Som PM. The incidence of concha bullosa and its relationship to nasal septal deviation and paranasal sinus disease. AJNR Am J Neuroradiol. 2004;25(9):1613-8.
64. Mikami T, Minamida Y, Koyanagi I, et al. Anatomical variations in pneumatization of the anterior clinoid process. J Neurosurg. 2007;106(1):170-4.
65. Hamid O, El Fiky L, Hassan O, et al. Anatomic Variations of the Sphenoid Sinus and Their Impact on Trans-sphenoid Pituitary Surgery. Skull Base. 2008;18(1):9-15.
66. Hui L, Hung KF, Yeung AWK, et al. Anatomical variations of the ethmoid sinuses and their association with health or pathology of the ethmoid and maxillary sinuses in a Southern Chinese population: An analysis using cone-beam computed tomography. Imaging Sci Dent. 2022;52(1):109-115.
67. Doğan E, Kilinç MR. Evaluation of paranasal anatomical variations with multidetector CT in Turkish population. Folia Med (Plovdiv). 2022;64(3):513-520.
68. Ferrareze Nunes C, Lieber S, Truong HQ, et al. Endoscopic endonasal transoculomotor triangle approach for adenomas invading the parapeduncular space: surgical anatomy, technical nuances, and case series. J Neurosurg. 2018;130(4):1304-1314.
69. Fernandez-Miranda JC, Zwagerman NT, Abhinav K, et al. Cavernous sinus compartments from the endoscopic endonasal approach: anatomical considerations and surgical relevance to adenoma surgery. J Neurosurg. 2018;129(2):430-441.
70. Abdullah SN, Abdullah B. Supreme Nasal Turbinate as an Additional Surgical Landmark in Endoscopic Sinus and Skull Base Surgeries. Cureus. 2020;12(5):e8132.
71. Lobo D, Calvo C, Maza-Solano J, et al. Evaluating the Quality and Safety of In-Office Rhinologic Procedures: A YO-IFOS Pilot Study. Surgeries. 2024;5:476-485.
72. Knisely A, Holmes T, Barham H, et al. Isolated sphenoid sinus opacification: A systematic review. Am J Otolaryngol. 2017;38(2):237-243.
73. Moss WJ, Finegersh A, Jafari A, et al. Isolated sphenoid sinus opacifications: a systematic review and meta-analysis. Int Forum Allergy Rhinol. 2017;7(12):1201-1206.