

Revisiting the Anatomy of the Paranasal Sinuses and their Radiological Correlations in Sinusitis: A Mini Review

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Abstract

This mini review aims to revisit the anatomy of the paranasal sinuses and highlight key radiological correlations relevant to the diagnosis, classification, and management of sinusitis.

A narrative mini-review was conducted using standard anatomy texts and peer-reviewed literature focusing on paranasal sinus anatomy, embryological development, anatomical variations, and imaging features of sinusitis. Emphasis was placed on radiological evaluation using high-resolution computed tomography (HRCT) and magnetic resonance imaging (MRI).

The maxillary, frontal, ethmoidal, and sphenoidal sinuses demonstrate complex anatomy, variable development, and close relationships with vital structures. HRCT remains the imaging modality of choice for assessing sinonasal anatomy, drainage pathways, and obstructive patterns. MRI provides complementary information in evaluating soft-tissue disease and complications. Common anatomical variations, including concha bullosa, deviated nasal septum, Haller cells, Onodi cells, sinus hypoplasia, and pneumosinus dilatans, were identified as important contributors to impaired sinus drainage and recurrent or chronic sinusitis. Distinct imaging patterns were noted in acute, chronic, and allergic fungal rhinosinusitis, as well as in orbital, intracranial, and osseous complications.

Keywords: Paranasal sinuses; Sinusitis; Computed tomography; Magnetic resonance imaging; Anatomical variations

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Introduction

Paranasal sinus pathologies, including sinusitis, remain one of the most common clinical conditions encountered in primary care, ENT practice, and radiology departments worldwide. Although often considered a routine diagnosis, the underlying anatomical and radiological foundations are far from simple. Understanding the complex anatomy of the paranasal sinuses, along with their embryological development, drainage pathways, anatomical variations, and imaging appearances, is essential for accurate evaluation, preventing complications, and planning appropriate management.

This article revisits the anatomy of the paranasal sinuses, discussing how modern radiology, particularly CT and MRI, plays a crucial role in diagnosing sinusitis and its complications, while highlighting the relevance of common anatomical variations frequently encountered in clinical practice.

Introduction to Paranasal Sinuses

The paranasal sinuses are air-filled cavities located within the skull and facial bones. These include the maxillary, frontal, ethmoidal, and sphenoidal sinuses. Sinuses are lined by pseudostratified ciliated columnar epithelium, which aids in humidifying inspired air and clearing mucus through coordinated ciliary movement. These spaces also contribute to voice resonance, reduction of skull weight, and protection against facial trauma.

Despite their functional importance, the sinuses are more prone to obstruction, mucosal inflammation, and infection, largely due to their narrow drainage pathways. When these outflow tracts become obstructed, a range of

complications, including sinusitis, develops.

Revisiting the Anatomy of the Paranasal Sinuses

Maxillary Sinus

The maxillary sinus is the largest of the paranasal sinuses, pyramidal in configuration, and the most frequently affected sinus in inflammatory disease. It is located within the body of the maxilla, with its medial wall forming the lateral boundary of the nasal cavity and its apex extending laterally into the zygomatic process (Figure 1a). Inferiorly, the sinus floor is related to the alveolar part of the maxilla and lies in proximity to the roots of the premolar and molar teeth, with odontogenic communication reported in up to 40% of individuals (1). The close anatomical relationship, together with shared sensory innervation via the superior alveolar branches of the maxillary nerve, explains the frequent overlap between dental pathology and maxillary sinus symptoms. Superiorly, the roof of the sinus contributes to the orbital floor and contains the infraorbital nerve, together with the superior alveolar branches of the maxillary nerve, which provide sensory innervation to the region. The maxillary sinus ostium is situated on the posterosuperior aspect of the medial wall. It drains into the middle meatus of the lateral nasal wall via the posterior part of the infundibulum. Because of this high, non-dependent position, effective drainage depends on intact mucociliary clearance rather than gravity. This anatomical configuration predisposes to secretion retention and recurrent maxillary sinusitis, particularly when mucosal oedema, anatomical variation, or obstruction of the ostiomeatal complex is present. (1,2)

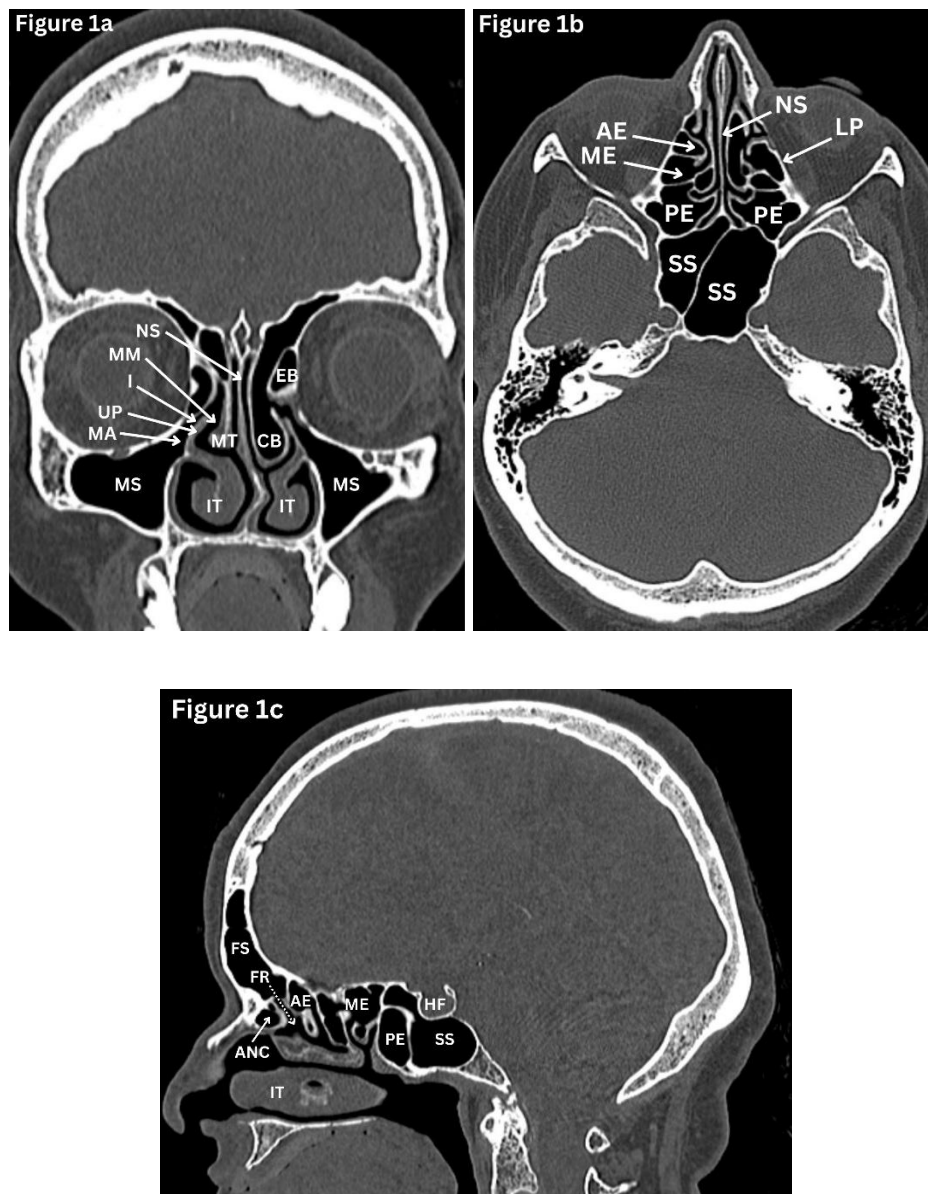


Figure 1a-c: HRCT paranasal sinuses (bone window). a-Coronal; b-Axial; c-Sagittal images. NS: Nasal septum; MT: Middle turbinate; IT: Inferior turbinate; MM: Middle meatus I: Infundibulum; UP: Uncinate process; MA: Maxillary antrum; MS: Maxillary sinus; AE: Anterior ethmoid sinus; ME: Middle ethmoid sinus; PE: Posterior ethmoid sinus; SS: Sphenoid sinus; FS: Frontal sinus; EB: Ethmoid bulla; CB: Concha bullosa; LP: Lamina papyracea; FR: Frontal recess; ANC: Agger nasi air cell; HF: Hypophyseal fossa.

Frontal Sinus

The frontal sinuses are unique among the paranasal sinuses in that they are absent from birth and develop later in childhood. They are the most superiorly positioned sinuses and are located within the frontal bone. The frontal sinuses exhibit marked variation in size and symmetry among individuals. Drainage of the sinus occurs via the frontonasal duct into the middle meatus (Figure 1c). Sensory innervation is provided by the supraorbital nerve, while vascular supply is derived from branches of the ophthalmic artery. Due to their highly variable anatomy and close proximity to the anterior cranial fossa and the orbit, the frontal sinuses present challenges during surgical intervention and carry an increased risk of intracranial complications in the context of frontal sinusitis (1, 2).

Ethmoidal Sinuses

The ethmoid labyrinth contains multiple small air cells arranged in anterior, middle, and posterior groups (Figure 1a-c). The number of ethmoid air cells varies between individuals, but they typically consist of about seven smaller anterior cells and four larger posterior cells. Their anatomical boundaries are clinically important. The anterior and middle cells drain into the middle meatus, while the posterior cells drain into the superior meatus. The ethmoid sinuses are separated from the orbit by the delicate, paper-thin lamina papyracea, making orbital complications of ethmoiditis potentially risky. Both nerve and blood supply arise from branches of the ophthalmic nerve and artery (1, 2).

Sphenoid Sinus

Sphenoid sinuses are a pair of sinuses separated by a septum and situated deep within the sphenoid bone (Figure 1c). The

sphenoid sinus demonstrates considerable variation in size. When underdeveloped, it lies anterior to the pituitary fossa, but with increasing pneumatization, it extends beneath the fossa. Posterior extension into the basiocciput may occur, and in extensively pneumatized sinuses, aeration can also involve the greater wing of the sphenoid and the pterygoid processes. The sphenoid sinus drains into the sphenoethmoidal recess. It is closely related to the optic nerve, cavernous sinus, pituitary gland, and internal carotid arteries. Even minor pathology in this region may result in significant neurological or visual symptoms (1, 2).

Embryological Development

The paranasal sinuses develop as mucosal outpouchings from the nasal cavity. The ethmoturbinals appear around the seventh week of fetal life and give rise to the middle and superior turbinates. The maxillary sinus begins to form at approximately the tenth week of gestation, while the ethmoid air cells progressively expand from the fifth month of fetal life. The sphenoid sinus has a prenatal origin; however, clinically significant pneumatization occurs mainly during childhood, with the sinus becoming fully aerated by around 14 years of age. The frontal sinus is the last to develop, typically becoming radiologically apparent after the age of six to seven years and continuing to mature through adolescence. Its size and configuration generally stabilize by late adolescence to early adulthood, around 18–20 years of age. The developmental timelines and maturation patterns of the paranasal sinuses are summarized in Table 1 (3,4). Knowledge of embryology helps explain the variations found in adults and offers forensic value, particularly in age estimation and individual identification.

Table 1: Embryological development of paranasal sinuses

Sinus	Time of Initial Development	Key Developmental Features	Maturation
Ethmoid	~7th week of gestation	Arises as mucosal outpouchings from the nasal cavity. Ethmoturbinals form the middle and superior turbinates. Anterior cells present at birth; posterior cells pneumatise later.	Expands during infancy and early childhood
Maxillary	~10th week of gestation	Develops as an invagination from the ethmoid infundibulum. Enlargement parallels facial growth and dental eruption.	Continuous growth through childhood and adolescence
Sphenoid	Prenatal origin	Begins as marrow conversion within the sphenoid bone, followed by postnatal pneumatization.	Fully aerated by ~14 years
Frontal	After 6–7 years	Develops from upward extension of anterior ethmoid cells into the frontal bone.	Stabilizes around 18–20 years

Osteomeatal Complex (OMC)

The osteomeatal complex is the functional hub of sinus drainage. It includes:

- The middle meatus
- The ethmoidal infundibulum
- The hiatus semilunaris
- The uncinate process

Obstruction at any level of the OMC compromises drainage of the maxillary, frontal, and anterior ethmoid sinuses. Even minimal mucosal thickening in this region may disrupt normal ventilation and predispose to recurrent or chronic sinusitis. On high-resolution CT (HRCT), assessment of osteomeatal complex patency is therefore a key determinant in the evaluation of sinonasal disease and in planning endoscopic sinus surgery.

Radiological Evaluation of Paranasal Sinuses***A. Plain X-Ray***

Plain X-rays have clear limitations because the sinus walls and other facial bones overlap. They also cannot clearly show soft tissue detail. However, they can still be useful for a quick look at the maxillary

sinuses, especially in areas where CT is unavailable. Common findings include fluid levels inside the sinus, complete opacity of the cavity, or thickening of the sinus lining. However, plain radiography has significantly lower sensitivity and specificity than sinus HRCT, especially for detecting early mucosal disease, anatomical variations, and ethmoid or sphenoid sinus involvement. The Waters, Caldwell, lateral, and submento-vertex views have traditionally been used to assess the different sinus compartments (5). Still, their role has largely been replaced by HRCT in contemporary practice due to its superior anatomical detail and multiplanar capability.

B. High-resolution computed tomography

High-resolution axial and coronal computed tomography is considered the method of choice in evaluating paranasal sinuses. It provides excellent anatomical detail, including anatomical variations, identifies obstructive patterns, and guides pre-operative planning and post-operative follow-up in cases of endonasal

interventions. It visualizes mucosal thickening, polyps, bony de-arrangements, fungal nodules, and OMC anatomy (5, 6).

C. MRI

MRI provides complementary information to HRCT. MRI is valuable in assessing soft-tissue abnormalities, differentiating tumors from inflammatory processes, fungal sinusitis and evaluating complications such as orbital or intracranial extension (6, 7).

D. Ultrasound

Sinus ultrasonography offers a rapid, safe, and inexpensive method for assessing fluid levels in cases of acute and subacute maxillary sinusitis. With minimal training, it can be effectively applied by clinicians in acute care and general practice settings (8).

E. Angiography

Reserved for suspected vascular complications such as aneurysm or venous thrombosis.

Anatomical Variations and Their Relevance in Sinus Disease

Anatomical variations are common and often asymptomatic. However, certain variants can predispose to sinus obstruction or increase the complexity of surgical intervention.

Anatomical variations of sinuses

Anatomical variation of the paranasal sinuses is common and has important clinical and surgical implications. Variants of the maxillary sinus include internal septation, the presence of accessory ostia, and varying degrees of sinus hypoplasia. In cases of maxillary sinus hypoplasia, endoscopic intervention carries an increased risk of orbital entry, either through the lamina papyracea or the sinus roof, owing to altered anatomical relationships (Figure 2). The frontal sinuses frequently exhibit asymmetry in size and

extent and are typically separated by a midline bony septum. One or both frontal sinuses may be markedly underdeveloped or absent in certain individuals. The sphenoid sinus demonstrates wide variability of variations, ranging from partial or complete agenesis to extensive pneumatisation, including extension into the clinoid processes and adjacent pterygoid or ethmoid bones (Figure 3). Variations in sphenoid septation, such as deviation or the presence of multiple septa, further contribute to the complexity of this region and are particularly relevant during surgical planning (9, 10) (Figure 4).

Concha Bullosa (CB)

This refers to a pneumatised vertical part of the middle turbinate (Figure 5). Concha Bullosa is observed in approximately 24–55% of individuals and is most commonly present on both sides of the nose (11). This variation may compress the OMC, leading to nasal obstruction or recurrent rhinosinus infections.

Deviated Nasal Septum (DNS)

This is defined as the displacement of the nasal septum from the midline, resulting in an increased angle of the septum detected on a coronal CT scan or nasal endoscopy (Figure 6). A significantly deviated septum reduces airflow and alters mucociliary clearance. It may narrow the middle meatus, thereby increasing the risk of chronic rhinosinusitis in maxillary or ethmoidal sinuses (11).

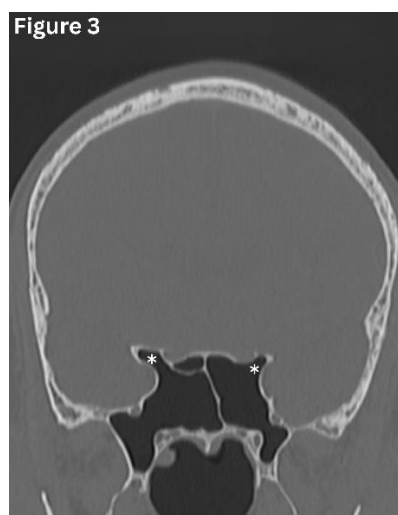
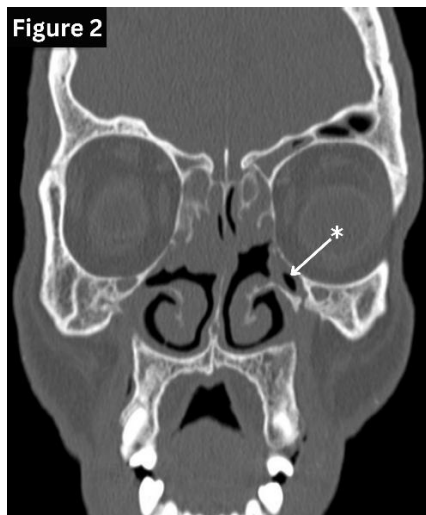


Figure 2: Coronal CT image shows hypoplastic both maxillary sinuses (arrow). (Figure 2: courtesy of Fakhry Mahmoud Ebouda, Radiopaedia.org, rID: 60030) **Figure 3:** Coronal CT image shows pneumatization of the sphenoid sinus extending into the anterior clinoid processes (asterisks). **Figure 4:** Coronal CT image shows multiple septations in the sphenoid sinus, creating multiple compartments. (asterisks)

Onodi Cells (OC)

Onodi cells are defined as posterior-most ethmoid cells, extend up to the sphenoid sinus and anterior clinoid processes (Figure 7). Their prevalence ranges from approximately 3% to 66% based on CT findings (12). Onodi cells have a close relationship with the sphenoid sinus, optic nerve, and internal carotid artery, which increases the risk of complications during endoscopic sinus surgery (12). Understanding these variations using sinus HRCT ensures safer and more effective sinus surgery. In addition, inflammation of the Onodi cell can lead to visual symptoms because of its intimate anatomical relationship with the optic nerve (11).

Haller Cells (HC)

Haller cells are infraorbital ethmoid air cells that arise from the anterior ethmoid complex and extend into the region of the maxillary sinus roof, along the inferomedial aspect of the orbital floor (Figure 8). Haller cells vary in size, shape, and number. On

coronal CT images, HC appears as a teardrop-shaped (round or oval) radiolucent area, which may be unilateral or bilateral. It has been associated with narrowing of the infundibulum, leading to nasal obstruction, chronic maxillary rhinosinusitis, and the development of mucocoeles. (13)

Pneumosinus dilatans

Pneumosinus dilatans (PSD) is characterized by abnormal expansion of a paranasal sinus beyond its normal boundaries, while maintaining normal mucosal lining and preserving bony walls (Figures 9 and 10). It is a developmental variant and is most often seen in the frontal, sphenoid, and maxillary sinuses. PSD most often affects a single sinus rather than multiple cavities, with isolated involvement reported in nearly 80% of cases (14). It is frequently detected incidentally on imaging. However, some may present with frontal bossing and a spectrum of visual disturbances, including proptosis, diplopia and headache. This predisposes to recurrent

episodes of sinusitis due to impairment of normal sinus drainage (14).

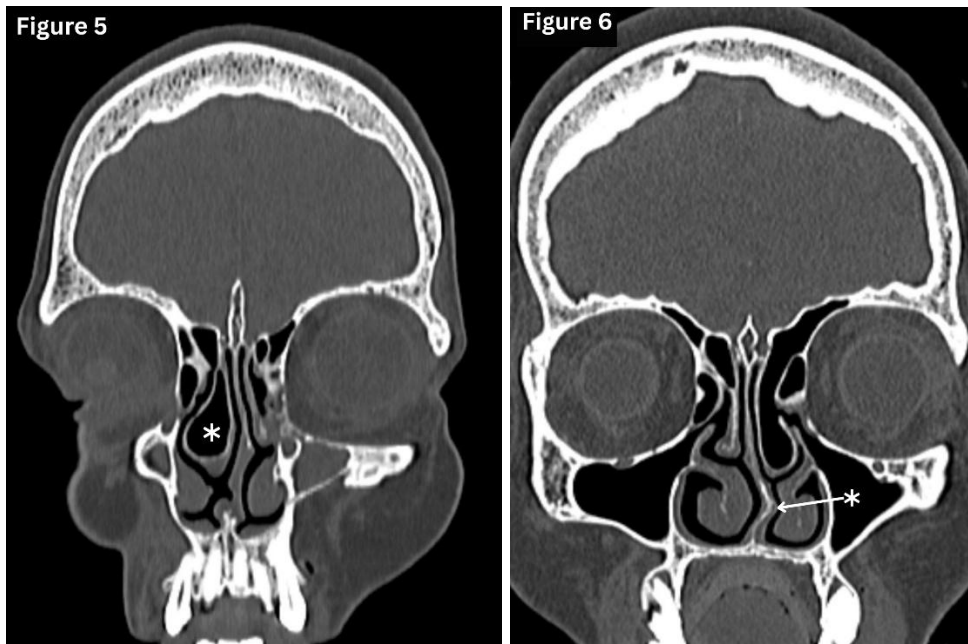


Figure 5: Coronal CT image shows pneumatization of the right middle turbinate-conchabullosa.

Figure 6: Coronal CT image shows mild nasal septal deviation towards the left side with a bony spur.

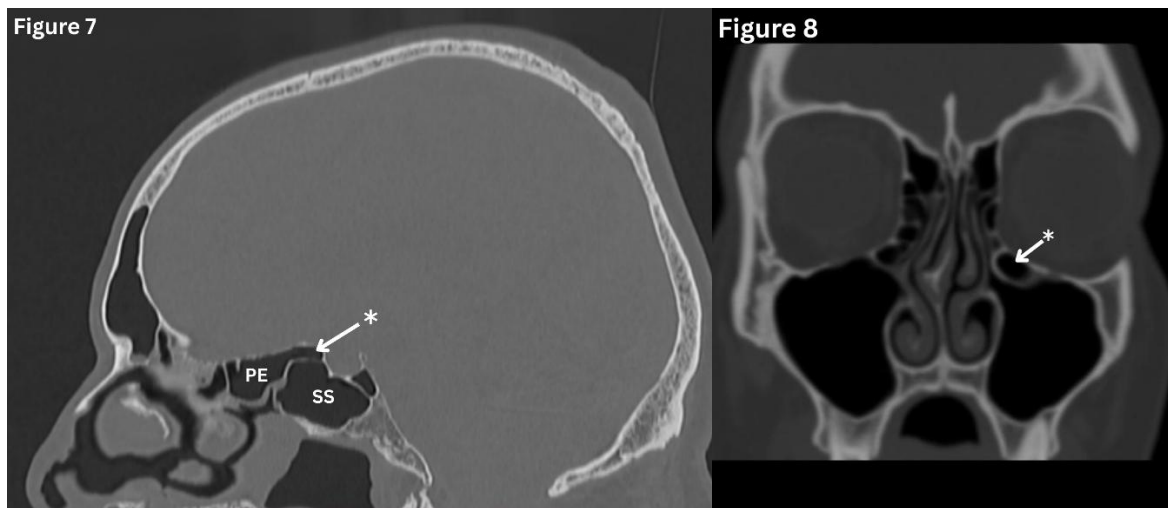


Figure 7: Sagittal CT image shows posterior-most ethmoid cells, extending over the sphenoid sinus (Onodi cells) (Arrow). **Figure 8:** Coronal CT image shows a teardrop-shaped air cell (Haller Cell) located at the inferomedial aspect of the orbital floor. (Arrow) **Figure 8-** Courtesy of The Radswiki, Radiopaedia.org, rID: 11469

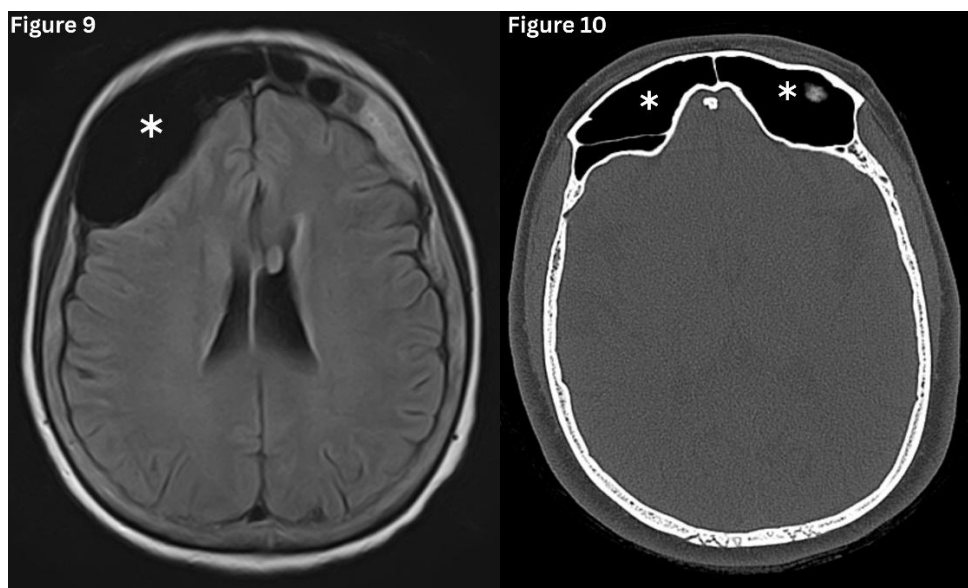


Figure 9: Axial MRI- FLAIR image shows abnormal pneumatisation of the right frontal sinus.

Figure 10: Axial CT image shows excessive pneumatisation of both frontal sinuses.

Pathophysiology of Sinusitis

Sinusitis results from mucosal inflammation triggered by infection, allergies or anatomical obstruction. When sinus drainage is impaired, mucus accumulates, becomes stagnant, and invites microbial proliferation, leading to recurrent or chronic disease (15).

Types of Sinusitis and Imaging Patterns

Acute sinusitis typically demonstrates air–fluid levels, diffuse mucosal thickening, and narrowing of the sinus drainage pathways on imaging (Figure 11). Chronic sinusitis develops over several months and

is characterized by persistent polypoid mucosal thickening, bony remodeling, and sclerosis of the sinus walls on sinus HRCT (Figures 12 and 13). Allergic fungal rhinosinusitis is characterized by expanded sinuses containing centrally hyperdense inspissated mucin, accompanied by a peripheral hypodense mucosal rim, often in association with nasal polyps, as seen on HRCT. Recurrent and subacute sinusitis exhibits overlapping features of both acute and chronic disease. This is often associated with partial ostial obstruction or underlying anatomical variations (5, 16).



Figure 11: Axial MRI- FLAIR image shows Fluid levels in the sphenoid sinus with mucosal oedema consistent with acute sphenoid sinusitis. **Figure 12:** Coronal MRI- T2 image shows significant mucosal thickening in the left maxillary and ethmoid sinuses consistent with chronic rhinosinusitis. **Figure 13:** Coronal CT demonstrates extensive chronic rhinosinusitis with complete opacification of the maxillary and ethmoid sinuses and near-total nasal cavity obliteration.

Complications of Sinusitis

Complications of sinusitis largely arise from direct extension of infection, indicating the close anatomical relationship between the paranasal sinuses and adjacent vital structures. Orbital complications, most often associated with ethmoid sinusitis, may be presented as orbital cellulitis, subperiosteal abscess, or orbital abscess, carrying a risk of visual impairment and ophthalmoplegia. Intracranial involvement is more commonly associated with frontal or sphenoid sinusitis. Complications include meningitis, brain abscess, subdural empyema, and cavernous sinus thrombosis. Osseous complications may also occur, particularly sinus wall osteomyelitis, typically manifesting as Pott's puffy tumour. Maxillary sinusitis is also frequently associated with oral and dental symptoms, including upper toothache, facial discomfort, and tenderness over the alveolar region. This reflects the close anatomical relationship between the maxillary sinus floor and the roots of the premolar and molar teeth, as well as their

shared sensory innervation via the superior alveolar branches of the maxillary nerve. Early and appropriate radiological assessment is essential to limit morbidity and prevent permanent sequelae (15,16).

Conclusion

A deep understanding of paranasal sinus anatomy and its radiological relationships is fundamental to diagnosing and managing sinusitis effectively. Radiology not only identifies mucosal disease but also reveals anatomical variants, assesses drainage pathways, and detects life-threatening complications. CT and MRI have transformed sinus evaluation, enabling clinicians to approach sinusitis with greater precision, safety, and insight.

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Availability of data and materials: Acquired DICOM medical images during the current review are available from the corresponding author upon reasonable request. The subject's identifying information was removed from the radiology images.

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

Ethical Approval: Ethical approval was not considered, as our work is a narrative review. However, we have secured informed consent to publish radiological images from each patient. Additionally, we have intentionally removed identifying information from the radiology images. Image credits are provided for Figures 4 and 8. Consent was obtained in the local and English languages; track versions without and fully completed consent forms are available upon request.

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