

Anatomic and physiologic considerations in sinusitis

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The anatomy and physiology of the nose, the paranasal sinuses, and related structures are of major importance in understanding sinusitis. A brief description of the airflow, blood flow, nasal cycle, histology and the developmental anatomy are given. These elements combine to condition inhaled air by warming, humidifying, and filtering it. An important mechanism for understanding sinusitis is mucociliary clearance. The nasal cavity and the paranasal sinuses are covered by a pseudostratified, columnar, ciliated epithelium with a thin mucous layer on top of it. In the sinuses the beat of the cilia is directed toward their natural ostia. The ostia of most of the paranasal sinuses lead into the region of the middle meatus and the anterior ethmoid, the osteomeatal complex. Obstruction in this area reduces clearance and plays a major role in the pathophysiology of sinusitis. (J ALLERGY CLIN IMMUNOL 1992;90:419-23.)

Key words: Nose, mucociliary transport, nasal cycle, sinuses, ethmoid, frontal, maxillary, sphenoid

Clinicians must appreciate the anatomy and physiology of the upper airway to fully understand sinusitis. This article provides a brief overview of the anatomy of the nose and the paranasal sinuses, its ostia, and related structures.

The nose conditions inhaled air and supplies water and heat. To assist in those functions, the nose must have a large surface area. The nasal septum, which consists of a cartilaginous anterior and a bony posterior part, separates the two nasal cavities, doubling the surface area. The mucosal surface is further increased by the three bony nasal turbinates. Anatomically and physiologically, the lower and the middle conchae are dominant. The nasal mucosa covers 100 to 200 cm² surface area and consists of a pseudostratified, ciliated, columnar epithelium. Goblet cells in the epithelium and submucosal seromucous glands contribute to the mucous layer that covers the epithelium. The mucous layer is 10 to 15 μ m thick and is continuously moved by the cilia at a speed of 6 mm/min.¹

The filling of the cavernous plexus in the submucosa

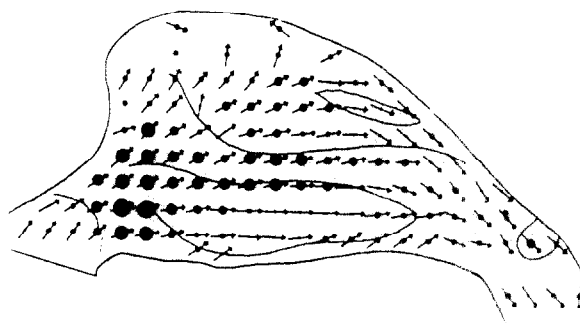


FIG. 1. Speed and direction of the inspiratory airflow in the nose. Size of the dots indicates velocity. (From Proctor DF, Anderson IB, eds. *The nose-upper airway physiology and the atmospheric environment*. Amsterdam: Elsevier Science Publishers, 1982:580.)

largely determines the thickness of the mucosa. It varies regularly during the physiologic nasal cycle. While total nasal airway resistance remains stable, each side alternates within a period of hours between congestion and decongestion.² Inflammation, caused, for example, by allergies or infections, can also lead to swelling of the mucosa. Anatomic preconditions will determine whether this will lead to obstruction as well as which areas will be affected. For example, nasal polyps frequently block the stream of air reaching the rima olfactoria in the superior parts of the nose, and the sense of smell is diminished or even lost. Another example relates to septal deflections. Airflow through the nasal cavity has a preferred route (Fig. 1). A deviation in a certain area, such as the anterior, will have more pronounced effects than those in the middle floor region. Additionally, the

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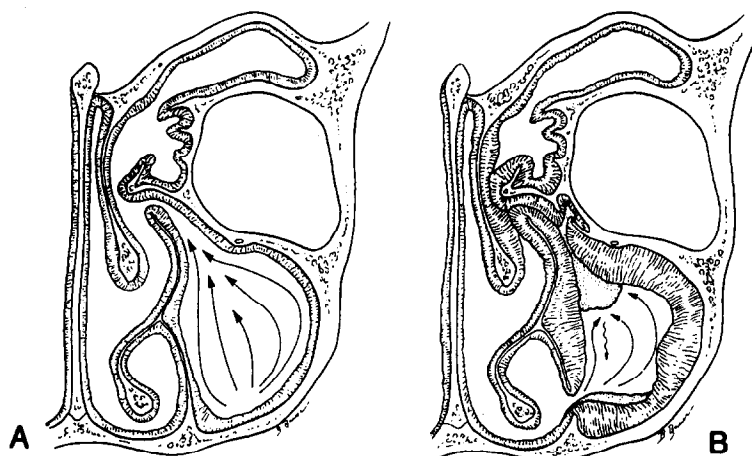


FIG. 2. **A**, Direction of mucociliary clearance in the maxillary sinus in normal conditions. **B**, Direction of mucociliary clearance in the diseased maxillary sinus after nasal antral windows. (From Graney DO. Anatomy. In: Cummings CW, et al., eds. Otolaryngology—head and neck surgery Vol. 1. St. Louis: The CV Mosby Co, 1986:846-50.)

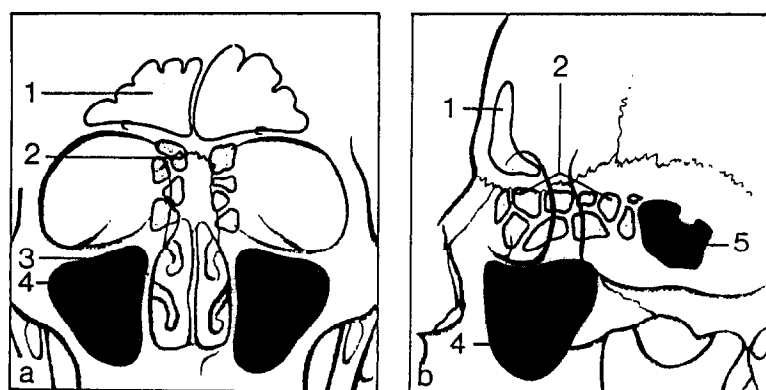


FIG. 3. Paranasal sinuses. **a**, Frontal view. **b**, Sagittal view. 1, Frontal sinus; 2, ethmoid sinus; 3, maxillary ostium; 4, maxillary sinus; 5, sphenoid sinus. (From Becker W, et al. Hals-Nasen-Ohren-Heilkunde. 4th ed. Stuttgart: Georg Thieme Verlag, 1989:247, 646.)

paranasal sinuses can be obstructed by anatomic variants.

The paranasal sinuses, like the nasal cavity, are lined by a pseudostratified, ciliated epithelium. The epithelium of the sinuses, however, contains fewer goblet cells and is thinner. A mucous blanket covers the epithelial surface. In all sinuses, mucus moves towards the natural ostia, which, in the case of the maxillary sinus, means against gravity. This direction is innate and remains unchanged after surgery (Fig. 2).³

The functional significance of the paranasal sinuses has been the subject of many hypotheses. They are thought to supply resonance to the voice, protect the ear from one's own speech, equalize pressure differences, help condition inhaled air by supplying already warmed and humidified air, aid in olfaction, reduce

the weight of the skull, and protect the intracranial structures from trauma. None of these hypotheses has been confirmed.

The size of the sinuses varies widely and is dependent on the age of the patient. Maxillary and ethmoid sinuses are present from birth, whereas the frontal and sphenoid sinuses develop later in childhood (5 and 9 years, respectively). This is a very important consideration in the management of pediatric patients.

The maxillary sinus is the largest of the paranasal sinuses. It is shaped like a pyramid with its base at the lateral nasal wall and the apex in the zygomatic process of the maxilla. The roof is the inferior wall of the orbit, whereas the floor is in close proximity to dental roots and in adults lies 4 to 5 mm inferior to the floor of the nasal cavity (Fig. 3). The natural ostium is located at the superior aspect of the maxillary

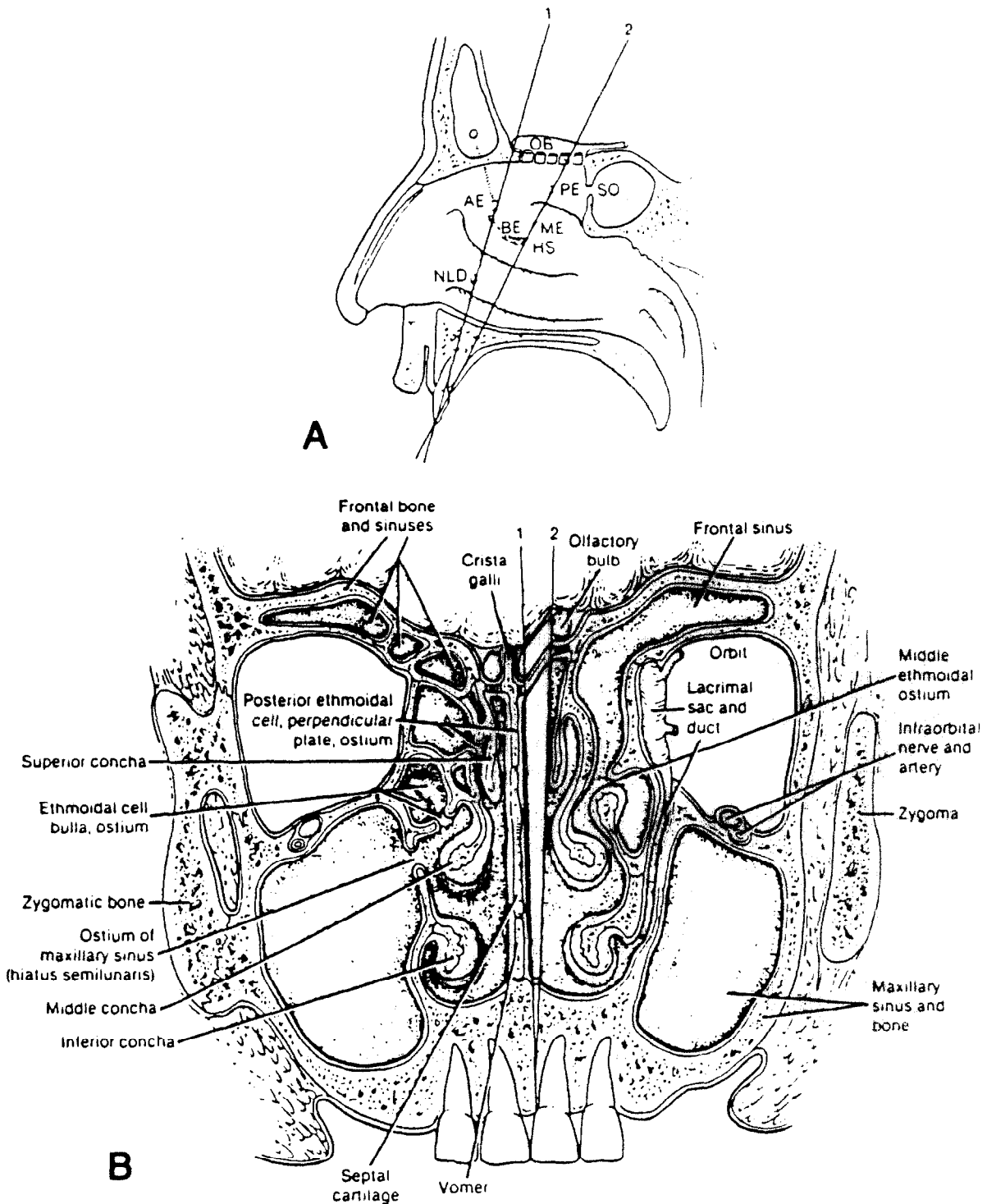


FIG. 4. A, Sagittal section of the nose. *OB*, Olfactory bulb; *SO*, sphenoid ostium; *PE*, posterior ethmoidal ostium; *ME*, middle ethmoidal ostium; *AE*, anterior ethmoidal ostium; *BE*, bulla ethmoidalis; *HS*, hiatus semilunaris; *NLD*, nasolacrimal duct. 1 and 2 = sectioning planes for B. **B,** Coronal sections of the nose and related structures. (From Graney. *Anatomy*. In: Cummings CW, et al., eds. *Otolaryngology—head and neck surgery*. Vol 1. St. Louis: The CV Mosby Co. 1986:846-50.)

sinus and opens in the lateral wall of the nose (Fig. 4). It leads into the infundibulum and finally into the hiatus semilunaris of the middle meatus. Its form and size are variable, and frequently (25% to 30%) accessory ostia are associated with it.⁴ Rather than clearance through the latter, mucus can recirculate between the accessory and the natural ostia, which leads to mucus retention.

The ethmoid sinuses consist of a complex system of air-filled cells located in the lateral nasal wall and medial to the orbit (lamina papyracea) (Fig. 3). They are divided into anterior and posterior cells by the grand lamella of the middle concha. The ostia of the anterior cells open into the hiatus semilunaris, whereas the posterior cells have their ostia in the superior meatus (Fig. 4). The ostia of the ethmoid sinuses measure only 1 to 2 mm in diameter, which makes them prone to occlusion.

The frontal sinuses in the frontal bones vary widely in size and extension. They are asymmetric in shape, and partial or complete aplasia is common. They usually open through a narrow recess into the superior part of the hiatus semilunaris (Fig. 4).

The sphenoid sinuses are located deep in the skull and are surrounded by many important anatomic structures such as the optic nerve, the internal carotid artery, the sinus cavernosus, and the vidian nerve of the canalis pterygoideus (Fig. 3). The ostium opens into the sphenoethmoidal recess posterior and superior to the superior concha (Fig. 4).

Most infections occur in sinuses that open into the middle meatus, the area between the lower and the middle turbinate, namely, the maxillary, the anterior ethmoid, and the frontal sinuses. Interestingly, the middle meatus bears the major part of the inspiratory nasal airflow, and thus the airflow changes from an upward to a horizontal direction, which causes many inspired particles to impact here (Fig. 1).⁵ Studies show that this area is the primary site for the development of adenocarcinomas in woodworkers and the development of mucosal changes and squamous carcinoma in nickel-exposed workers.^{6, 7}

Computerized axial tomographic scans and endoscopic evaluation of sinus disease allow a characterization of anatomic variations and pathologic conditions in this area. It has become clear that (chronic) infection of the maxillary and frontal sinuses is almost always accompanied and probably preceded by disease of the ipsilateral anterior ethmoid region, suggesting a rhinogenic origin.⁸⁻¹⁰ The middle meatus and the region of the anterior ethmoid are often described together as the ostiomeatal complex.¹¹ Clinical observations underline the relevance of this area, which shows that even severe mucosal disease of the frontal

and maxillary sinuses can be resolved when mucociliary clearance and normal airflow are restored by endoscopic surgery of the ostiomeatal complex.⁸ In normal anatomic conditions the ostiomeatal complex is very narrow. Abnormalities that reduce the distance between the mucosal surfaces are potential risk factors for the development of sinus disease. A large number of such conditions and the relevance of each are frequently discussed.¹⁰ Only the conjunction of clinical history, endoscopic nasal examination, and coronal computed tomographic scans, however, will reveal the relevance in the individual case, especially because studies of computerized tomographic scans have shown anatomic changes and even mucosal thickening in a high number of healthy subjects.¹⁰

The following paragraph gives a brief description of some clinically important structures that can narrow the middle meatus. Generally, variations in bony structures or inflammation can lead to ostial obstruction and eventually to inflammation of the related sinus.

Among those, septal deviations and spurs are the most easily detected. They can reach into the middle meatus, and in severe cases the mucosal surfaces of the septum and the lateral nasal wall touch.

All other structures that can increase the risk of sinusitis are located in the lateral nasal wall and are only occasionally detectable by anterior rhinoscopy. A concha bullosa, a pneumatized head of the middle turbinate, is believed to be the most frequent anatomic cause of recurring sinusitis.¹⁰ The middle turbinate can be bent paradoxically, sometimes even touching the lateral nasal wall with its convex side. The ethmoidal bulla, which is the anterior face of the ethmoidal cells, represents the superior and posterior border of the hiatus semilunaris. Anterior to the ethmoidal bulla, the frontal recess opens, and it can be affected by changes in its size. The inferior margin of the hiatus semilunaris is built by the uncinate process, which can also be air filled. Haller cells are ethmoidal cells that reach into the maxillary sinus and can obstruct the infundibulum and the maxillary ostium. The drainage of the frontal sinus can be impaired by agger nasi cells. Most of these structures are normal variations of the bony anatomy, and it should be carefully determined for each case if they play a role in the pathophysiologic process.

On the other hand, nasal polyps are pathologic changes in the nasal mucosa. They are located mostly on the lateral wall of the nose in the middle meatus and frequently originate in the ethmoid sinuses. Sometimes they also arise from the maxillary and sphenoid sinuses. Whether they are the cause or the result of chronic sinusitis is the subject of much discussion.

However, when they exist, they often obstruct the ostia of the paranasal sinuses and thus increase the likelihood of sinusitis.

It is widely accepted that ostial obstruction is a primary pathophysiologic mechanism in sinusitis. It can be caused by anatomic variations or by mucosal inflammation, and in many cases the combination of these two leads to recurring or chronic infections of the paranasal sinuses. During the past few years the greater appreciation of anatomy and physiology has had a major impact on the therapeutic approach to sinus disease.

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DISCUSSION

Dr. Spector. I have a few questions. One deals with the normal cycling of the nose. It is an interesting phenomenon. Can you think of a physiologic purpose for the advantage of why the nose cycles?

Dr. Naclerio. The total airflow through the nasal cavity remains fairly uniform, while in about 80% of normal individuals, there is an alternating flow between side to side. The reason for this cycle is unknown. Some postulate that it allows one side to rest while the other side takes over most of the filtering and warming of the air. Thus there may be some recuperative activities, permitted by the nasal cycle.

Dr. Spector. The second question is on the interesting work you have done with cold air.

Dr. Naclerio. Is it good or bad to have your nose run in response to cold air temperature? In other words, is it an important compensatory mechanism that helps warm and humidify the air, or is it just a nuisance? If it is a nuisance, you want to block it, and the only agents known to block the response are anticholinergics.

People who respond to cold air may or may not have a history of allergies. If you take a patient who is both allergic and has a history of cold air sensitivity and you induce allergic inflammation and then expose them to cold air, the response is much greater.