Surgical Techniques in Otolaryngology—Head & Neck Surgery

SINONASAL SURGERY



Series Editor

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CHAPTER

2

Physiology of the Nose and Paranasal Sinuses

Erika McCarty Walsh, Bradford A Woodworth

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INTRODUCTION

The nose is a dynamic unit that works to purify and condition air while functioning as a sensory organ. The sinonasal unit conditions inhaled air, and nasal conditioning is a direct consequence of the unique anatomy and physiology of the upper airway. The sinonasal cavity is an efficient barrier against constant bombardment by pathogens. However, transient or chronic aberrations in the structure and function of the sinonasal cavity may result in rhinosinusitis and other sinus and nasal disorders. This chapter details sinonasal physiology as it relates to air flow dynamics, host defense, and olfaction.

AIR FLOW DYNAMICS

Advances in technology, particularly computational fluid dynamics, have improved our understanding about the structure and function of the nose. Airflow into the nasal vestibule is laminar, or smooth and linear, in nature. However, once air encounters the resistance of the nasal valve and turbinates, the flow pattern becomes transitional. Transitional air flow has mixed laminar and turbulent properties, increasing the exposure of respiratory debris, including antigens and olfactants, to respiratory mucosa. Notably, turbulence is nearly absent during expiration, underlining its importance in filtration of inhaled air.[1] The nasal valve is the flow limiting structure for inhaled air, providing at least half of the total resistance of inspired air to the lungs.[2] The nasal valve is small, with a cross-sectional area of approximately 40 mm^2, and has external and internal components. The external nasal valve exists between the lateral and medial crura of the lower lateral cartilage, and the internal nasal valve resides between the upper lateral cartilage and the septum. At high inspiratory velocities, the nasal valve may completely collapse secondary to the Bernoulli effect. An additional example of the dynamic properties of the sinonasal unit is the nasal cycle. The nasal cycle refers to an alternating pattern of congestion whereby the total nasal resistance remains unchanged but the resistance of each nasal cavity reciprocally increases and decreases (Fig. 2.1). Although the functional significance of the nasal cycle is uncertain, it is controlled by inputs from the hypothalamus, suggesting a homeostatic or autoregulatory role.[3] The turbinates are three shelves of bone and soft tissue attached to the lateral nasal wall. The turbinates add surface area to the nasal epithelium, providing greater territory for conditioning. The nasal mucosa and inferior and middle turbinates especially serve to warm and humidify the air, preparing it for gas exchange in the alveoli.[4] Even at high air flow rates and

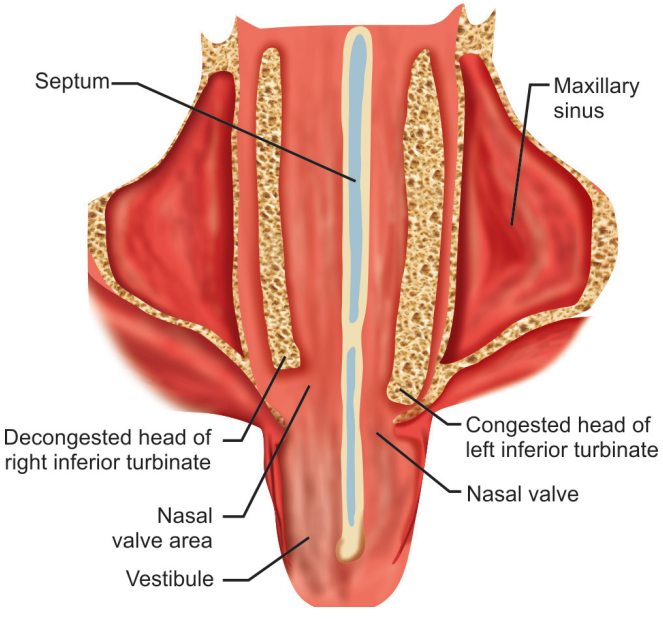
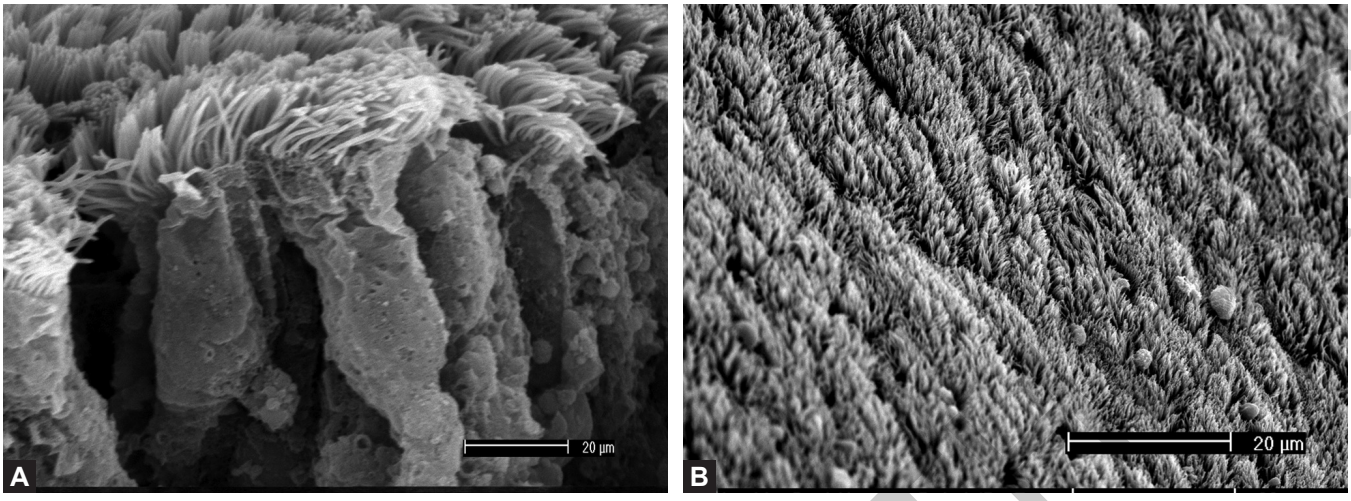


Fig. 2.1: Axial cross-sectional anatomy of the nasal cavity and maxillary sinuses. The nasal cycle results in alternate swelling and decongestion of the inferior turbinate as demonstrated. The head of the inferior turbinate is a component of the internal nasal valve that can significantly affect nasal air flow.



Figs. 2.2A and B: Scanning electron micrographs of sinonasal ciliated respiratory epithelium from lateral (A) and superior (B) views.

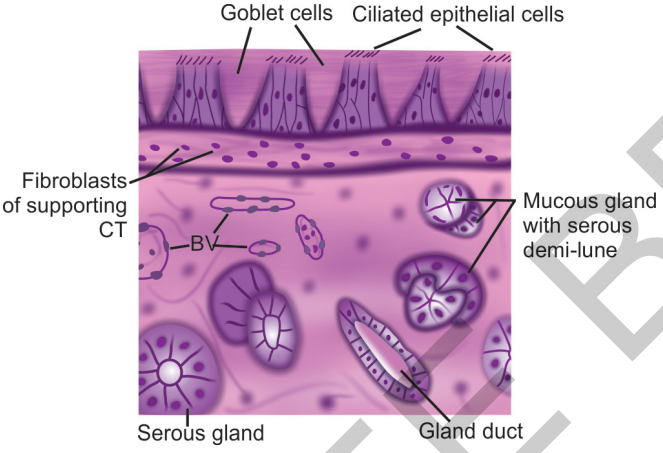


Fig. 2.3: Histology and compositional layers of the nasal mucosa. BV: Blood vessel; CT: Connective tissue.

low ambient temperatures, air can be warmed to an optimal 38°C.[5] After passing through the sinonasal unit, inhaled air is prepped for gas exchange, and deviations from normal anatomy, such as those seen in chronic rhinosinusitis or septal deviation, have deleterious effects on nasal conditioning.[6]

SINONASAL HOST DEFENSE

Given that humans are preferentially nose breathers, air purification is an essential function of the sinonasal unit. Nasal air filtration is a stepwise process—vibrissae, the coarse hair lining the nasal meatus anterior to the nasal valves, trap large particles while progressively smaller particles are trapped more proximally in the mucus layer of the sinonasal epithelium. Particles on the order of 1–10 µm in diameter are effectively trapped by this method.[7] Sweat and sebaceous glands located in the nasal vestibule further help sequester debris caught by vibrissae. Proximal to the nasal valves, the nonciliated stratified squamous epithelium of the anterior nose gives way to ciliated, pseudostratified columnar epithelium (Figs. 2.2A and B). The cilia work synergistically with the mucus layer of the nose to herd trapped debris toward the nasopharynx to be swallowed. Cilia are composed of axonemes, which exist in a 9 plus 2 configuration with two single central microtubules wreathed with 9 pairs of microtubules. Outer doublets interact via motile dynein arms, which produce the characteristic beating motion central to ciliary function.[8] Evidence suggests that decreased mucociliary clearance is seen in a number of disease states, including diabetes and hypertension,[9] suggesting a causative role in the increased frequency and severity of respiratory tract infections seen in certain patient populations and emphasizing the protective role of mucociliary clearance. Similarly, patients with chronic rhinosinusitis have decreased mucociliary clearance.[10]

Intimately related to ciliary function, sinonasal secretions are of considerable functional significance in health and disease. The nasal mucosa consists of, from deepest to most superficial: periosteum, lamina propria, and its associated glands, acellular basement membrane, and pseudostratified columnar ciliated epithelium with interspersed goblet cells (Fig. 2.3). Paranasal sinus epithelium, in contrast, is simple, ciliated, and columnar. Inhaled particles, after passing through the nasal valve, are subject to nasal secretions produced by the nasal mucosa.

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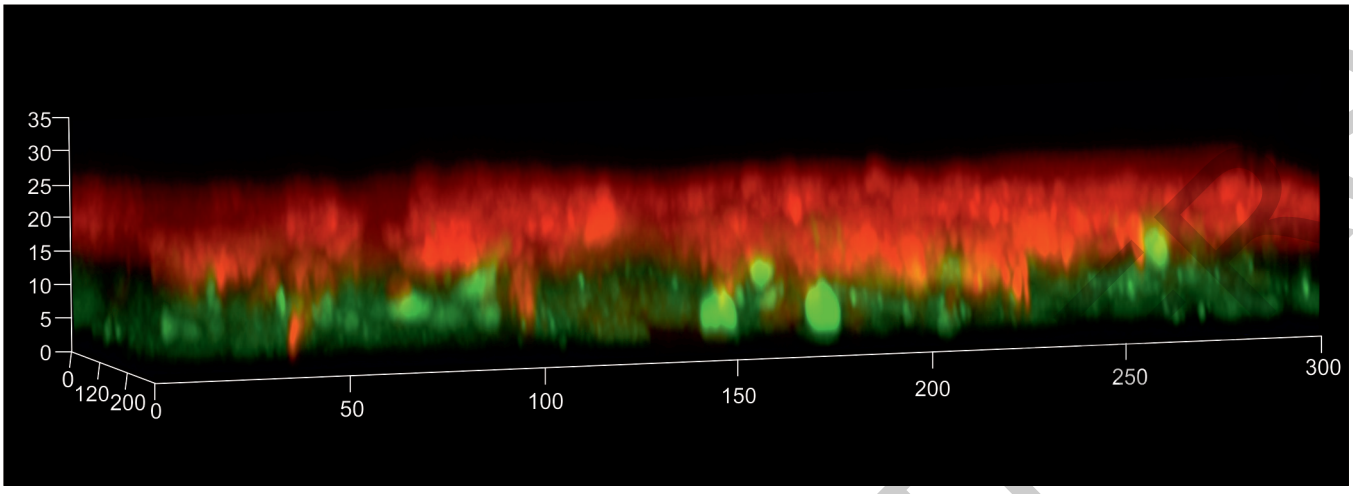


Fig. 2.4: Confocal scanning laser microscopy of a sinonasal respiratory epithelial cell culture on a semipermeable membrane. The cells are stained green, while the airway surface liquid is stained red.

These secretions act as an additional line of defense against antigens and their protective qualities have long been recognized; Alexander Fleming first described the antimicrobial properties of nasal secretions in 1922.[11] Nasal secretions are made up of varying quantities of water, ions, and proteins, including immunoglobins. Immunoglobins A and G, secreted by plasma cells found in the submucosa, are found in nasal secretions and are responsible for antigen specific, or adapative, immune function in the sinonasal unit.[12,13] Lysozyme, lactoferrin, uric acid, and peroxidase are just a few of the proteins thought to mediate innate, or nonspecific, immunity in the nose.[12,14,15] Individual differences in the complement of proteins found in nasal secretions exist, and there is growing evidence that chronic carriers of antigens, for example, patients colonized with *Staphylococcus aureus* in the nasopharynx, may have a deficiency in one or several protein mediators of innate immunity.[12] The exact ionic milieu of nasal secretions is an area of active research, but studies suggest sodium and potassium concentrations between 102 and 150 mEq/L, and 41 and 46 mEq/L, respectively.[16] Active chloride secretion and sodium absorption across the apical membrane of airway epithelial and glandular cells drives water into and out of the nasal passages, respectively.[17-19] Free water also enters the sinonasal unit via the nasolacrimal duct, and mechanical obstruction of fluid transport to the nose, as seen in patients with nasolacrimal duct obstruction, results in expected hypertonic nasal secretions.[20] Nasal fluid over the respiratory epithelia is called airway surface liquid and is composed of two layers: a gel, or mucus-containing, layer, and a less viscous sol layer adjacent to the cilia.[21-25] The composition and depth, usually 5–20 μm in healthy subjects, of nasal secretions are of considerable physiologic significance (Fig. 2.4).[18] Cilia beat through the thin sol layer, effectively propelling the mucus to the oropharynx; the exception is the most anterior portion of the sinonasal unit, where mucus is relatively stationary and nasal secretions rely on innate antimicrobial properties to fight infection.[12,14] Mucus aids in the trapping and transport of inhaled pathogens, and the essential role mucus plays in the upper respiratory tract is highlighted by disorders of mucus production, like cystic fibrosis (CF).[26-31] Caused by mutations in the cystic fibrosis transmembrane conductance regulator (CFTR) gene, patients with CF have impaired transmembrane chloride transport, and CF appears to decrease the depth and volume of nasal secretions secondary to perturbations in ion secretion.[32-36] One theory suggests the decreased secretion of chloride lowers the diffusion gradient, decreasing the amount of free water in nasal secretions.[37] Similarly, it is postulated that lower salt concentrations in nasal secretions may predispose patients to infection by interfering with neutrophil-mediated destruction of bacteria.[37,38] Mucins, which are secreted by goblet cells, are proteins bonded to oligosaccharides; these carbohydrates make up the overwhelming majority of the molecular weight of mucus.[39] The properties of mucins and, therefore, mucus depend on the unique glycosylation pattern. Variations in the composition of these glycoproteins determine the viscosity of mucus. Inflammatory conditions, like chronic rhinosinusitis, result in alterations in glycoproteins that are responsible for the thicker, more tenacious secretions seen in these diseases.[40]

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OLFACTION

Olfaction, too, is a function of air dynamics within the nose. Sniffed air travels preferentially to the olfactory groove in the superior portion of the nasal cavity.[41] Located in the roof of the sinonasal unit and shielded by the ethmoid bone, the ciliated, pseudostratified, columnar bipolar cells of the olfactory groove transform stimulation from olfactants into electrical potentials that are processed by the olfactory cortex.[42] These cells provide a nonstop conduit from environment to brain without synapsing—resulting in efficient transmission for both olfactory stimuli and neuropathogens.[43] Olfactory mucus has a complex and distinct composition, with proteins that perform anti-inflammatory, antimicrobial, and signaling functions.[44] In order for odorants to be exposed to their receptors in the olfactory mucosa, these typically hydrophobic particles must move from air into the mucus overlying the olfactory mucosa, and soluble proteins in olfactory secretions may be responsible for mediating the phase change.[45,46] Olfactory receptors are phylogenetically conserved seven transmembrane domain receptors that come in a wide variety of flavors.[47] Each receptor cell expresses only one olfactory receptor, which in turn may respond to a wide range of olfactants.[42,45] When an odorant binds to its receptor, the resultant increase in cyclic AMP leads to opening of ion channels and receptor cell depolarization.[48] The electrical signal is then transmitted to the central nervous system for processing by the olfactory cortex.

CONCLUSIONS

The sinus and nasal cavities have developed effective physiologic processes to control air flow; purify the air of aerosolized pathogens, environmental toxins, and miscellaneous debris; and eliminate filtered waste via mucociliary clearance. These highly evolved physiologic mechanisms arm the respiratory system with the capability to adapt despite constant alteration of environmental conditions and continuous bombardment with respiratory pathogens.

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Surgical Techniques in Otolaryngology—Head & Neck Surgery

SINONASAL SURGERY

Sinonasal Surgery is part of a comprehensive series entitled "Surgical Techniques in Otolaryngology—Head & Neck Surgery". Other atlases in this series are devoted to various specialties within the field, including Head & Neck Surgery, Otologic & Neurotologic Surgery, Laryngeal Surgery, Pediatric Otolaryngologic Surgery and Facial Plastic & Reconstructive Surgery.

Thirty chapters are included in Sinonasal Surgery. Each chapter outlines an evidence-based approach to the development of each surgical procedure, a detailed step-by-step description of the techniques with intraoperative drawings or photographs, and a discussion of the benefits and pitfalls. Alternatives to surgical management are discussed as well.

This volume is a practical guide to otolaryngologists of all levels with an overview of the most common and some of the more advanced surgical procedures performed in a rhinologic practice. Basics of clinical management are provided from initial patient selection to optimizing postoperative outcomes after surgery. Surgical techniques covered include everything from basic and revision FESS to approaches to the anterior cranial fossa as well as more specific procedures such as medial maxillectomies and frontal drillout procedures. In addition, descriptions of newer surgical methods such as balloon dilation of the sinuses, endoscopic transodontoid approaches, and nasopharyngectomy, make this Atlas truly unique in its breadth of offerings.

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