Basic Otorhinolaryngology

A Step-by-Step Learning Guide

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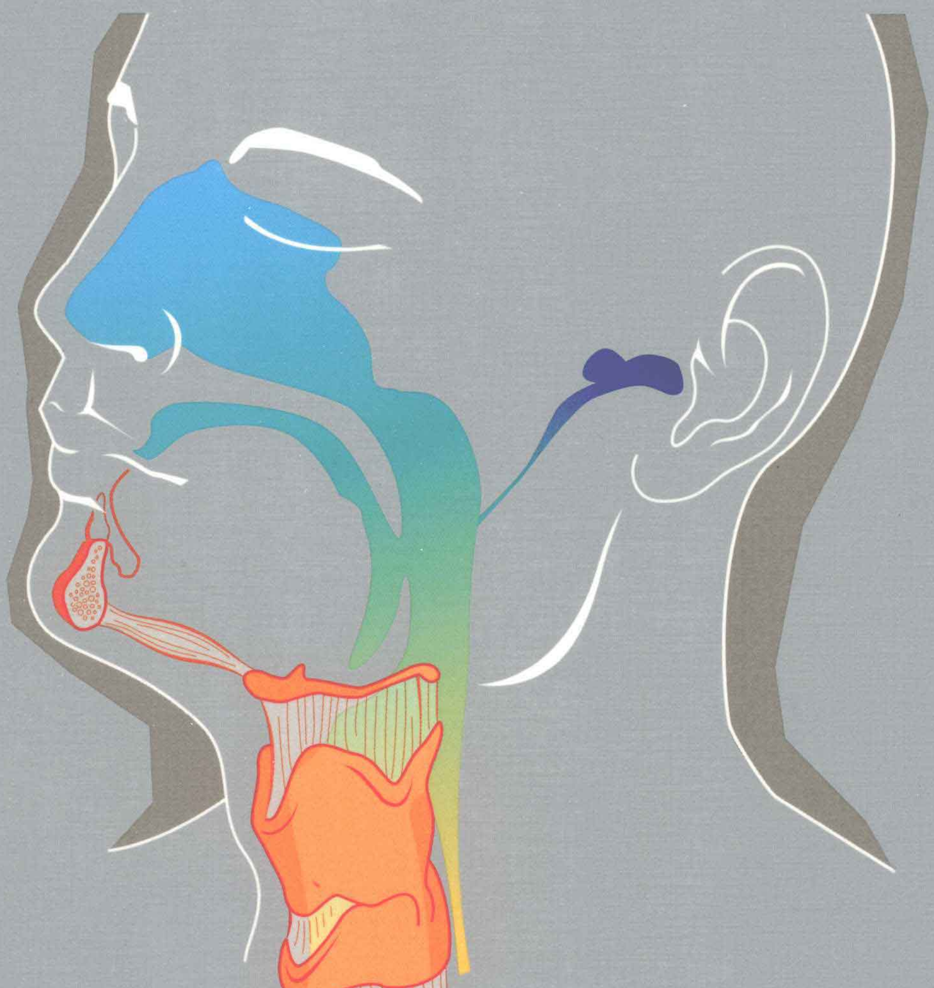

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Basic Otorhinolaryngology

A Step-by-Step Learning Guide

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Preface

This preface aims to provide you with some background information on this textbook: Who can benefit most from this book? What is the teaching approach that is used—i.e., how are the contents presented to make them easier to learn? Who are the members of the "textbook team"?

Approach

Who is the book written for? This book is both a textbook and a reference work. It is intended primarily for students, but is also written for physicians, especially those taking part in further training.
True learning means understanding, and so teaching means explaining. An essential part of learning is understanding basic concepts and potentially complex interrelationships. Learning should also be interesting, and it should convey enjoyment of the material and its fascinating aspects. In this sense, this book aspires to be more than an exam review.
The capabilities of digital production technology have been used with the goal of creating an educationally compelling, graphically attractive, yet affordable textbook.

Structure: One of the main goals was to present the material in an easy-to-learn, user-friendly format. The result is a new kind of textbook in which the material is broken down into brief **study units** ( ), which represent a cohesive learning unit. Subdividing the contents into manageable portions makes it possible to present thematic highlights that are usually not found in textbooks and would have been more difficult to incorporate into chapters with a traditional structure.
Each study unit begins with a **starter** in boldface type. This states the topics that are covered in the unit and the way in which they fit into the overall scheme. Special points are noted, and the material is related to other study units. The starter is not a summary.
The topics in each study unit are presented on **facing pages.** For clarity, "open-book" logos are shown at the bottom corner of the right-hand page: the number of logos (from one to six) indicates the number of facing-page sets that are contained in the current study unit. The red-colored logo shows where you are in the unit.

Subject matter: This textbook conforms to the latest developments in otorhinolaryngology and head and neck surgery. All main information that is needed for the basic understanding of a topic is contained in the main text, figures, and tables.

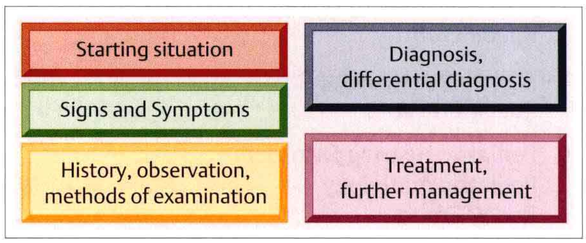
1 Knowledge in depth

Boxes marked with this symbol provide information that goes beyond a basic understanding. This may include operating techniques, illustrative case descriptions, historical information, or repetitions from earlier study (e.g., in embryology). If you are in a hurry, you can skip the in-depth boxes and still understand the material in the main text.

Points of emphasis are meant to indicate "caution" or "take note," and serve to direct attention to key points.

Terminology: Efforts have been made in recent years to establish a standard international nomenclature in various areas of otorhinolaryngology. The most up-to-date terms are used in the text, while older or less commonly used terms are noted as *synonyms.*

Fig. 1 Color code for flowcharts



Acknowledgments

We have very much enjoyed working together on this book, and our collaboration on it has resulted in a text that is greater than the sum of the authors' individual contributions. Ms. Richter, our project editor at Thieme Medical Publishers for the original German version of this book, made a substantial contribution to this outcome through her enthusiasm and tireless efforts in editing our manuscripts. Time and again, she pointed out areas that needed clarification, as well as passages that could be omitted. As a result, the book is her work as well as ours, and she has earned our sincere gratitude.
Terry Telger of Waco, Texas, prepared the English translation. Apart from approaching this project with his usual professionalism and tremendous skills, he revealed time and again points in need of clarification. Stephan Konnry was our project editor at Thieme International for the English version. He managed the translation process, keeping in mind not only the language but the entire cultural aspects of such a process. Just as much as Ms. Richter for the German version, they earn our gratitude for the English version. We are also grateful to the publishers, Thieme, for promoting the project and fostering its development. Our thanks also go to Ms. Baum for her skillful artwork.
Special gratitude is owed to our families. A great deal of time that should really have belonged to them was spent preparing this project. Even so, they supported our lengthy work on the book with the encouragement that only a family can provide.

Table 1 The textbook team

Team members	*Tasks*
Prof. Rudolf Probst, M.D. Prof. Gerhard Grevers, M.D. Prof. Heinrich Iro, M.D.	Authors and editors, s. Fig. **2**
Prof. Frank Rosanowski, M.D. Prof. Ulrich Eysholdt, M.D.	Author of the chapters on phoniatrics
Dr. Frank Waldfahrer	Colleague of Prof. H. Iro
Dr. Ulrike Szeimies, Institute of Diagnostic Radiology, City Center Hospital, University of Munich	Prepared three-dimensional CT images for initial chapter pages
Dr. Jürgen Lüthje	Medical program planning and concept development, German edition
Antje-Karen Richter Simone Profittlich	Project management, German edition
Stephan Konnry	Project management, English edition
Terry Telger	Translator
Gert Krüger Ingrid Schöllhammer	Production
Karin Baum	Graphics

What Can We Improve?

Our goal was to tailor this book to meet readers' needs. Only you, the reader, can judge whether we have accomplished this. We would therefore be delighted for you to contact us or the publishers regarding any changes that you would like to see in the next edition.
We wish you much enjoyment and every success with this book.

R. Probst G. Grevers H. Iro

Fig. 2 The editors

Left to right: Prof. H. Iro is the chairman of the Dept. of Otorhinolaryngology at Friedrich Alexander University Hospital in Erlangen, Germany; Prof. G. Grevers is a practicing otorhinolaryngologist in Starnberg, Germany; and Prof. R. Probst is the chairman of the Dept. of Otorhinolaryngology at the University Hospital Basle, Switzerland.

Contents

Anatomy, Physiology, and Immunology of the Nose, Paranasal Sinuses, and Face

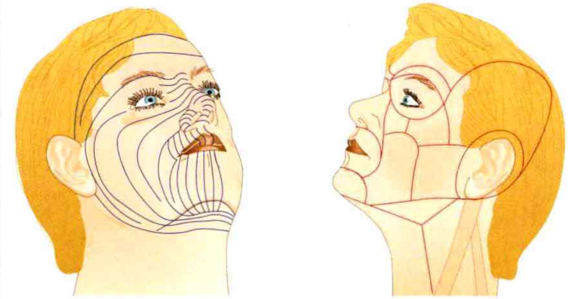
1.1 Basic Anatomy of the Nose, Paranasal Sinuses, and Face

The shape and appearance of the external nose affect not only the overall appearance of the face, but also the functional processes that take place inside the nose. The structural anatomy of the nose is important for both aesthetic and functional reasons, since the nose, as the gateway to the respiratory tract, performs a variety of physiologic functions.

Facial Skin and Soft Tissues

For the effective surgical treatment of soft-tissue defects in the face, whether of a traumatic or neoplastic nature, it is important to consider some distinctive features of the morphology and topographical anatomy of the face, since this is a highly conspicuous region in which the faulty or inadequate treatment of tissue changes will have obvious consequences. One such feature involves the **tension lines** of the skin (Fig. **1.1a**), known also as the relaxed skin tension lines (RSTLs). Scars can be made less conspicuous by taking these tension lines into account when suturing facial skin injuries. The **aesthetic units** of the face are an important consideration in the treatment of larger soft-tissue defects (Fig. **1.1b**). Failure to take these units into account will produce a poor cosmetic result.

Fig. 1.1 Skin tension lines and aesthetic units

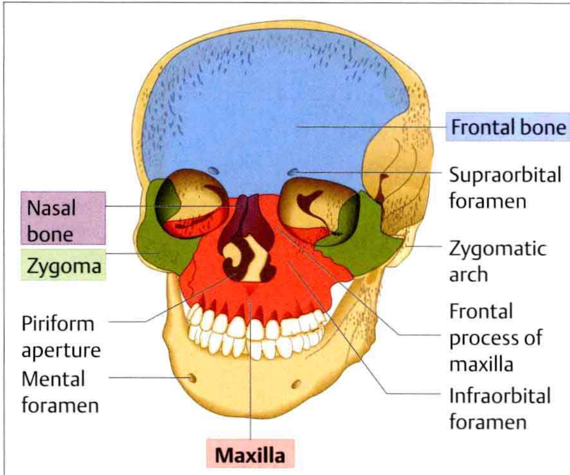


The incisions in facial operations should be placed along skin tension lines (**a**) whenever possible. The aesthetic units (**b**) should be considered in the closure of soft-tissue defects in order to achieve a satisfactory cosmetic result.

The Facial Skeleton

Knowing the various components of the bony facial skeleton (Fig. **1.2**) and their relationship to one another is important in trauma management and also in the diagnosis and treatment of inflammatory diseases of the facial skeleton and their complications. The upper jaw bone, or *maxilla*, houses the maxillary sinus and articulates laterally with the *zygomatic bone* (zygoma) via the zygomatic process (Fig. 1.2). The upper part of the maxilla borders the *nasal bone*, and its frontal process projects upward to the *frontal bone*. The zygoma also has a frontal process that connects superiorly with the frontal bone lateral to the orbit. The zygoma communicates posteriorly with the *zygomatic arch*.

Fig. 1.2 The cranial bones



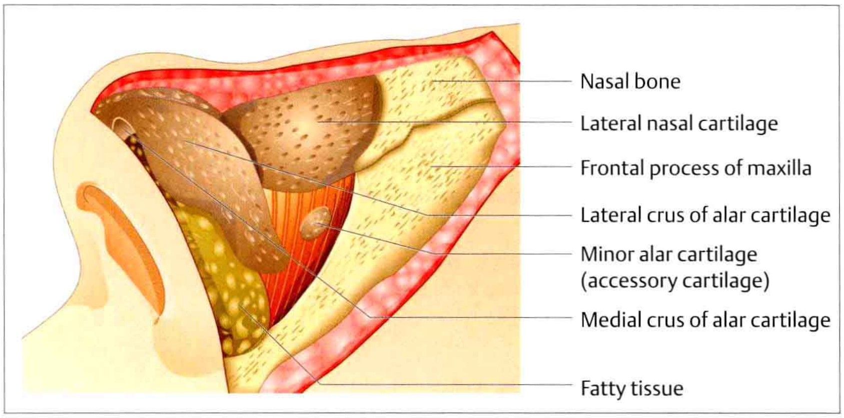
The diagram shows the cranial bones that are relevant to rhinologic disorders.

External Nose

The shape of the external nose is defined by the *nasal bones*, a pair of rectangular bones in the upper nasal dorsum, and by the paired *lateral cartilages* (upper nasal cartilages) and *alar cartilages* (major alar cartilages) in the central and lower portions of the nose (Fig. **1.3**). The lateral portions of the nasal alae also contain several small accessory cartilages, called the *minor alar cartilages*, which are embedded in the lateral soft tissues of the nose.

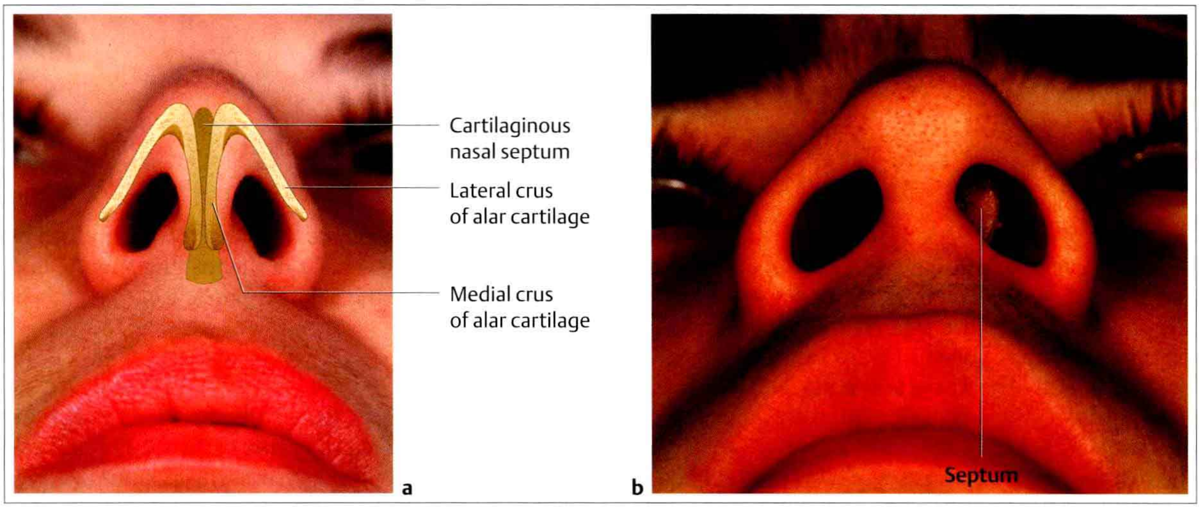
The shape and stability of the alar cartilages, each of which consists of a *medial and lateral crus*, chiefly de-

Fig. 1.3 Structure of the external nose



Various bony and cartilaginous structures define the appearance of the external nose.

Fig. 1.4 Anatomy of the nasal base



a The anatomically important cartilaginous structures are projected onto the nasal base.

b The nasal septum is subluxed toward the left side, partially obstructing the nasal airway.

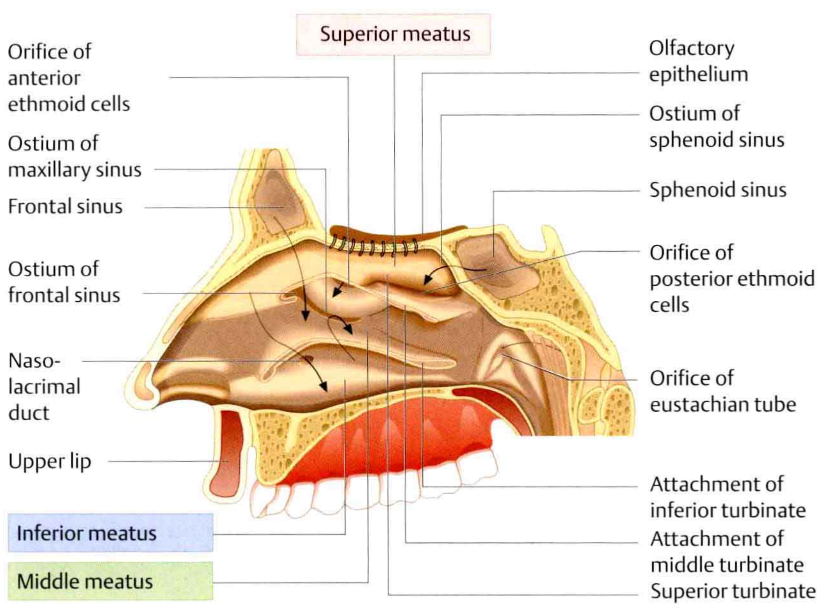
termine the appearance of the nasal tip and the shape of the nares. As a result, they are also important in maintaining an effective nasal airway. Besides the medial crura, the inferior septal margin and the connective-tissue septum *(columella)* are also responsible for stabilizing the base of the nose (Fig. **1.4 a**). Subluxation of the inferior septal margin can also hamper nasal breathing by partially obstructing the nasal airway (Fig. **1.4 b**).

Nasal Cavities

The **nasal cavities** begin anteriorly at the *nasal vestibule*, which is bordered posteriorly by the internal *nasal valve* (limen nasi) located between the posterior border of the alar cartilage and the anterior border of the lateral cartilage. This valve area is the narrowest portion of the upper respiratory tract and, as such, has a major bearing on the aerodynamics of nasal airflow (see also 1.3, Basic Physiology and Immunology of the Nose, pp. 10–13). The anterior bony opening of the nasal cavity, called the *piriform aperture*, is bounded laterally and inferiorly by the maxilla and superiorly by the nasal bone (Fig. **1.2**). The interior of the nose behind the nasal valve is divided by the *nasal septum* into two main cavities. The **nasal septum** is composed of an anterior cartilaginous part and two posterior bony parts. Abnormalities in the shape of the nasal septum (see also 3.2, Nasal Deformities, p. 30), which may consist of a deviated septum, tension septum, spurs or ridges, are a frequent cause of nasal airway obstruction.

The *choanae* are the paired posterior openings through which the nasal cavities communicate with the nasopharynx.

Fig. 1.5 Structure of the lateral nasal wall



The relationship of the middle meatus to the sinus ostia is of special importance. See also **1.3** (p. 7).

The nasal cavity is bounded laterally by the lateral nasal walls, which are formed by the *ethmoid bone* and *maxilla*, and posteriorly by the *palatine bone* and the *pterygoid process* of the sphenoid bone. Several functionally important structures are located on the lateral nasal wall: the **nasal turbinates** and their associated passages (meati), sinus ostia, and the orifice of the nasolacrimal duct (Fig. **1.5**).

The *inferior turbinate* consists of a separate bone that is attached to the medial wall of the maxillary sinus. The opening of the nasolacrimal duct is located in the corresponding *inferior meatus* (**1.1**). The middle and superior turbinates are part of the ethmoid bone. In rare cases, a rudimentary "supreme turbinate" is also present above the superior turbinate.

The *middle turbinate* has by far the greatest functional importance, because most of the drainage tracts from the surrounding paranasal sinuses open into the middle meatus (see also **1.3**, Anatomy of the Ostiomeatal Unit, p. 7).

The nasal cavity is bounded superiorly by the *cribriform plate* of the ethmoid bone. This thin bony plate has numerous openings for the passage of the *fila olfactoria* and also forms the boundary of the anterior cranial fossa. The floor of the nasal cavity is formed mostly by the *hard palate*, which is formed in turn by the two palatine processes of the maxilla and the horizontal laminae of the palatine bone.

> **1.1 Nasolacrimal duct**
>
> The *nasolacrimal duct* is part of the lacrimal apparatus, which also includes the lacrimal gland, the lacrimal ducts, and the lacrimal sac. It runs in a bony canal between the medial canthus of the eye and the inferior nasal meatus.

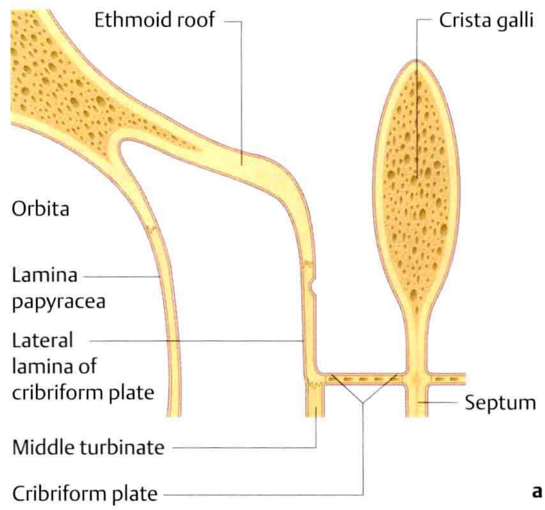
Paranasal Sinuses

The *paranasal sinuses* are air-filled cavities that communicate with the nasal cavities (Fig. **1.6**). All but the sphenoid sinus are already present as outpouchings of the mucosa during embryonic life, but except for the ethmoid air cells, they do not develop into bony cavities until after birth. The frontal sinus and sphenoid sinus reach their definitive size in the first decade of life. The maxillary sinus is present at birth but remains very small until the second dentition, because the presence of tooth germs in the maxilla limit the extent of the sinuses. The maxillary sinus, frontal sinus, and anterior ethmoid cells drain into the nasal cavity through the middle meatus—i.e., below the middle turbinate (Fig. **1.5**). The posterior ethmoid cells drain into the nasal cavity through the superior meatus. The ostium of the sphenoid sinus is located in the anterior wall directly above the choanae. The anatomical connections between the nasal cavity and paranasal sinuses are functionally important and play a key role in the pathogenesis of many rhinologic diseases that involve the paranasal sinuses (see also **1.3**, Anatomy of the Ostiomeatal Unit, p. 7).

The **maxillary sinus** borders the nasal cavity laterally, and the orbital floor separates the upper part of the sinus from the orbit. Behind the maxillary sinus is the *pterygopalatine fossa*, which is traversed by the maxil-

1.2 Ethmoid roof and cribriform plate

The roof of the ethmoid labyrinth is formed mainly by the portion of the frontal bone that covers and closes the ethmoid cells superiorly. The ethmoid roof is continuous medially with the cribriform plate, the lateral lamina of which represents the continuation of the attachment of the middle turbinate and is very easily injured during surgical manipulations in this region (**a** ethmoid roof and anterior ethmoid at the level of the crista galli). The levels of the ethmoid roof and cribriform plate can vary considerably, even in the same patient, depending on the vertical extent of the lateral lamina. Computed tomography scans should be taken preoperatively to define the individual anatomy of the anterior skull base region (**b–e** coronal scans of the anterior skull base in a patient with conspicuous nasoethmoidal opacity caused by nasal polyps).



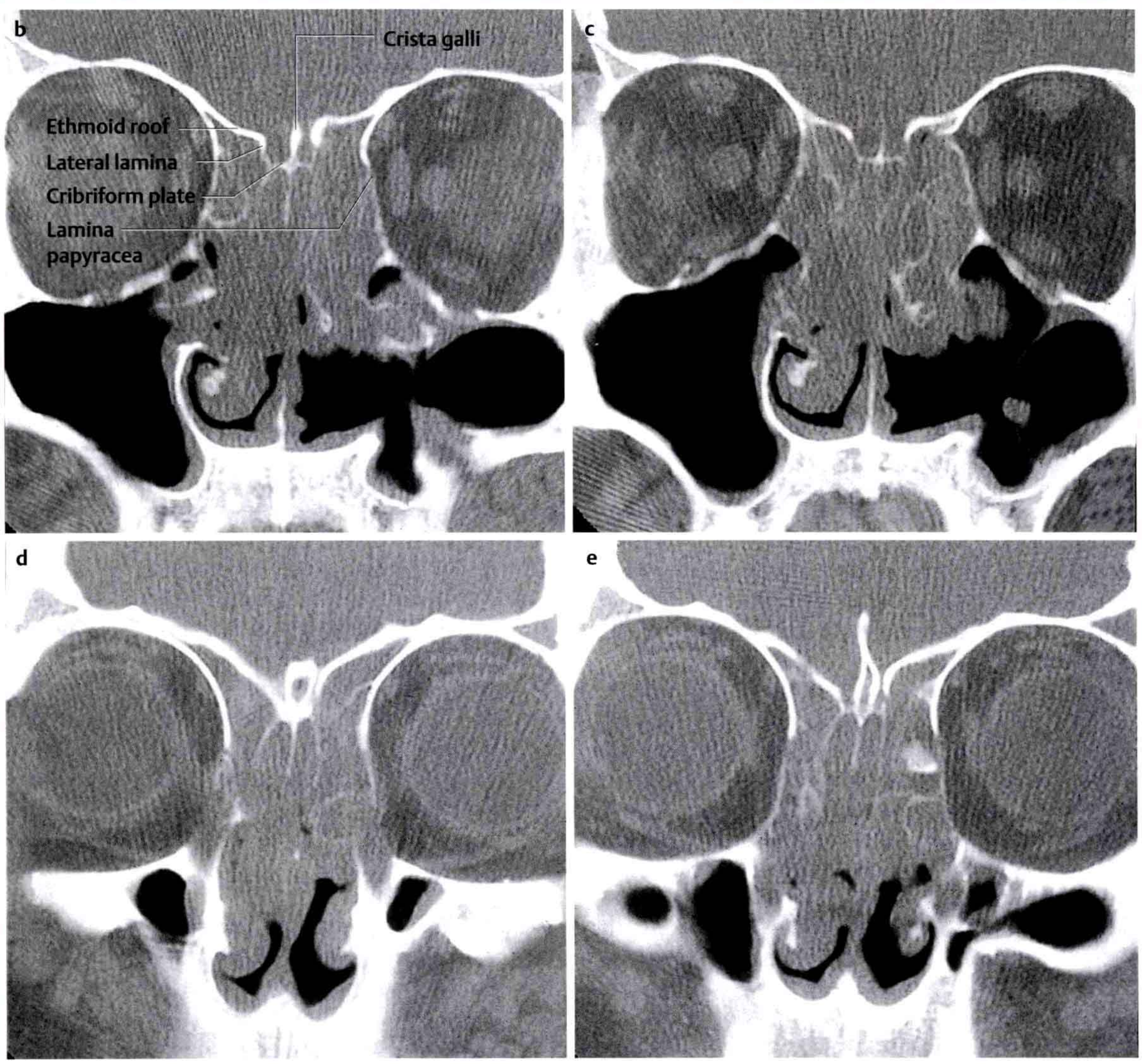


Fig. 1.6 Paranasal sinuses

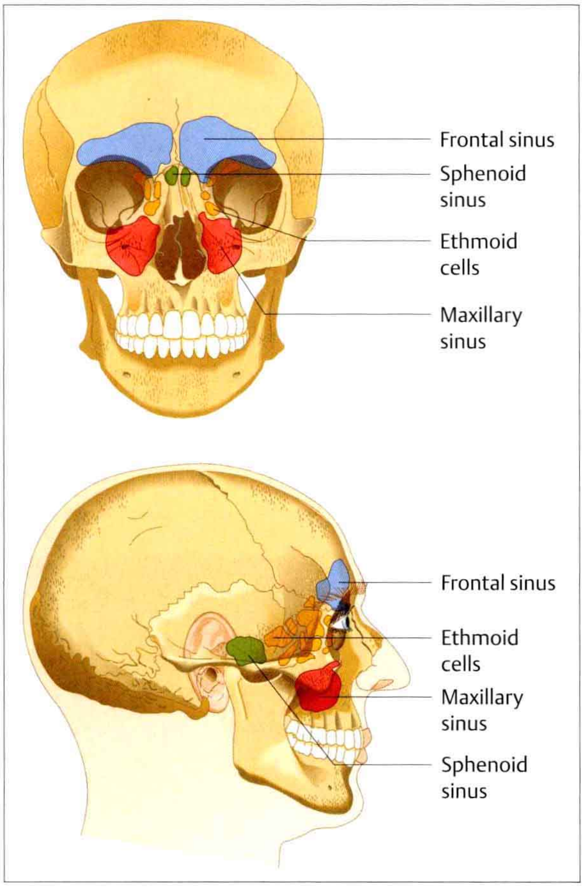


Diagram of the sinuses projected onto the cranial surface.

lary artery along with branches of the trigeminal nerve and autonomic nervous system. The floor of the maxillary sinus is closely related to the roots of the second premolar and first molar teeth. This creates a potential route for the spread of dentogenic infections, and a tooth extraction may create a communication between the oral cavity and maxillary sinus (oroantral fistula).

Superior and medial to the maxillary sinus are the **ethmoid air cells**—a labyrinthine system of small, pneumatized sinus cavities that are separated from one another by thin bony walls and extend posteriorly between the middle turbinate (medial border) and orbit to the sphenoid sinus. The orbital plate of the ethmoid bone, called also the *lamina papyracea*, forms the lateral bony wall that separates the ethmoid air cells from the orbit. Paranasal sinus inflammations can spread through this lamina to involve the orbit (orbital complications). The posterior ethmoid cells are closely related to the *optic nerve*. The ethmoid roof and cribriform plate (**1.2**) form the bony boundary that separates the ethmoid cells from the *anterior cranial fossa*. The surgeon who operates in this region must have a detailed knowledge of the relations of these structures to the ethmoid labyrinth.

The **sphenoid sinus** is located at the approximate center of the skull above the nasopharynx. Its posterior wall is formed by the clivus. It relates laterally to the *cavernous sinus*, the *internal carotid artery*, and *cranial nerves II–VI*, and it is very closely related to the optic canal.

! The optic nerve and internal carotid artery may run directly beneath the mucosa of the lateral wall of the sphenoid sinus, without a bony covering.

The sphenoid sinus is bordered superiorly by the sella turcica and pituitary and by the anterior and middle cranial fossae.

The **frontal sinus** is located in the frontal bone, its floor forming the medial portion of the orbital roof. The sinus, which is highly variable in its extent, is bounded behind by the anterior cranial fossa. Inflammations of the frontal sinus can give rise to serious complications because of its close proximity to the orbit and cranial cavity (orbital cellulitis, epidural or subdural abscess, meningitis).

Vascular Supply

The external nose derives most of its **blood supply** from the *facial artery*, which arises from the external carotid artery, and from the *ophthalmic artery*, which springs from the internal carotid artery. The internal nose receives blood from the territories of the external and internal carotid arteries: the terminal branches of the *sphenopalatine artery*, which arises from the maxillary artery, and the *anterior and posterior ethmoid arteries*, which arise from the ophthalmic artery. A detailed knowledge of the vascular supply is particularly important in the management of intractable epistaxis (nosebleed), which requires vascular ligation or angiographic embolization as a last recourse (see also 3.3, Epistaxis, p. 35). The **venous drainage** of the facial region is handled by the facial vein, retromandibular vein, and internal jugular vein.

The **regional lymphatic drainage** of the face and external nose is handled mainly by the submandibular lymph nodes, while the nasal cavity is additionally drained by the retropharyngeal and deep cervical lymph nodes.

Nerve Supply

The facial skin receives its **sensory innervation** from terminal branches of the *trigeminal nerve* that enter the facial region through the supraorbital, infraorbital, and mental foramina (Fig. **1.2**). Only the skin over the mandibular angle and the lower portions of the auricle are supplied by the great auricular nerve. The facial muscles are classified as mimetic or mastica-

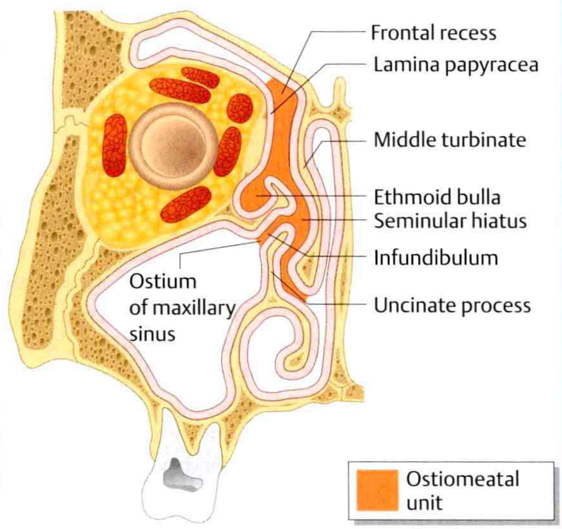
1.3 Anatomy of the ostiomeatal unit

The term "ostiomeatal unit" describes the area on the lateral nasal wall where the ostia of the paranasal sinuses (except for the sphenoid sinus) open into the nasal cavity in a duct-like fashion. Even minor changes (e.g., anatomical variants, mucosal swelling) can hamper ventilation in this region, leading to pathologic sequelae in the paranasal sinuses (see below).

The functionally significant anatomic structures of the ostiomeatal unit are the uncinate process, the semilunar hiatus, the frontal recess, the ethmoid bulla, the ethmoid infundibulum, and the maxillary sinus ostium (a coronal section is shown at right). The **frontal sinus** is connected to the ostiomeatal unit via the frontal recess, which has an hourglass-like shape. The **uncinate process** is a thin fibrous or bony process on the lateral nasal wall that arises slightly behind the anterior border of the middle turbinate and may narrow the passage from the nasal cavity to the ostiomeatal complex, depending on its degree of development. Located between the posterior border of the uncinate process and the first ethmoid cell (the **ethmoid bulla**) is another slitlike passage within the ostiomeatal complex, known as the **semilunar hiatus**. The space between the uncinate process, ethmoid bulla, and lamina papyracea of the ethmoid bone is called the **ethmoid infundibulum**.

The ostiomeatal unit is bounded medially (toward the nasal cavity) by the middle turbinate and laterally by the lamina papyracea.

The main *clinical significance* of this region relates to the sites of narrowing in the ostiomeatal unit. For example, hyperemia and swelling of the mucosa in the setting of a common cold can obstruct the narrow passages in the ostiomeatal unit, preventing adequate ventilation of the dependent paranasal sinus system and setting the stage for a rhinogenic inflammation of the paranasal sinuses (sinusitis).



tory, each of these groups receiving different **motor innervation**. While the mimetic muscles of the face develop from the blastema of the second branchial arch (the hyoid arch) and accordingly are supplied by the *facial nerve*, the masticatory muscles trace their embryonic development to the first branchial arch (the mandibular arch) and are therefore supplied by mandibular nerve branches arising from the *trigeminal nerve*.

Functional Anatomy of the Ostiomeatal Unit

The nose and paranasal sinuses are regarded as a functional unit. Many rhinologic disorders are transmitted from the nasal cavity into the paranasal sinus system. The ostiomeatal unit is the collective term for various anatomical structures located about the middle meatus. It represents the region on the lateral nasal wall that receives drainage from the anterior ethmoid cells, frontal sinus, and maxillary sinus (**1.3**). It is important to know the anatomical details of this region in order to understand the pathophysiology of acute and especially chronic paranasal sinus inflammations and the surgical procedures that are used in the causal treatment of these conditions.

1.2 Morphology of the Nasal Mucosa

Besides the anatomical structure of the external nose and nasal cavity, the nasal mucosa plays an essential role in numerous functions of the nose owing to its "gateway" location in the respiratory tract (see also 1.3, Basic Physiology and Immunology of the Nose, pp. 10–13). This deals with the morphologic structure of the nasal mucosa. Understanding this structure is necessary for an understanding of functional processes.

The anterior part of the nasal cavity (the nasal vestibule), like the external nose, is covered by skin composed of a multilayer, keratinizing **squamous epithelium**. Anterior to the head of the inferior turbinate, this keratinized epithelium gives way to a nonkeratinized squamous epithelium, a nonciliated columnar epithelium, and finally a **ciliated respiratory epithelium**. Along with the submucous tissue, this ciliated epithelium forms the typical mucosal lining of the nasal cavity and paranasal sinuses (Fig. **1.7**). A small area on the upper nasal septum, superior turbinate, and part of the middle turbinate, located adjacent to the cribriform plate, is covered by **olfactory mucosa** and is called the *olfactory region*.

Respiratory Mucosa

Epithelium

The epithelium of the respiratory mucosa is composed of ciliary cells, goblet cells, and basal cells and provides an initial, mechanical barrier against infection. The **ciliary cells** dominate the surface of the respiratory epithelium. Each ciliary cell has approximately 150–200 cilia, which are composed of microtubules and are interlinked by "dynein arms." This cytoskeleton of the ciliary cells and the activity of dynein, a specialized protein, enable the typical, synchronous beating of the cilia in the respiratory epithelium. This ciliary action propels a blanket of mucous secretions (from the **goblet cells**) and serous secretions (from the **nasal glands**) toward the nasopharynx, mechanically cleansing the inspired air in a mechanism called *mucociliary transport* (see also 1.3, Basic Physiology and Immunology of the Nose, pp. 10–13).

The **basal cells** represent the morphologic connection between the columnar epithelium and goblet cells on the one hand and the epithelial basement membrane on the other. They are distinguished from the other epithelial cell types by an increased expression of certain adhesion molecules (e.g., intracellular adhesion molecule-1, ICAM-1) and increased cytokine synthesis (e.g., interleukin 1). Besides the four cell types mentioned, the epithelium also contains **immunocompetent cells**, mostly CD8-positive T cells, along with smaller numbers of mast cells, macrophages, and MHC-II–bearing dendritic cells, which function as antigen-presenting cells.

Lamina Propria

The **lamina propria** of the nasal mucosa is separated from the epithelium by a basement membrane. Some areas of the lamina propria, especially about the inferior turbinate, show a marked preponderance of vascular structures known as **venous erectile tissue** or sinusoids. They consist of thin-walled and thick-walled venous capacitance vessels, which are important not only in warming the inspired air and producing secretions but also in controlling the tumescence of the nasal mucosa. Besides the venous capacitance vessels there are capillaries and, in deeper areas, arterial vessels. The lamina propria also contains numerous **nasal glands**, which mainly produce a serous secretion. The **immunocompetent cells** in the lamina propria consist of CD4-positive T lymphocytes along with CD8-positive cytotoxic cells and suppressor cells such as CD4-/CD8-negative T lymphocytes, mature B lymphocytes, Ig-plasma cells, mast cells, and macrophages. These cellular elements demonstrate the importance of the nasal mucosa, which acts in concert with local host reactions to mediate inflammatory and allergic responses in the nose (see also 1.3, Basic Physiology and Immunology of the Nose, pp. 10–13).

Nerve Supply

Finally, the nasal mucosa is endowed with a rich nerve supply. It receives its sensory innervation from the trigeminal nerve and its autonomic innervation from the pterygopalatine ganglion. The parasympathetic fibers of this ganglion induce vasodilation and stimulate the secretory activity of the nasal glands, while the sympathetic fibers produce vasoconstriction and inhibit glandular secretions.

Olfactory Mucosa

Topography: The olfactory mucosa (see **1.4** for details on structure and function) covers the olfactory region, which occupies the anterior superior part of the nasal septum and adjacent areas of the lateral nasal wall, including the side of the superior turbinate facing the septum and part of the middle turbinate. The junction of the olfactory mucosa with the respiratory mucosa is variable in its location.

Stimulus processing system: Although it covers an area of only a few square centimeters, the olfactory mucosa contains between 10 and 20 million *bipolar sensory cells*. The olfactory sensory cells have dendritic epithelial processes as well as basal axons that pass through the basement membrane between the supporting cells and basal cells and then join into bundles that are ensheathed by Schwann cells. These axon bundles, called the fila olfactoria, pass through foramina in the cribriform plate of the ethmoid bone and enter the cranial cavity. There they unite to form the olfactory nerve and pass to the olfactory bulb in the brain, the *primary olfactory center*. The latter is connected via the olfactory tract to the *secondary olfactory center* (olfactory cortex) in the temporobasal cortex, which is responsible for the perception of smells and their association with other sensory impressions. The secondary olfactory center also has projections to the limbic system that connect with the autonomic centers in the thalamus and hypothalamus; this creates a pathway that mediates the emotional and affective phenomena that are associated with smells. The olfactory cortex has connections with the *tertiary olfactory centers* (including the hippocampus, anterior insular region, and reticular formation), which are believed to have polysensory associative functions.

1.4 Olfactory mucosa

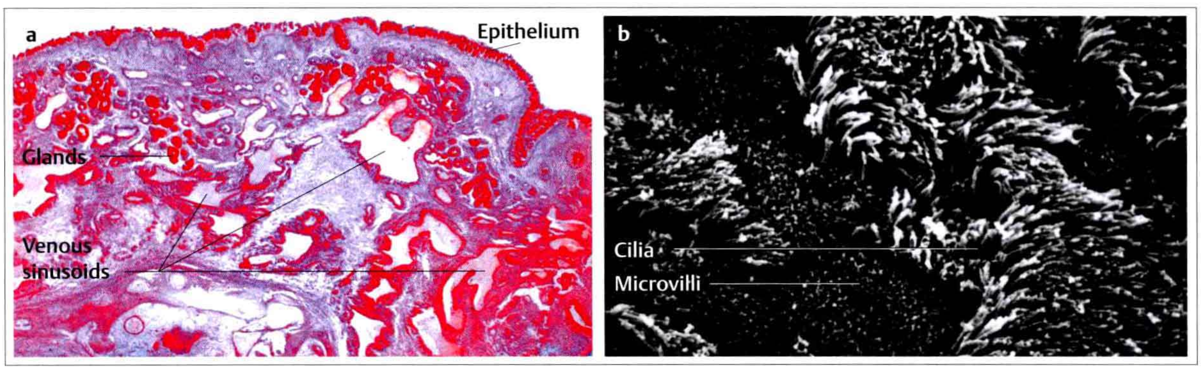
Microscopic anatomy: Besides receptor cells, the epithelium of the olfactory mucosa is composed of microvilli, supporting cells, and basal cells. The lamina propria additionally contains serous glands (olfactory glands) and vessels.

The **function** of the microvilli and of the olfactory glands located in the lamina propria of the olfactory mucosa is not yet fully understood.

The *microvilli* most likely represent extra chemoreceptors in the olfactory epithelium, which perform their function along with the classic receptor cells.

As for the *olfactory glands*, it is assumed that the secretions from these glands, released at the surface of the epithelium, also play a role in mediating the olfactory sense. Recent studies have shown that the secretion layer on the epithelium contains a specific protein that has a high affinity for most odorous substances, and thus could facilitate or even mediate their binding to the sensory cells.

Fig. 1.7 Respiratory nasal mucosa



a Structure of the lamina propria in histologic section.

b Scanning electron micrograph of cilia and microvilli.

1.3 Basic Physiology and Immunology of the Nose

To understand the pathologic processes that are important in inflammatory and allergic diseases of the nose, it is necessary first to understand the physiologic functions. As the threshold of the respiratory tract in humans, the nose is of major importance in conditioning the air before it reaches the lower airways. To understand this complex process, we must know something about the physics of nasal airflow, which also affects the warming and humidification of the inspired air. Due to its exposed position, the nasal mucosa is in constant primary contact with the environment and thus with a variety of potential pathogens. As a result, the nose is equipped with a variety of defense mechanisms (mechanical defenses, specific and nonspecific immune responses). As part of the supraglottic vocal tract, the nose also contributes to speech production (see 18.1, pp. 386–389). Finally, the nose contains the olfactory sensory cells, giving it an essential role in olfaction (see p. 13).

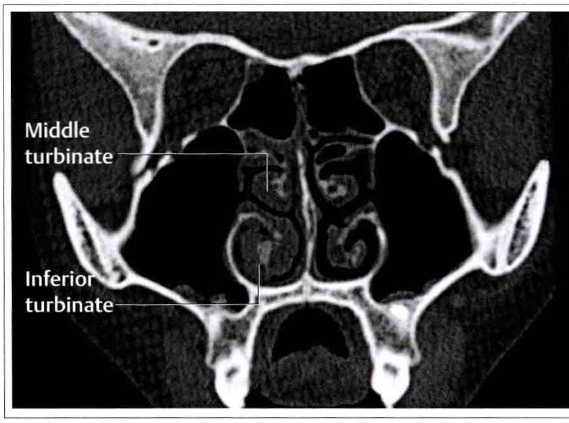
Physical Principles of Nasal Airflow

During inspiration, the air stream enters the nasal vestibule in an oblique vertical direction. Aerodynamically, this air is in a state of *laminar flow*, meaning that there is no mixing of the different air layers. When the inspired air reaches the nasal valve located between the vestibule and nasal cavity, it passes through the narrowest site in the upper respiratory tract (limen nasi). Just past the nasal valve, the cross-section of the airway becomes greatly expanded, creating a "diffuser effect" that transforms most of the laminar flow of the inspired air into *turbulent flow*, in which different air layers are swirled together. Besides the velocity of the air, the degree of change in airflow characteristics at this stage is very strongly influenced by the specialized anatomy of the nasal cavity, which is subject to substantial individual differences. Septal deviation and cartilaginous or bony spurs on the septum can be as significant in this regard as turbinate hyperplasia or septal perforation. To a degree, the transition from laminar to turbulent flow within the nose is functionally desirable because it slows the flow velocity of the inspired air. This prolongs its contact with the nasal mucosa, contributing to olfaction and making it easier for the nose to clean, humidify, and warm the inspired air (see below).

Nasal Cycle

The "nasal cycle" is a physiologic phenomenon marked by an alternation between luminal narrowing and widening of the nasal cavities. This alternate congestion and decongestion of the nasal mucosa is effected mainly through reactions of the venous capacitance vessels of the inferior and middle turbinates, which are regulated by the autonomic nervous system (Fig. **1.8**).

Fig. 1.8 The nasal cycle



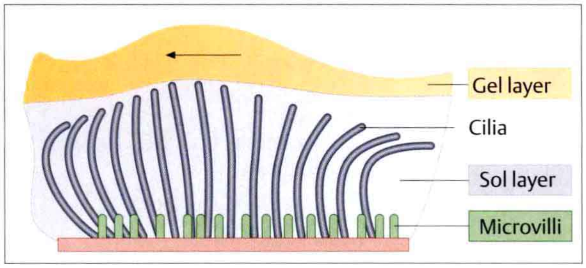
This coronal computed tomography scan shows mucosal swelling in the right nasal cavity, predominantly on the inferior and middle turbinates, and mucosal decongestion in the right nasal cavity.

Conditioning of the Inspired Air

Inspired air is warmed and humidified in the nose before reaching the lower airways. Turbulent flow and other special physical conditions promote the necessary contact of the inspired air with the nasal mucosa. Moreover, the favorable relationship between the relatively small nasal cavity and the comparatively large mucosal surface area, which is further enlarged by the turbinates, also promotes the functionally important interaction between the inspired air and the mucosa. **Humidification** is accomplished by secretion and transudation from the nasal glands, the epithelial goblet cells, and the vessels of the lamina propria. **Temperature regulation** is controlled by the intranasal vascular system and especially the venous erectile tissue, which is particularly abundant in the inferior turbinates. The temperature in the anterior portions of the nasal cavity is lower than in the posterior regions. This temperature gradient produces a gradual warm-

ing of the inspired air, while on expiration, moisture and heat are returned to the nose through condensation. The warming capacity of the nasal mucosa is so efficient that even with ambient temperatures below zero, the temperature of the inspired air is raised by 25°C on entering the nasopharynx, with a relative humidity of over 90%.
Disturbances in the conditioning function of the nose can result from age-related drying of the mucosa due to involution of the goblet cells and glands. They can also result from chronic inflammatory changes or extensive resections of the mucosa during intranasal surgery.

Fig. 1.9 Mucociliary transport



Cilia on the respiratory epithelium beat in a coordinated, metachronous pattern in the periciliary fluid (deeper sol layer), which transports the superficial gel layer toward the nasopharynx (arrow).

Protective Functions of the Nasal Mucosa

Here the protective functions of the nose are separated into two parts to facilitate learning, although in life the various defense mechanisms are interrelated and should not be thought of as separate entities.

Nonspecific Defense Mechanisms

Mechanical defenses: The most important mechanical defense mechanism of the nasal mucosa is the *mucociliary apparatus*, which physically cleanses the inspired air. The mucociliary transport system consists of the cilia of the respiratory epithelium and a mucous blanket composed of two layers: a deeper, less viscid "sol layer" in which ciliary motion occurs, and a superficial, more viscid "gel layer" (Fig. **1.9**). The physiology of ciliary movements is described in **1.5**.
Disturbances of mucociliary transport can have various causes, such as increased viscosity and thickness of the periciliary sol layer, hampering ciliary movements, or changes in the viscoelasticity of the gel layer resulting in ineffectual mucus transport. Finally, various pathogenic mechanisms can produce changes in the cilia themselves, regardless of the viscosity of the mucous blanket. For example, an acute viral infection of the upper respiratory tract can lead to desquamation of the epithelium, with a loss of ciliated cells. Also, certain micro-organisms can directly affect ciliary motility by reducing the beat frequency of the cilia. Finally, ciliary dyskinesia syndromes are congenital disorders based on morphologic changes in the cilia such as absence of the dynein arms. This results in uncoordinated, dyskinetic ciliary movements that prevent effective mucus transport (see also Paranasal Sinus Inflammations).

Nonspecific protective factors: The nasal mucosa also has a number of other, nonspecific defense mechanisms in the form of protective factors in the mucous blanket (Table **1.1**).

1.5 Physiology of ciliary motion

Ciliary motion consists of three phases and is initiated by adenosine triphosphate (ATP)-splitting proteins, which cause a movement of the filaments within the cilia (sliding filament theory). The superficial gel layer is propelled toward the nasopharynx by a coordinated but metachronous beating of the cilia. The dynamics of ciliary motion has been likened to a "field of grain swaying in the wind." The cilia beat at a high frequency (10–20 times per second), but their motion is influenced by external factors such as temperature and humidity.

Cellular defenses: The mucosa has nonspecific defense mechanisms at the cellular level as well. The predominant phagocytic cells are neutrophilic granulocytes, monocytes, and macrophages. They are accompanied by "natural killer cells" (NK cells), which comprise a small percentage of the peripheral lymphocytes and protect mainly against viral infections of the nasal mucosa.

Specific Immune Responses

Besides the nonspecific defense mechanisms of the nasal mucosa noted above, the nose possesses a specific immune system that can be viewed as a separate immunologic unit. It is made up of the *nasal mucosa* itself and the lymphoepithelial tissue of *Waldeyer's ring* (see below). Recent discoveries indicate that the structures of Waldeyer's ring, especially the pharyngeal and palatine tonsils, function as inductive components that are active in the absorption, processing, and presentation of antigens, whereas the nasal mucosa itself is purely an effector organ in which, for example, foreign material is phagocytized by immunocompetent cells.
The local, specific immune system of the nasal mucosa is based on the actions of antibodies, which are responsible for the humoral immune response, and of