Introduction

Classical anatomy of the nasal cavity and paranasal sinuses was elucidated originally by elegant gross dissection, and more recently with even greater resolution facilitated by modern imaging. Advances in rhinology, including the advent of the rigid nasal endoscope with superior fiber optics and precise localization techniques using surgical navigation systems, have allowed newer perspectives and a better understanding of functional anatomy. Most surgeons today are very familiar with the video display of surgical navigation systems and this technology is now used routinely in the operating room. Image guidance technology utilizing high-resolution CT imaging of the sinuses affords extremely detailed three-dimensional views of the sinonasal anatomy, which, when coupled with the endoscopic image, provides a more complete understanding of complex anatomical relationships. Thorough knowledge of this anatomy is necessary for the sinus surgeon to effectively and safely treat pathology in and around the sinonasal tract. In this chapter we present the sinus anatomy and review key functional regions from the
surgical perspective, utilizing an image guidance system (Vectorvision; BrainLAB AG, Munich, Germany) to reinforce three-dimensional relationships.

Embryology

A brief review of embryological development helps to elucidate the intricate anatomy and relationships of the paranasal sinuses and their outflow patterns. A series of bony prominences occurs in the lateral nasal wall between weeks 7 and 9 of fetal development. Generally, six bony ridges from the ethmoid, or ethmoturbinals, are present at week 8, three to four of which will persist. Each ethmoturbinal has an anterior ascending and posterior descending aspect [1, 2]. The ascending and descending portions of the first ethmoturbinal will form the agger nasi and uncinate process respectively. The second lamella gives rise to the bulla ethmoidalis, or ethmoidal “bleb.” The third ethmoturbinal becomes the middle turbinate, and the fourth develops into the related superior turbinate. The fifth and sixth ethmoturbinals fuse to become the supreme turbinate. The inferior turbinate arises from a separate entity, the maxilloturbinal, which is not part of the ethmoid, but instead relates to the maxillary and palatine bones [3]. The lamellae of each of these processes gradually develop and give rise to the mature structures described.

Whereas the ridges of the ethmoturbinals form structures, the spaces between the ethmoturbinals, described as furrows, correspond to spaces and clefts of the mature sinus drainage pathways. These furrows can be subdivided into primary or secondary [1, 4]. The first primary furrow gives rise to the infundibulum, hiatus semilunaris, middle meatus, and frontal recess. The second primary furrow corresponds to the superior meatus, and the third primary furrow, the supreme meatus. Secondary furrows form supra and retrobullar recesses, and the ethmoid air cells proper. The frontal recess, and subsequently the frontal sinus, likely develop as an expansion of the furrow between the first and second ethmoturbinals. Whether the frontal sinus originates from the frontal recess, anterior ethmoid air cells, or infundibulum is debatable [4–6].

There is some discussion as to whether the sinuses develop from cartilaginous condensations and subsequent ossification centers primarily, or from the invagination of mucosa with pneumatization secondarily. Primary pneumatization occurs prenatally, while secondary pneumatization and expansion occur largely postnatally [6, 7]. Early in the process of sinus development, a cartilage capsule surrounds the budding nasal cavity and paranasal sinus areas [8]. At week 6 of fetal development, paranasal condensations form lateral nasal swellings and the condensed mesenchyme forms a continuous capsule around the primary nasal cavity with the exception of the early nasal floor [3, 7]. The cartilage condensations are found laterally and centrally. The ectodermal ethmoid plate is at this point a thin cartilaginous plate that laterally forms the concha nasalis and ala orbitalis, which form the second and third ethmoturbinals. In this model, the smooth ectodermal ethmoid complexifies and around weeks 10–12, mucosal folds develop followed by intracochal cartilage [3]. Sphenoid development, however, seems to favor the latter argument, with largely postnatal development.

The Paranasal Sinuses

The paranasal sinuses are made up of the anteriorly draining group: the maxillary, anterior ethmoid, and frontal sinuses; and the posteriorly draining group: the posterior ethmoid and the sphenoid sinuses. These mucosa-lined, air-containing spaces in the skull are named for the bones into which they have pneumatized. Through a series of narrow spaces and channels, the mucus produced by the sinuses makes its way into the nasal cavity and nasopharynx at which point it is swallowed. Conventional techniques of functional endoscopic sinus surgery (FESS) for chronic inflammatory disease target this complex drainage system by enlarging the openings of the sinuses and their outflow tracts in a mucosa-sparing manner [7]. Although the exact physiologic role of the sinuses is not known for certain, theories on the functions of the paranasal sinuses include: olfactory, respiratory (humidification, buffer pressure changes, local immunologic defense), phonetic (resonance, reduce bone conduction of our own speech), static (reduce weight of the skull), mechanical (trauma protection), and thermal (provide heat insulation).

Sinonasal Mucosa

Three different mucosal types line the nasal cavity and paranasal sinuses. The primary function of the nose pertains to olfaction and this is reflected in the mucosa associated with fibers from the olfactory nerve traversing the cribriform plate. This mucosa is a ciliated, pseudostratified, columnar epithelium with odor receptors and a high concentration of mucous glands. The olfactory receptor cells are bipolar, with their sensory aspect in the nasal cavity and project directly onto the rhinal cortex. This mucosa is centered on the cribriform plate in the roof of the nasal cavity and can extend variably onto the supreme, superior, and middle turbinates, the superior septum, and even parts of the lateral nasal wall. Drying and inflammation of the olfactory mucosa, as well as nasal obstruction, can result in decreased olfactory sensation.

The predominant mucosal surface of the sinonasal tract is the respiratory epithelium, which lines the walls of the nasal and sinus cavities, the nasopharynx, and the nasal floor. This is also ciliated, pseudostratified, columnar epithelium, with an equally high concentration of glands, and greater innervation by the trigeminal nerve (via V2 and some of V1). In the healthy state, the mucosa of the sinonasal tract produces over 600 cc of mucus daily. The mucus is propelled along the surface of the