ABSTRACT

Frontal and/or maxillary sinusitis frequently originates with pathologic processes of the ethmoid sinuses. This clinical association is explained by the close anatomical relationship between the frontal and maxillary sinuses and the ethmoid sinus, since developmental trajectories place the ethmoid in a strategic central position within the nasal complex. The advent of optical endoscopes has permitted improved visualization of these spaces, leading to a renaissance in intranasal sinus surgery. Advancing patient care has consequently driven the need for the proper and accurate anatomical description of the paranasal sinuses, regrettably the continuing subject of persistent confusion and ambiguity in nomenclature and terminology. Developmental tracking of the pneumatization of the ethmoid and adjacent bones, and particularly of the extramural cells of the ethmoid, helps to explain the highly variable adult morphology of the ethmoid air sinus system. To fully understand the nature and underlying biology of this sinus system, multiple approaches were employed here. These include CT imaging of living humans (n = 100), examination of dry cranial material (n = 220), fresh tissue and cadaveric anatomical dissections (n = 168), and three-dimensional volume rendering methods that allow digitizing of the spaces of the ethmoid sinus for graphical examination. Results show the ethmoid sinus to be highly variable in form and structure as well as in the quantity of air cells. The endochondral bony origin of the ethmoid sinuses leads to remarkably thin bony contours of their irregular and morphologically unique borders, making them substantially different from the other paranasal sinuses. These investigations allow development of a detailed anatomical template of this region based on observed patterns of morphological diversity, which can initially mask the underlying anatomy. For example, the frontal recess, ethmoid infundibulum, and hiatus semilunaris are key anatomical components of the ethmoid structural complex that are fully documented and explained here on the basis of the template we have developed, as well as being comprehensively illustrated. In addition, an exhaustive 2000-year literature search identified original sources of nomenclature, in order to help clarify the persistent confusions found in the literature. Modified anatomical terms are suggested to permit proper description of the ethmoid
The paranasal sinuses are among the most poorly described anatomic sites in the human body. In large part this is because of the great morphological variations seen among individuals; but it is also due to the inconsistency of the terminology used to describe these structures. Much of the terminological confusion arose from uncertainty about the origin of individual sinuses versus their function, and from an arbitrary system of nomenclature in which a sinus might be named for where it drained, or in which bone it lay, or after an individual. Most of the terms now used were generated during the active debate among surgeons in the first half of the 20th century over the treatment of acute and chronic sinusitis. Among the paranasal sinuses, the ethmoid sinus is often considered as the “keystone of the sinus system,” because each paranasal sinus drainage pathway is through, or adjacent to its lateral wall (Terrier, 1991).

This investigation examines the adult condition of the ethmoid sinus in order to better understand its development. Multiple approaches are used, including CT imaging, anatomical dissection, three-dimensional reconstructions, and examination of dry cranial material. Tracking the migration of extramural cells and understanding their variation helps to clarify the anatomical basis of this paranasal sinus.

**BACKGROUND**

Phylogenetically the ethmoid sinus appears to have only an olfactory function, and it is not generally considered a “true” paranasal sinus because it lacks pneumatization. The recognition of “true” paranasal sinuses is thus based purely on the ontogenetic pattern given by Cave (1967). In this view a “true” paranasal sinus must have its respiratory diverticulum originate from, and remain in communication with, the nasal cavity. Its growth must be from a given meatus of the nasal cavity, and it must retain a patent communication via an ostium that remains permanently associated with that meatus. The sole guide to the morphological identity of a sinus is provided not by the bone or bones it may ultimately pneumatize, but by the bone or bones that circumscribe its ostium, or point of origin. Cave (1967) makes the point that neglect of this basic consideration has resulted all too frequently in the confusing misinterpretation of analogous cavities as homologues. An example of such misclassification can be drawn from a CT examination of an orangutan (Fig. 1), which has been traditionally reported as exhibiting only one paranasal sinus—the maxillary sinus.

In most of the mammals, the ethmoid bone and its associated turbinal extensions, along with the nasoturbinal and maxilloturbinal, are placed posterior to the paranasal sinuses. The lamina cribrosa is in a frontal position, for optimal olfactory function. Only in humans, chimpanzees and perhaps in orangutans (Márquez et al., 1999), does the ethmoid become pneumatized and contain a sinus. This is probably related to the upright posture of humans, in association with which a retraction of the snout occurs and the orbit migrates anteriorly, resulting in a deepening of the face. The anterior migration of the ethmoid bone forces its sinus between the nasoturbinal and maxilloturbinal, displacing the frontal sinus upwards, and disconnecting the latter from the maxillary sinus. This bony ethmoidal migration in humans made possible an upper aerodigestive tract crossing so that, in conjunction with the descent of the larynx, the unique modern human speech apparatus could eventually develop (see Laitman and Reidenberg, 1993). As olfaction became less important for human survival compared with more macrosmatic mammals, the position of the lamina cribrosa becomes more horizontal, the olfaction function shifts toward the microsmatic, and the ethmoid bone becomes pneumatized to attain paranasal sinus status. This apparent adaptive evolutionary shift has resulted in very narrow drainage channels (i.e., tight spots) of the ethmoid; in contrast to most other mammals in which rhinosinusitis is a rare disease, this configuration favors infection. As a result, Stackpole et al. (1996) described the ostiomeatal complex as the “eye of the needle” of the paranasal sinuses. Thus, for adventitious reasons, the ethmoid bone, phylogenetically never destined to be a sinus, has evolved into a drainage and ventilation pathway of the maxillary and frontal paranasal sinuses (i.e., “ostiomeatal complex”), forming not an anatomical but a “functional” unit.

Embryologically the ethmoid is different from all the other sinuses. The ethmoid bone originates from the cartilaginous nasal capsule, or paleosinus (endochondral bone), whereas the other paranasal sinuses are extensions from the ethmoid (extracapsular) into membranous bone (neosinus) via epithelial diverticula extensions. Specific stages of development are necessary for paranasal sinus development to occur. These include primary and secondary pneumatization patterns that involve differential growth of the cartilaginous nasal capsule, which initially produces diverticular pouches that expand within the confines of the capsule creating elaborate intracapsular airway spaces (Smith et al., 2005). Secondary pneumatization patterns involve the paranasal recess, the region of the nasal capsule that is destined to become a sinus; as its diverticula leave the confines of the nasal capsule, this becomes extracapsular and is left occupying space in adjacent structures. Thus, the paranasal recess becomes a paranasal sinus through a specific sequence of developmental events and fulfills...
the sole criteria for proper sinus identification (Rossie, 2006). Although the extent of the paleosinus, or ethmoid, is inherently fixed and constrained, the sizes of the neo-sinus (frontal, maxillary and sphenoidal) are highly variable, because paranasal recesses are not predictable. There is no apparent uniformity in the rate of development or the degree of differentiation in the migration of these extracapsular diverticula, which when extramural, expanding beyond the confines of the ethmoid bone, can variably pneumatize adjacent structures leaving diverse drainage pathways.

Historically, investigators have mixed extramural and intramural structures in their anatomical descriptions of this region. To avoid confusion, Layton (1934) advised that the following principles should be followed when describing anatomical structures: “a name must (1) denote one thing only; (2) be used by all to denote this thing; and, if it connotes any attribute, then (3) this attribute should always be present.” According to Layton (1934), two terms that violate these principles are “infundibulum” and “hiatus semilunaris.” Both are applied to regions or spaces, much as the pharynx is a space bounded by muscles, rather than a structure. This concept, that spaces and structures are of equal importance, is critical for a full understanding of the nasal complex—defined as the nose plus the paranasal sinuses (Marquez, 2002).

Probably, no other term has been more confused in the anatomical literature of the nose and paranasal sinuses than the term infundibulum (meaning “funnel”). Layton contends that the term infundibulum entered the anatomical language as a name passed from Latin to the other romance languages. The apparent first appearance of this term in the English anatomical literature was in the 1797 Edinburgh textbook of anatomy known as “Monro’s” (Layton, 1934). The first part contains the anatomy of the Human Bones by Alexander Monro the First (the senior Monro), and the first volume says:

“A cellular and spongy bone substance depends from the cribriform plate. The number and figure of the cells, in this irregular process of each side, are very uncertain, and not to be represented in words; only the cells open into each other, and into the cavity of the nose: The uppermost, which are below the aperture of the frontal sinuses, are found like funnels.”

However, in volume II it states:

“The frontal, maxillary, and sphenoidal sinuses open into the internal nares, but in different manners. The frontal sinuses open from above downwards, answering to the infundibula of the os ethmoidales described in the history of the skeleton.”

Zuckerkandl (1892), on the other hand, credits Baron Alexis de Boyer with being the originator of the term infundibulum, a term that emerges in his published French work of 1815 (vol. 1, p 125):

“Entre la face externe de ce cornet (i.e., middle turbinate) et les masses laterales se trouve un enfoncement qui fait partie du meat moyen des fosses nasales. A la partie antérieure de cet enfoncement on remarque une espèce de gouttière qui monte de derrière en devant dans les cellules antérieures de l’os; la cellule dans laquelle cette gouttière aboutit est large supérieurement et étroite inférieurement, ce qui lui a fait donner le nom l’infundibulum; elle s’abouche avec l’ouverture du sinus frontal.”

Comparing these accounts, it appears that the Edinburgh School of Anatomists can claim credit for originating the usage of the term familiar today, since they recognized the frontal sinuses as being of the same nature as the ethmoidal cells, and applied the term infundibulum specifically to the channel that often erroneously known today as the fronto-nasal duct (see Discussion later).
Layton (1934) alerts the reader to the fact that Boyer believed that the frontal sinus drained through an ethmoidal cell into the nose, that and it is to this cell, rather than the groove, that Boyer applied the term infundibulum. Layton’s contention is justified on the basis of Boyer’s description of the nasal fossa under splanchnology, where we read (Tome IV, p 176), under “Le Méat moyen,” that:

“On voit à la partie moyenne et antérieure de ce meat une gouttière étroite qui monte de derrière en devant, et va communiquer dans les cellules antérieures de l’ethmoide, et par le moyen de celles-ci dans le sinus frontal.”

It is precisely to this erroneous notion that the frontal sinus opens through an ethmoidal cell that Layton (1934) attributes the ongoing nomenclatural confusion. It may be that Monro had the same idea when he gave his many lectures on the topic. But even as anatomists’ understanding of this region improved, some continued to use infundibulum to describe the less common drainage of the frontal sinus via an intermediate cell, whereas some used the term “nasofrontal duct,” some retained the term for the groove into which the sinus opened; and others used it only for the upper part of this groove where an ethmoidal cell would lie if the frontal sinus opened through it. What is certain is that Zuckerkandl set the standard for the use of the term infundibulum for the groove, and also added the modifier ethmoidale, in an attempt to distinguish this feature clearly from the hiatus semilunaris. The latter is properly a two-dimensional space, the gap through which this groove opens on the middle meatus. We note that His (1885) in his pamphlet Die Anatomische Nomenclatur, which became the basis of the British Nomina Anatomica, distinguishes the two terms by an indentation of the margin:

“Infundibulum Ethmoidale
Hiatus Semilunaris.”

However, a number of workers still used the term infundibulum (i.e., Tillaux, 1878; Bosworth, 1888; Turner, 1901), whereas others used infundibulum ethmoidalis (i.e., Shambaugh, 1907).

Currently, there are three structures in the nose described as infundibula: (1) the frontal infundibulum; (2) the maxillary infundibulum; and (3) the ethmoidal infundibulum. The frontal and maxillary infundibula lie totally within their respective sinuses, and their openings are their respective ostia. In contrast, the ethmoidal infundibulum is not contained within a given sinus, but rather is a three-dimensional space whose funnel is much wider at its lateral base, permitting it to receive the common drainage of the frontal, maxillary, and anterior ethmoid sinuses. The apex of this space orients toward the hiatus semilunaris, before emptying into the middle meatus.

The ontogeny of the ethmoid sinus permits the categorization of the ethmoid sinuses into anterior and posterior ethmoidal components. However, a survey of anatomy textbooks used in first-year medical gross anatomy courses (i.e., Rose and Gaddum-Rose, 1997, p 832; Snell, 2000, p 747; Drake et al., 2005, p 971; Moore and Dalley, 2006, p 1019) as well as laboratory dissecting manuals (Tank, 2005, p 197), continue to divide the ethmoid sinuses into anterior, middle, and posterior groups. As early as 1901, Turner (1901) divided the ethmoid sinuses into two groups, anterior and posterior groups, based on development and their position of their ostia. Douglas (1906) believed that division of the ethmoid sinus into an anterior and posterior group is the correct classification because it is based on sound embryological grounds because it is to be understood that the criteria of grouping divisions is on its drainage destiny. Any ethmoidal cell, which normally drains into the middle meatus of the nose belong to the anterior ethmoidal cell group; and that all ethmoidal cells that normally drain into the superior meatus of the nose belong to the posterior ethmoidal cell group. The addition of a middle ethmoid group serves only to confuse students in the area of rhinology (Douglas, 1906, p 75).

The most recent edition of British Gray’s Anatomy recognized the confusion in the literature with this statement: “the ethmoidal sinuses are now commonly considered by clinicians as consisting of anterior and posterior groups on each side with the middle ethmoidal air cells being incorporated into the anterior group” (Standring, 2005, 39th edition, p 576). This last comment appears to fit anatomists and clinicians as two separate entities that are in conflict when it comes to describing this region. Let us remember that the early pioneers who helped established the discipline of rhinology such as Hartmann, Zuckerkandl, Bosworth, His, Hajek, Onodi, Killian, Turner, Mosher, Schaeffer, Van Alyea, and Davies were not only all great physicians but also helped lay the foundation of present-day anatomic description of the region.

**MATERIALS AND METHODS**

A sample of 488 specimens was examined for this study, and included dry skulls from the osteological collections in the Division of Anthropology, American Museum of Natural History, and at SUNY Downstate Medical Center. Additional specimens were examined and photographed from University Hospital-Free University, Brussels. Cadaveric dissections (n = 168) from gross anatomy courses over a 4-year period were utilized and digitally photographed for examination. Fresh tissue dissection (unembalmed) material was also included in this study (n = 8), involving the removal of heads in the pathology autopsy room at SUNY Downstate Medical Center and the University of Texas Southwestern Medical Center. These specimens were frozen to a temperature of −70°C. The Head was then fixed to a wood block and anchored with screws. Two-centimeter sagittal sections were prepared, utilizing a butcher’s band saw. Specimens were digitally photographed using a Nikon D100 camera. CT imaging of patients with and without sinus disease was performed in order to document the variability of this sinus, using a mixed-sex sample size of 200 adult individuals. Selective images were reprocessed using a three-dimensional CT program (Anatomage®). We also drew on the clinical perspective possessed by two of the senior authors (SDS and PARC), who together have over 70 years of clinical experience. Together they have served on anatomical nomenclature committees (i.e., see Stammberger et al., 1995), taught and trained
more than 10,000 physicians worldwide, and have operated in this region in more than 9,000 cases combined.

RESULTS

The ethmoid sinus system is comprised by a number of air cells that ranged from 6 to 16 on one side from the osteological collections of the American Museum of Natural History and at SUNY Downstate, 7–14 from the anatomical embalmed material (see Table 1), and 8–11 on the fresh anatomical material Figs. 2–4 (see Discussion regarding the term cell). Observation from hard and soft tissue material shows the ethmoid sinus to have a consistent pattern of aeration of the bony labyrinth, but the quantity of air cells is highly variable. The hard tissue anatomical material from the osteological collections and unembalmed cadavers illustrate how variable and irregular these air cells are in situ (see Figs. 2–4). The observed air cells present with “paper-thin” bony lamellae1 walls that are morphologically distinct from any other bony substrate found in our sample (for discussion on bony lamellae see Bohatirchuk et al., 1972).

TABLE 1. Identification of ethmoid air cells in embalmed material

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aUnable to identify air cell quantity due to preservation of material.

The term lamella has been used by Vitruvius Pollio (De Architectura 7, cap 3, paragraph 9, 25 BC). "Quemadmodum enim speculum argentum tenui lamella ducunt incertas et sine viribus habet remissiones splendoris...". "Lamella" is here used as a diminutive of lamina and means to describe a thin metal plate. Nathaniel Highmore was one of the original anatomists to use the thickness of paper to describe a thin wall structure by the following: "It is covered by thin bone or bony scale;...barely exceeds the thickness of packing paper" (Highmore, 1651, p 226).
Fig. 2. A: Sagittal paramedian section through dried skull. Labels: ES, ethmoid sinus; FS, frontal sinus; SS, sphenoid sinus; MS, maxillary sinus. B: Magnified view showing thin enchondral bone of ethmoid sinus. C: Sagittal paramedian section through unembalmed cadaver illustrating paranasal sinus anatomy. Labels: SS, sphenoid sinus; FS, frontal sinus; D: 1882 illustration by Emil Zuckerkandl showing the paranasal sinuses in a coronal plane.
An analysis of the medial wall of the bony orbit shows the contour of lamina orbitalis ossis ethmoidalis, or lamina papyracea, of the recessus frontalis and of os lacrimale (Fig. 5). A number of sutures can be clearly identified that include the frontoethmoid, frontolacrimal, frontomaxillary, and frontonasal sutures (Fig. 5). A number of ocular muscles attach on the medial wall of the orbit (Fig. 6). The lateral wall of the frontal recess, the area of attachment of the lamella bullae ethmoidalis, and the attachment of the basal lamella of the middle turbinate can also be observed in the skull (Fig. 6). It was documented on this specimen that a small part of the lateral wall of the frontal recess is made up by lamina papyracea. The attachment of the middle turbinate can be outlined on the ethmoid bone (Fig. 7) and a small agger nasi cell can be detected on the lateral wall of the ethmoid (Fig. 8). Considerable pneumatization of the agger nasi can take place and can be easily observed in CT scans (see Fig. 9). The topographical location of the agger nasi is considered as the anterior limb of the uncinate process. Further pneumatization of the agger includes the migration of ethmoid cells into the lacrimal bone, increasing the prominence of this eminence of the lateral nasal wall. Identification of the lacrimal bone is an important landmark because it defines the border between the frontal bone and the frontal process of the

Fig. 3. A: Sagittal paramedian section through dried skull in different specimen than Fig. 2A–B illustrating variations in ethmoid anatomy. Inset of whole skull provides for orientation. Labels: SS, sphenoid sinus; MS, maxillary sinus; FS, frontal sinus. B: Sagittal paramedian section through additional unembalmed cadaver head showing variation in sinus anatomy. C: Paramedian three-dimensional reconstruction of multiple CT images showing complexity of sinus anatomy. Labels: SS, sphenoid sinus; MS, maxillary sinus; FS, frontal sinus; pe, posterior ethmoid sinus; ae, anterior ethmoid sinus.
maxilla (see Fig. 10). When the ethmoid bulla is prominent by CT imaging, the lamina papyracea is observed as its lateral border (Fig. 10). The lamina cranialis of the frontal bone is the roof of the supraorbital recess, which is shown in Fig. 10.

Frontal sinus variation exhibited a number of different morphological patterns. For example, utilizing the Bent classification (Bent, 1994), Type-III cells are found in both frontal sinuses of one individual on CT images (Fig. 11). However, parasagittal CT slices of the same person reveal that these cells communicate with the frontal recess where the anterior part of the supraorbital recess becomes part of the frontal recess (Fig. 12). In a CT scan of an individual with frontal sinus disease Type-A-II and Type-A-III cells (see Discussion later for definition of Type-A versus Type-B cells) are identified with a frontal recess that extends into the nasal bones and septum (the so-called nasal recess) (Fig. 13). Figures 16 and 17 show the variation of Type-A-II and Type-A-III cells in the frontal sinus region. Divisions of the frontal sinus can occur with septated bony divisions that can affect the frontal sinus outflow tract. These bony divisions referred to as interfrontal septum or septum sphenoidale can present partial (incomplete) or complete division of the sinus (Fig. 14). Figure 15 shows the potential effect of a deviated nasal septum on frontal sinus drainage. Examples of migrating extramural cells by the ethmoid into adjacent structures are consistently variable. A concha media bullosa is a pneumatization of the anterior middle turbinate bone via a posterior ethmoid air cell. This is referred to as an interlaminar cell

Fig. 4. A: Sagittal paramedian section through dried skull in a third specimen, again illustrating the variation in development of the ethmoid sinus, Inset of whole skull provides for orientation. Labels: SS, sphenoid sinus; MS, maxillary sinus; B: Sagittal paramedian section through unembalmed cadaver other than seen in prior figures showing anatomy of ethmoids, frontal recess and frontal sinus. Labels: FS, frontal sinus; fo, frontal ostium or outflow tract; fr, frontal recess; pe, posterior ethmoid cell.
of Grünwald (Fig. 18). Other extramural cell migration occurs when these cells migrate to the floor of the orbit or infraorbital cells (Fig. 19). These cells are called Haller cells in honor of August von Haller who originally described them in the early 19th century (Haller and Cullen, 1803). Other findings include extensive pneumatization that envelopes the nasal bones, nasal septum, and frontal recess (Fig. 20).

**DISCUSSION**

The hard tissue anatomy of the ethmoid is of endochondral origin forming part of the cranial base, which is considered a highly phylogenetically conserved region among the bony elements of the skull (De Beer, 1937). From an anatomical perspective, the ethmoid is significantly different than all the other sinuses in that it is the only paranasal sinus that presents with very thinned bony wall lamellae. The other paranasal sinuses can form septations, but these are much more rigid and robust. The consequence is that these very thin bony lamellae and cells can migrate easily (extracapsular) into adjacent bones or other paranasal sinuses. These extramural extensions can migrate into frontal recess cells, frontal cells, supraorbital cells, and/or infraorbital cells, or any combinations thereof. This crucial developmental concept explains the source of ethmoid sinus cell variation in that extramural migration can take different paths thus presenting different morphologies. Classic anatomic studies of the ethmoid have failed to document the entire spectrum of ethmoid sinus construction either due to low sample sizes or random sampling error. For the surgeon, however, the varied manifestations of extramural migration of the ethmoid is critically important for it decides the proper surgical procedure to be implemented to resolve the pathologic condition of the patient. The intramural cells and lamellae do not show any uniformity, resulting in the “ethmoidal labyrinth.” One cell may outgrow its neighbor and force the latter to progress in a direction other than toward it was primarily directed (Anon et al., 1996).

The architectural construction of the ethmoid sinus can be understood by examining the early ontogeny of the region (Shambaugh, 1907). During prenatal development the attachments of bony structures originating from the ethmoid to the lateral wall such as the uncinate process,
A small line: attachment of the bulla and lamina bullae racea (less than 10% of area is between red and green line). Part of lateral wall of the frontal recess that is made up by lamina papyracea. Fr, line). Dashed line represents the transition of the is the lateral extension of the uncinate process. The second lamella is referred to as the plate of the bulla because its extension into the nasal cavity forms the bulla ethmoidalis.\(^2\) The third lamella serves as the attachment of the frontal part of the middle turbinate. The middle turbinate has three parts: the parasagittal, the frontal, and the transversal. The parasagittal and the transversal do not play a role in the division of anterior and posterior ethmoid. This is an important anatomic structure, demarcating the division between the anterior ethmoid cells from the posterior cells and directing the drainage patterns of these air cells into the middle and superior meatus, respectively. It is also clinically significant as it is considered as a natural boundary to the spread of infection into the posterior ethmoid and serves as the posterior landmark in anterior ethmoidectomy (Schaefer et al., 1998). The ethmoid air cells during development tend to expand beyond the labyrinth to form prominences that extends into the nasal cavity. The most anterior of these lamellae is the lateral extension of the uncinate process. The sec-

**Fig. 8.** Internal view of the lateral wall of the ethmoid (parasagittal section). Dashed line represents the agger nasi. In this case, there exists a small agger nasi cell in close contact with the uncinate process (yellow line). Fr, Frontal recess. Black double headed arrow: posterior border of agger nasi. Black arrows: anterior and posterior ethmoidal artery. Green line: attachment of the bulla and lamina bullae to lamina papyracea. Blue line: attachment of ground, or basal lamella (lamina basalis) to lamina papyracea. Red line: anterior border of lamina papyracea. Note small part of lateral wall of the frontal recess that is made up by lamina papyracea (less than 10% of area is between red and green line).

**Fig. 9.** A and B: coronal CT scans. A: a large agger nasi cell (note the intimate relation between agger nasi cell and uncinate process). B: transition of the agger nasi cell into a lacrimal cell (note again that the floor of this cell is shaped by the uncinate process that is now more visible). Yellow arrows: frontal process of the maxilla. Blue arrows: orbital plate of the frontal bone. Green arrows: lacrimal bone. Note in A the free border of the middle turbinate is not visible or adjacent to the agger nasi cell, and the lateral wall of that cell is made up by the lacrimal bone and free border of the middle turbinate begins to become visible. As this cell is posterior to the agger nasi, it would be considered a “lacrimal cell.”

middle and superior concha, are formed by ground plates, or basal lamellae. Although the lateral attachments of these lamellae end abruptly, their medial aspects project beyond the labyrinth to form prominences that extends into the nasal cavity. The most anterior of these lamellae is the lateral extension of the uncinate process. The sec-

**Fig. 10.** A and B: coronal CT scans. A: Purple arrows point to the lamina orbitalis of the frontal bone that is always superior to the lacrimal bone (red arrows). The lacrimal bone is an easy landmark to define the difference between frontal bone and frontal process of the maxilla. In this CT scan one can see the frontal recess underneath the floor of the frontal sinus. B: Green arrows: lamina papyracea (lateral wall of the bulla ethmoidalis). 1: Frontal sinus; 2: Frontal recess; 3: Suprabullar recess. Red line: Lamina orbitalis of frontal bone. Yellow line: Lamina cranialis of frontal bone (roof of the supraorbital recess). Purple line: roof of the suprabullar recess (or fovea/frontal bone).

\(^2\) Other frequently made errors are inconsistent with Latin grammar. “Bulla lamella” (Stammberger et al. 1995, Owen and Kuhn 1997, Wormald 2003) is grammatically incorrect. In Latin, the correct term is lamella bullae ethmoidalis or in English a bullar lamella, as in suprabullar recess. Furthermore the term “lamella” does not exist in the “Terminologia Anatomica” nor in Cassel’s Latin Dictionary (see Simpson, 2000 and footnote 1). A more appropriate Latin name for the basal, or ground lamella which divides the ethmoid into an anterior and posterior sinus is “lamella basalis.”
extend to the *fovea ethmoidalis*-frontal bone (this hyphenated term is used to remind the reader of the complex nature of the roof of the ethmoid sinus), the *sinus lateralis* continues anteriorly to the frontal recess. Superiorly, this “sinus” is formed by a space known as the suprabullar furrow, or suprabullar recess, which communicates with the middle meatus (Grunwald, 1925; Messerklinger, 1978; Stammberger et al., 1995). Sometimes the sinus lateralis can extend very laterally when there exists a well-developed supra-orbital recess. A true *sinus lateralis* is rare, perhaps only occurring 7% of specimens (Bolger and Mawn, 2001) as a bony lamella more often separated the superior spaces from inferior and posterior retrobullar and infrabullar spaces. The superior aspect of the *hiatus semilunaris* communicates with this space, and this crescent-shaped two-dimensional structure forms the final common pathway for secretion to drain into the nose. The fourth lamella is at the attachment of the superior concha, and when a supreme concha3 is also present, a fifth lamella arises lateral to this turbinate.

The frontal recess is an important space for it is part of the outflow drainage pathway of the frontal sinus (Fig. 11). A description of the pneumatization patterns of adjacent structures by the extramural migration of the ethmoid is essential for describing the anatomy of the frontal recess and its contiguous structures that borders the recess. Describing supraorbital and ethmoid bullar cells requires clarifying what is meant when referring to an ethmoid air cell. We suggest with some trepidation that the term “cell” should only be used for every sphere-like structure, which are composed of thin bone of endochondral origin. For this reason, the frontal and maxillary sinus cannot be considered as extramural ethmoidal cells. Consistent with the above, Zuckerkandl (1892) stated that the frontal sinus is not an invasion by the ethmoid into the frontal bone, but a bulging of the nasal mucosa of the frontal recess into the frontal bone.

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3Giovanni Santorini, described this conchae in 1724, and in honor of him, this conchae bears his name today as the “Conchæ of Santorini” (Santorini, 1724). In the hollow walls of Padua, where there is so much tradition with the many famed anatomists that trained and taught there that the highest honour was to have the skull of an anatomy master bequeath to the medical school. Santorini’s skull is still displayed in the library of the anatomy department at the University of Padua Medical School (Fig. 21).
Fig. 12.  A through F coronal CT scans of the same case as 11. 1: Frontal sinus, 2: Anterior part of the supraorbital recess that becomes a part of the frontal recess, and 3: Frontal recess.

Fig. 13.  A, B, and C: coronal CT scans. White arrow: part of the frontal sinus that is diseased. 1: Type-A-II cell using proposed revised classification. 2: Type-A-III cell using proposed revised classification. 3: Frontal recess with an extension to the nasal bones and septum (nasal recess).
and has since been corroborated by other investigators (Kasper, 1936). In fact, the frontal sinus consists of a pneumatization of the frontal bone (membranous bone). Sometimes it is difficult to differentiate between the possible origins of a structure. When the frontal recess pneumatizes the floor of the frontal sinus, the nasal bones and the region of the crista galli, these structures and spaces may appear as if an ethmoidal cell has invaded the frontal sinus or frontal recess. In those cases, the bony wall of such a recess may look like a cell, but the walls are mostly much thicker (membranous bone) than the thin bony walls of cells from ethmoidal origin (endochondral bone). Sometimes these recesses are often misinterpreted as the presence of a double frontal sinus (Shambaugh, 1907). Despite the earlier discussion of a “cell,” our definition becomes clinically more problematic when we observe the migration of posterior ethmoid cells into the sphenoid bone. These extramural, endochondrial-derived cells are extending into the membranous sphenoid bone. Although these cells begin as thin-walled structures they pneumatize in the adult into the much thicker membranous bone along their superior and lateral surfaces, hence not appearing on these surfaces as endochondrial derived cells.

The term “frontal recess” originated from developmental embryology, whereas already discussed by Killian (1895) employed the term to describe a frontal curve or bend in the supranoanterior middle meatus (“Stirnbucht”). Later, Van Alyea (1946) used frontal recess to describe the supero-anterior prolongation of the infundibulum ethmoidale. The processus frontalis, a recognized term in the “Terminologia Anatomica, p 14,” has sometimes been incorrectly used to describe the frontal recess. One can define the frontal recess as the most anterior-superior part of the middle meatus (Márquez et al., 2002). The lateral part of it is also the
most anterior extension of the supraorbital recess reaching the posterior wall of the frontal sinus (Figs. 10 and 12). McLaughin et al. (2001) defined it as the cleft in the anterior ethmoid complex, just inferior to the frontal sinus ostium. The frontal recess (when a supraorbital recess is present) invades the frontal bone just inferioposterior to the aperture of the frontal sinus. This makes the medial orbital plate (pars orbitalis ossis frontalis) of the frontal bone pneumatized resulting in a “lamina orbitalis ossis frontalis” and a “lamina cranialis ossis ethmoidalis” (Fig. 10B red and yellow line). The lamina orbitalis of the frontal bone should be differentiated from the lamina orbitalis of the ethmoidal bone. Therefore, it would be better to keep the older nomenclature “lamina papyracea” in order to prevent confusion with the lamina orbitalis of the frontal bone. The lamina cranialis of the frontal bone forms the roof of the frontal recess (fovea/frontal bone) and supraorbital recess. The roof of the ethmoid sinus is frequently referred to as the fovea ethmoidalis, when in fact the fovea or pit-like migration of the ethmoids cells into the frontal bone forms the roof of this sinus (Figs. 10 and 22). When looking at the facies orbitalis of the frontal bone in the orbits (Fig. 6) one can observe that the cranial border of the lacrimal bone is always lower than the cranial border of the lamina papyracea of the ethmoids (a range difference of 3–6 mm). This results in a bent and sometimes even a notch of the margo ethmoidalis of the frontal bone (Figs. 5 and 6). This curve or notch can be called “incisura laminae papyraceae” or “incisura laminae orbitalis ossis ethmoidalis.” It is not possible to call this incisura “incisura ethmoidalis” because this term exists already and is reserved for the defects in the frontal bone, caused by the cribiform plate (intraorbital gap). This incisura has never been described before, but it is important because it explains why the lateral wall of the frontal recess is not made up by the lamina papyracea but mainly by the orbital plate of the frontal bone (Lang, 1988).

Another frequent mistake is to use the same name for very different anatomical structures. A typical example for this is “agger nasi cell.” According to Berkovitz and Moxham (2002), agger nasi is “... a curved ridge called agger nasi may be found close to the atrium. This ridge overlies the anterior part of the ethmoidal crest of the maxilla.” As the agger is an eminence or mound anterior to the middle turbinate or concha media, a coronal CT projection through this structure must show laterally the frontal process of the maxilla (site of the ethmoidal crest). On the same CT projection, the middle turbinate should be absent because the agger nasi is anterior to the free border of the concha media. In the literature, however, many anatomical structures of the frontal recess are misnamed “agger nasi cell.” The term agger nasi cell has been given to lacrimal cells, to the recessus terminalis (Wormald, 2003, 2005a,b) or even frontal sinus cells (Brunner et al., 1996; Orlandi et al., 2001). According to a recent study of Chaiyasate et al. (2007) in twins, an agger nasi cell can be seen on CT of normal test subjects in 65% of the cases. Mostly, these cells have a very small size. We recommend that the term agger nasi cell be assigned to the surface feature anterior to the insertion of the middle turbinate on the lateral nasal wall which is consistent with the definition of an agger as an eminence and agger nasi cell be reserved for the ethmoidal cells which constitute its pneumatization (Figs. 7–9).

Some comments need to be given on the nomenclature of the anterior extramural ethmoidal cells. These ethmoidal cells should not be called a “bulla” (Navarro et al., 1997). The term bulla should only be used for the...
ethmoidal bulla (bulla ethmoidalis), which is normally the most prominent cell in the anterior ethmoid. It is also very confusing to link the name of the cell to the region where it comes from or where it drains into (infundibular cell for the lacrimal and anterior frontal recess cell). Cells should be named according to the site where they actually are (i.e. frontal sinus cells, frontal recess cells, lacrimal cell). Furthermore, for clinical purposes, the classifications of cells must have a clinical relevance. Therefore, the classification of Bent et al. (1994) should be adapted for the following reasons: (1) the difference between Type-I (single frontal recess cell above agger nasi) and Type II (tier of cells in the frontal recess above agger nasi) is not very relevant. Both types can result in a blockage of the drainage of the frontal sinus into the frontal recess and if this is caused by two, three, or even more cells in the frontal recess, then this is not relevant and (2) the most important fact is that the frontal recess needs to be cleared from obstructing cells. The same authors define Type-III cells as those arising above the agger nasi and extending into the frontal sinus. These are examples of extramural endochondral ethmoid cells, which have migrated into frontal sinus (Fig. 7). Type-IV cells are described as a single isolated cell within the frontal sinus which is pneumatization of the membranous frontal bone and not an isolated, migrated endochondral ethmoid cell. Sometimes after trauma a compartmentalization of the frontal sinus can occur, or an excessive septation can arise resulting in a partial opacification of the frontal sinus, but these are completely different structures from the frontal cells. Wormald (2005a,b) suggested modifying the Bent-classification, a Type-IV cell should arise from the frontal recess and extend over 50% of the vertical height of the frontal sinus. In this revised classification, Type-III cells would be extramural ethmoid cells, which occupy less than 50% of the vertical height of the frontal sinus. Such a differentiation is useful because Type-IV cells may potentially adhere to the frontal sinus walls and be difficult to remove. So, a better classification of cells blocking the drainage of the frontal recess and sinus should be:

A. Concave structures (Figs. 7–9, 12, and 13)
   - Type I: excessive number, or size of frontal cells blocking the frontal recess.
   - Type II: frontal cells occupying less than 50% of the height of the frontal sinus.
   - Type III: frontal sinus cells occupying more than 50% of the height of the frontal sinus. Cell Types II and III occur in about 10% of the adult population (Chaiyasate et al., 2007).

B. Convex structures (Fig. 10): The intersinus septum of the frontal sinus (=septum sinuum frontalium) can under pathologic conditions involve the aperture of the frontal sinus forming a convexity. This very rare condition can confuse the surgeon as one is always expecting a concave structure obstructing the drainage of the frontal sinus and instead finds a convexity. The concave structures (Type A) are extramural ethmoidal cells, whereas the convex structures (Type B) are not from ethmoidal origin.

Sometimes peculiar nomenclature is introduced such as “internal frontal ostium” (Bent et al., 1994; Kuhn, 1996), which means that there should also exist an “external frontal ostium.” The term “ostium” also deserves some comments. In basic anatomy textbooks the term “ostium” is not typically used to refer to opening of a paranasal sinus. The term “ostium” is mostly used for a dynamic structure that opens and closes, that
Ostium in Latin means a "door," whereas "apertura" is a rigid opening in bone such as "apertura piriformis," "apertura sinus frontalis," "apertura canaliculi vestibuli," or "apertura canaliculi cochlea," which are all accepted terminologia anatomica terms (Terminologia Anatomica, 1998).

As sinus ostia are never dynamic structures, they should be called "aperturae," but the term sinus ostium has been used extensively by ENT surgeons and many anatomists. Therefore, we suggest ostium is best restricted to a rounded sinus opening, through which the sinus drains and ventilates, and that can be found in every individual. Although the ostia of the maxillary and the sphenoid sinuses are such structures, the drainage of the frontal sinus is completely different. Also, the drainage openings of the ethmoidal cells are mostly irregular in shape and cannot be called ostia.

Presently, there is a gathering if not general consensus that the nasofrontal duct is a myth because this "duct" is a highly variable space, or outflow tract, rather than the homologue of the nasolacrimal duct. Vogt and Schrade (1979) using contrast radiography showed that the drainage of the frontal sinus into the ethmoid is quite complex. Also Lee et al. (1997), Friedman et al. (2004), and Daniels et al. (2003) describe different drainage patterns from the frontal sinus into the frontal recess, ethmoidal infundibulum, or directly into the middle meatus (Duque and Casiano, 2005). Since the introduction of endoscopes, the frontal sinus is now more often approached endonasally. In adults one very seldom finds a structure that looks like a nasofrontal duct. Following the surgical removal of the frontal recess cells, most often a triangular-shaped opening leading to the frontal sinus is found. This triangular opening is formed lateroinferiorly by the orbital plate of the frontal bone.
superiorly by the cranial plate of the frontal bone, and medially by a bony process from the floor of the frontal sinus up to the posterior wall of the frontal sinus. The frontal aperture is in a plane perpendicular to the posterior wall of the frontal sinus (Daniels et al., 2003) going from laterosuperior to inferomedial, and therefore, this structure is very difficult to visualize on conventional CT scanning using only coronal, axial, or sagittal projections. This opening of the frontal sinus into the frontal recess is called “apertura sinus frontalis.” Given the current practice of utilizing an hour–glass analogy to describe the frontal sinus outflow tract, the apertura sinus frontalis is the neck of the glass, the upper body of the hour glass in the frontal sinus, and the lower body is the frontal recess (Figs. 7, 11, and 22).

With these new definitions and recalling the migration of the ethmoid cells, one can redefine the boundaries of the frontal recess, although still remembering that this term has evolved from its original application for developmental embryology. When viewed from within, the walls of the frontal recess can be defined as follows (Fig. 5).

The anterior wall is formed by the upper-posterior face of the frontal process of the maxilla and partly by the posterior part of the sulcus lacrimalis of the ethmoid bone (Fig. 5 between arrow a and b). If the frontal recess extends posterior to the frontal sinus the upper anterior part of the wall is made up by the posterior wall of this frontal sinus.

The posterior wall is formed by the anterior face of the bulla ethmoidalis and of the lamella bullae.

The superior wall or the roof is formed by the skull base or the roof of the supraorbital recess and frontal bone (Figs. 6B, 22, and 23).

The lateral wall is made up mainly (45%) by the orbital plate of the frontal bone and for another 45% by the upper part of the lacrimal bone (Owen and Kuhn, 1997). The lamina papyracea makes up never more than 10% of the lateral wall of the frontal recess Figs. 6 and 8). The inclusion of the all three bones in the lateral boundary of the recess is a departure from other authors (Stammberger et al., 1995; Daniels et al., 2003; Wormald, 2003; Friedman et al., 2004), and reflects the difficulty in defining bony borders from CT or anatomical specimens. Only skull preparation will show the exact relationship between the sutures of the bones of the skull.

The medial wall is formed by the sagittal attachment of the middle turbinate to the skull base and the floor of the frontal sinus. Sometimes the anterosuperior part of the frontal recess can extend toward the posterior wall of the frontal sinus anteriorly of the sagittal attachment of the middle turbinate and the crista galli (sometimes pneumatizing the latter) and rarely reaching as far as the nasal bones and the nasal septum. In this configuration, both frontal recesses meet each other at the midline and form a small triangular septum in line with the nasal septum and the septum sinuum frontalium. A possible name for this septum can be “septum recessum frontalium.”

One way on coronal CT projections to differentiate between lamina orbitalis of the frontal bone and lamina papyracea is to identify the lacrimal bone. As long as on a coronal CT-scan the lacrimal bone can be located, the bony structures superior to it must be frontal bone (Figs. 9A and 10A).

The anterosuperior attachment of the uncinate process is very complex and most likely influences the popula-
tion of the frontal recess by migrating ethmoid cells. In most textbooks one of the most common variants of this attachment is described laterally onto the *lamina papryacea*. As was already demonstrated before, this is not possible because the lateral wall of the frontal recess consists mainly of the orbital plate of the frontal bone. Mostly, the anterosuperior attachment of the uncinate process is like a palm tree with branches going in every direction, mainly orbital plate, skull base, floor of the frontal sinus, and middle turbinate. A very masterly dissection of the superior attachment of the uncinate process in the frontal recess can be seen in Bolger and Mawn (2001). Sometimes the latter attachment of the uncinate process can make the ethmoid infundibulum end blindly in a dome-like structure obstructing a good view of the frontal recess and *apertura* of the frontal sinus. Such a blind ending recess is called terminal recess or *recessus terminalis* (Stammberger et al., 1995).

**CONCLUSION**

The advent of optical telescopes to permit minimally invasive endoscopic sinus surgery is probably the event that has most driven the need for proper and accurate anatomical description of the region. In this article, most structures of the lateral nasal wall have been defined and described extensively. The tracking of extramural cells offers a greater understanding of the variation of contiguous structures observed in the adult. An attempt is made to identify and correct anatomical errors and new terms are suggested in order to properly describe the region. The reexamination of the historical findings from past anatomy masters served only to reaffirm present day findings of modern applied surgical anatomists employing the latest in technological advances in endoscopic sinus assessment and the use of CT imaging for three-dimensional reconstructions of the region. In conclusion, one can state that the ethmoid (*sinus ethmoidale*) is phylogenetically, embryologically, anatomically, and functionally completely different from all the other paranasal sinuses, and that only in humans it has taken a key position between all the other paranasal sinuses, controlling their ventilation and drainage.

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**LITERATURE CITED**


Cicero MT. c. 100 BCE. Pro S Roscio Amerino, paragraph 65, 2.


