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# A Computer-Assisted Anatomical Study of the Nasofrontal Region

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***Objectives/Hypothesis:* Objectives were as follows: 1) to define the variations of the uncinate process' superior attachment, 2) to study the diameter of the frontal sinus ostium, 3) to study the prevalence of the agger nasi cells, and 4) to evaluate the side-to-side variability of these structures. *Study Design:* A retrospective clinical study at a tertiary care center. *Methods:* One hundred forty-four consecutive computed tomography scans were studied with image-guided surgery software (InstaTrak, Visualization Technology, Inc., Wilmington, MA) that provides continuous coronal, sagittal, and axial sections. We reported the superior attachment sites of the uncinate process, the diameter of the frontal sinus ostium, and prevalence of the agger nasi cells. *Results:* The uncinate process' main superior attachment into the surrounding structures was found to have the following distribution: 52% to the lamina papyracea, 18.5% to the posteromedial wall of the agger nasi cell, 17.5% to the lamina papyracea and the junction of the middle turbinate with the cribriform plate, 7% to the junction of the middle turbinate with the cribriform plate, 3.6% to the ethmoid roof, and 1.4% to the middle turbinate. The frontal ostium anterior–posterior diameter (mean ± SD) was 7.22 ± 2.78 mm and its transverse diameter (mean ± SD) was 8.92 ± 2.95 mm. Agger nasi cells were found in 78% of the scans. *Conclusions:* The frontal sinus opens into the middle meatus medial to the uncinate process in 88% of the patients and lateral to the uncinate process in 12% of the patients. The naturally wide dimensions of the frontal ostium help to explain why postoperative patency can be achieved merely by exposing the ostium without the need to enlarge it. The frontal ostium dimensions in one side may differ considerably from the contralateral side. An agger nasi cell or a terminal recess, or both, are found in most cases. Image-guided surgery software is a helpful new tool for anatomical studies and for preoperative evaluation. *Key Words:* Frontal sinus anatomy, superior attachment uncinate, nasofrontal anatomy, frontal ostium.**

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## INTRODUCTION

Our knowledge of the anatomy of the nasofrontal region was, until recently, derived from anatomical studies performed during the first half of the previous century, before the endoscopic sinus surgery (ESS) era.[1–3] These studies were based on cadaver dissections and provided invaluable detailed descriptions of the anatomy that created a solid ground for the developing field of nasal and sinus surgery. Despite this, the fine structure of the nasofrontal complex was unknown to the vast majority of ENT physicians and even to experienced rhinologic surgeons. It was the development of ESS by Messerklinger and Stammberger[4] that revolutionized the surgeons' interest in this area. As ESS has become more sophisticated, it is not uncommon to find the old anatomy literature insufficient for the advanced endoscopic sinus surgeon.

Although great progress has been achieved in ESS, frontal sinus surgery still remains a challenge. Many surgeons avoid this region because of its reputation as a complicated and unpredictable anatomical labyrinth. Paradoxically, as ESS becomes an increasingly common practice, the need for experience in frontal sinus surgery is growing because of an increasing rate of iatrogenic frontal sinusitis.[5]

In a previous study we described our technique and experience in frontal ESS.[6] Our experience led us to view the uncinate process' superior attachment as the most important anatomical landmark in frontal recess surgery. We also described how frontal sinus patency can be achieved by merely exposing the natural sinus ostium with only a rare need to enlarge it. In addition, removal of agger nasi cells, when present, played a key role while exposing the frontal ostium. A search of old and contemporary literature provided sufficient data on the agger nasi cells. However, the frequency of the various uncinate process superior attachments and the dimensions of the frontal ostium were only minimally addressed.

We found the image-guided surgery software a useful tool for studying the frontal recess anatomy. This system provides simultaneous 1-mm section cuts in the coronal, axial, and sagittal planes. It also allows continuous dy-

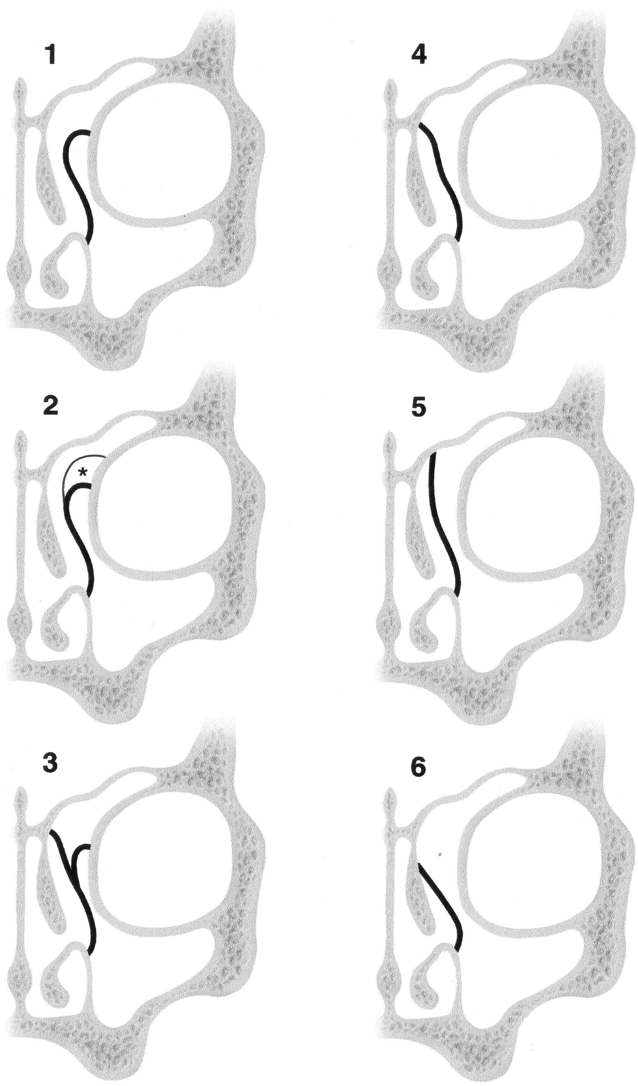


Fig. 1. Types of uncinate process's superior attachment. Type 1: insertion to the lamina papyracea (52%). Type 2: insertion to the posteromedial wall of the agger nasi cell (18.5%). Type 3: insertion to both the lamina papyracea and the junction of the middle turbinate with the cribriform plate (17.5%). Type 4: insertion to the junction of the middle turbinate with the cribriform plate (7%). Type 5: insertion to the skull base (3.6%). Type 6: insertion to the middle turbinate (1.4%).

namic fine-structure tracing through the different plains. The system also contains a dynamic ruler.

The objectives of the current study are as follows: 1) to study the anatomical variations of the uncinate process' superior attachment and their frequency, 2) to measure the anteroposterior and transverse diameters of the frontal sinus ostium, 3) to study the prevalence of the agger nasi cells, and 4) to evaluate the side-to-side variability of these structures.

## MATERIALS AND METHODS

One hundred forty-four consecutive CT scans processed by the image-guided surgery software (InstaTrak, Visualization Technology, Inc., Wilmington, MA) were analyzed at the computer working station. These images were originally ordered for patients who were found to have chronic sinusitis resistant to medical therapy and were candidates for ESS. On each scan the frontal recess region was thoroughly examined bilaterally. The structures were traced by scrolling the marking cross on the screen with the computer's mouse. Usually, a 2:1 magnification provided the clearest picture. The level of the uncinate process was identified in the coronal plane and was marked with the cross. Then, by meticulously scrolling the cross back and forth along that level in the axial plain and viewing the coronal plain, the fine superior portions of the uncinate process could be traced to their insertion. The frontal ostium was located on the sagittal plain by scrolling from side to side at the axial plain. The search was halted where the shortest distance between the frontal "beak" and the junction between the anterior base of the skull and the posterior table of the frontal sinus could be identified. A line perpendicular to this junction was passed to the frontal "beak." We defined that distance as the anterior–posterior diameter of the frontal ostium and used the built-in ruler on the marking cross to measure it. Then, by marking the frontal ostium with the cross at the sagittal plain, we could instantly view and measure the transverse diameter at the coronal or axial planes. The agger nasi cell was identified in the various planes. It was more clearly identified as a distinct cell in the sagittal plane just posterior–inferior to the frontal "beak" and in the coronal plane at the level of the frontal recess, usually anterior to the middle turbinate anterior insertion.

## RESULTS

Two hundred eighty-eight sides were analyzed.

### *Uncinate Process*

In 173 (60%) of the 288 sides we could identify the uncinate process' superior attachment. We could not identify the superior attachment in 115 (40%) sides. In 52 sides (18%) it was because of a mucosal disease that made the fine bony septa indistinct. In 43 sides (15%) it was because of previous ESS that disrupted the natural anatomy, and in 20 sides (7%) it was because of an unclear anatomy, that is, an inability to clearly define the final destination of the superior attachment. A total of six pattern types were noted in the superior attachment of the uncinate process (Fig. 1): to the lamina papyracea in 52%, to the posteromedial wall of the agger nasi cell in 18.5%, to both the lamina papyracea and the junction of the middle turbinate with the cribriform plate in 17.5%, to the junction of the middle turbinate with the cribriform plate in 7%, to the ethmoid roof in 3.6%, and to the middle turbinate in 1.4%.

In 93% of the scans the type of the superior attachment was either identical or similar bilaterally.

### *Frontal Ostium*

Previous ESS or mucosal disease did not interfere with the identification of the frontal ostium (Table I). In

TABLE I.
Frontal Sinus Dimensions.

| Diameter | Range (mm) | Mean ± SD (mm) |
|---|---|---|
| Anterior–posterior | 2–16 | 7.22 ± 2.78 |
| Transverse | 3–20 | 8.92 ± 2.95 |
| Frontal ostium sectional area | 50.5 mm$^2$ | |

SD = standard deviation.

279 sides, frontal ostia could be measured. The anterior–posterior diameter of the frontal ostium ranged from 2 to 16 mm, and the mean diameter (± SD) was 7.22 ± 2.78 mm. The transverse diameter of the frontal ostium ranged from 3 to 20 mm, and the mean diameter (± SD) was 8.92 ± 2.95 mm.

The mean sectional area of the frontal ostium was calculated by using the equation for elliptical area ($\pi \times r_1$ [radius (anterio-posterior)] $\times$ $r_2$ [radius (transverse)]. It was found that the mean sectional frontal ostium area was 50.5 mm$^2$ (3.14 × [7.22/2] × [8.92/2]).

One (0.7%) scan had no frontal sinuses. Seven (4.9%) scans had unilateral frontal sinus. When comparing the anterior–posterior diameter between the two sides in the remaining scans (Table II), in 78.4% the difference was 0 to 2 mm, in 13.5% the difference was 3 to 5 mm, and in 8.1% the difference was more than 5 mm.

When comparing the transverse diameter between the two sides in each scan, in 77.2% the difference was 0 to 2 mm, in 16% the difference was 3 to 5 mm, and in 6.8% the difference was more than 5 mm.

### *Agger Nasi*

In 55 (19%) of the 288 sides it was impossible to determine whether the agger nasi was present (in 27 sides [9.4%] because of mucosal disease, in 23 sides [8%] because of previous ESS, and in 5 sides [1.6%] because of an unclear anatomy). In the remaining 233 sides (81%) we identified the agger nasi in 78%. When present, the agger nasi was bilateral in 94% and unilateral in 6%.

## DISCUSSION

Since 1997, we have been using an image-guided system in ESS for various indications. As others, we find this tool helpful, although as we gain experience we tend to reserve it for selected cases, mainly revision surgeries. The great advantages of using the navigation systems at the time of surgery are well known and documented. However, to our knowledge, the potential application of this system as a tool for studying anatomy at the working station has never been pointed out. In contrast to a regular CT, where 3- to 5-mm coronal sections are usually performed, the preoperative scanning for image-guided surgery includes 1-mm axial sections that are reconstructed to coronal and sagittal images. As already shown, the sagittal reconstruction provides an invaluable contribution to the evaluation of the frontal recess.[7,8] This substantial addition of information, the ability to simultaneously view any spot in three dimensions, and the dynamic search through the various planes dramatically enhance the investigator's orientation in the complex nasofrontal anatomy.

When observing the frontal recess region in a sagittal section, an hourglass-shaped structure can be identified.[4] The narrowest part is located at the frontal ostium, the upper part widens into the frontal sinus, and the lower part opens into the frontal recess. The limits, shape, and width of the frontal recess are largely determined by the neighboring structures. Its medial border is the lateral surface of the most anterior portion of the middle turbinate. It is only when the uncinate process is fused with the insertion of the middle turbinate or with the skull base that its most anterior part serves as the medial wall of the recess. The lamina papyracea forms the lateral wall. If the upper portion of the uncinate process bends toward the lamina papyracea, it forms part of the lateral wall and also contributes to the floor of the frontal recess in its most anterior aspects. Above, on its way anteriorly, the ethmoid roof gradually bends superiorly to become the posterior wall of the frontal sinus. The posterior wall of the frontal recess is most frequently created by the bulla lamella (the second lamella). Agger nasi cells, when present, are located anterior to the frontal recess and may mechanically constrict the frontal recess when well pneumatized.

The uncinate process is the most anterior bony lamella, one of four lamellae that traverse the entire ethmoid (uncinate process, bulla lamella, basal lamella of the middle turbinate, and basal lamella of the superior turbinate). Superiorly, the configuration of the ethmoidal infundibulum, and therefore its relationship to the frontal recess, depends largely on the anatomy of the uncinate process. If, as is most common, the uncinate process bends laterally in its uppermost portion and inserts on the lamina papyracea, the ethmoidal infundibulum is closed superiorly by a blind pouch called the terminal recess. In this case, the superior uncinate is not a thin plate of bone but a dome-shaped structure. When this is the case, the ethmoidal infundibulum and the frontal recess are separated from each other so that the frontal recess opens into the middle meatus medial to the ethmoidal infundibulum between the uncinate process and the middle turbinate. When the uncinate process extends superiorly and to the roof of the ethmoid or medially to the middle turbinate, the frontal recess and the frontal sinus open directly into the ethmoidal infundibulum.

The inferior portion of the uncinate process is well recognized by surgeons and is clearly visible. If just a 0° endoscope is used, the uppermost segment of the uncinate process is no longer visible behind the anterior insertion of the middle turbinate. Standard CT coronal sections could also be "blamed" for obscuring the upper portion of the uncinate; because the uncinate process runs obliquely from posterior–inferior to anterior–superior and the standard CT sections are made perpendicular to the hard palate, it is usually impossible to view the full extent of the uncinate in one section (Fig. 2). Therefore, it is not uncommon for surgeons to refer to the uncinate as a short process only and to ignore its superior attachment. The uncinate process has been recently investigated but, interestingly, the focus was on its posterior–inferior segment.[9,10] Stammberger[4] did refer to the superior attachment and described its extensions to the lamina papyracea, base of the skull, or middle turbinate. However, he did not describe other extensions or possible com-

TABLE II.
Frontal Ostium Side-to-Side Difference.

| | 0–2 mm | 3–5 mm | >5 mm |
|---|---|---|---|
| Anterior–posterior diameter | 78.4% | 13.5% | 8.1% |
| Transverse diameter | 77.2% | 16% | 6.8% |

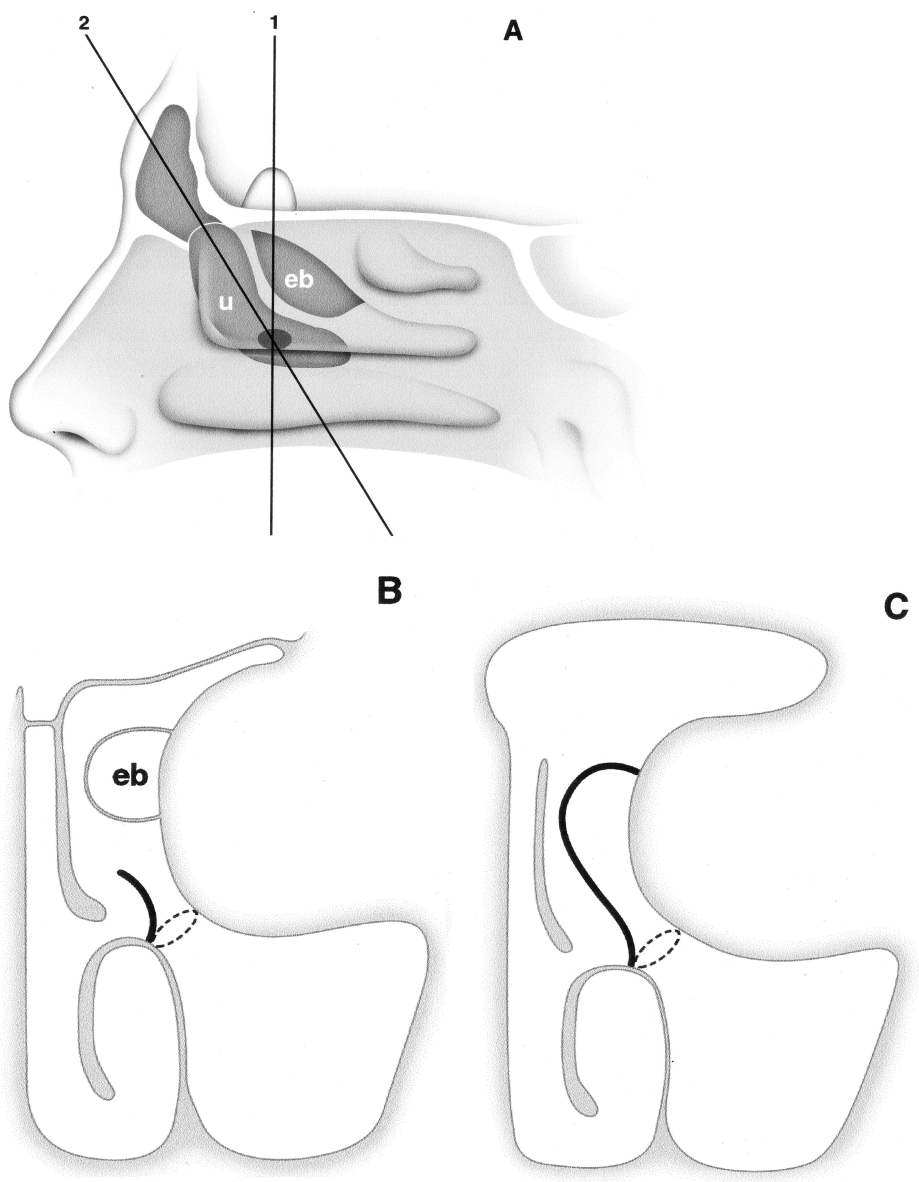


Fig. 2. (**A**) A sagittal section scheme along the lateral nasal wall showing the standard vertical cut (line 1) used for computed tomography coronal section at the level of the uncinate process and a demonstrative angled cut (line 2) along the natural axis of the uncinate process. Eb = ethmoid bulla; u = uncinate process. (**B**) A coronal section corresponding to line 1, showing a "short" uncinate process. (**C**) A coronal section corresponding to line 2, showing the "true" full extension of the uncinate process.

binations and their prevalence. In a previous study we found that a thorough knowledge of the superior attachment of the uncinate process anatomy is crucial for the precise dissection through the frontal recess and an adequate exposure of the frontal sinus.[6]

Six types of superior extension were identified in our study (Fig. 1). The first three types included 88% of the cases.

Type 1 (52%) is the most frequent. The uncinate process bends laterally in its uppermost portion and inserts into the lamina papyracea. Consequently, the ethmoidal infundibulum, which is always lateral to the uncinate process, is closed superiorly by a blind pouch called the terminal recess,[4,6] or "infundibular anterior ethmoidal cell" by the old literature.[1,2]

In type 2 (18.5%), the uncinate process confluents with the posterior-medial wall of the agger nasi. In this case the infundibulum is closed superiorly by the floor of the agger nasi.

Type 3 (17.5%) has two insertions: One forms a terminal recess (like type 1) and a second insertion, more anterior, runs to the junction of the middle turbinate with the cribriform plate.

These more common types include the vast majority of cases (88% all together), and from a surgical standpoint mandate the same approach (i.e., the frontal recess can be reached by dissecting medial or posteromedial to the uncinate process). In type 2, the presence of the agger nasi should not alter this approach; because in this case the terminal recess and the agger nasi cell share the same posteromedial wall, removal of the agger nasi is similar to removal of the terminal recess, only more superiorly and anteriorly. Although it appears in the type 3 scheme that the medial insertion blocks the way to the frontal sinus, practically it does not because it is located anteriorly during a routine frontal recess dissection.

Types 3 to 5 include only 12% of the cases and mandate a different approach (i.e., the frontal recess can be reached by dissecting lateral to the superior attachment of the uncinate process). In these types, an attempt to find the frontal recess medial to the uncinate process might inadvertently end in the olfactory fossa or the frontal lobe. In 1916, Schaeffer[1] found that "the ductus nasofrontalis and the infundibulum ethmoidale are in the vast majority of the instances discontinuous channels. . .the ductus nasofrontalis and the infundibulum ethmoidale are occasionally directly continuous." In 1936, Kasper,[2] "at the suggestion of Dr. Schaeffer," performed the dissection and study of 100 consecutive adult specimens. In his outstanding work, he found that in only 4% a state of direct anatomic continuity was present between the ethmoidal infundibulum and the frontal sinus. In the rest of the specimens he found discontinuity in 62% and contiguity in 34%.

Unlike the maxillary or the sphenoid sinuses, in our opinion, the frontal sinus does not have a real ostium. "Ostium," as defined by a medical dictionary, is "an opening between two distinct cavities."[11] As clearly shown in sagittal sections, the so-called frontal ostium is in fact the narrowest diameter, or "the waist," in the continuum between the ethmoid cavity and the frontal sinus. For the sake of convenience, we shall use the term "ostium." Before our evolving interest in the frontal sinus region, we assumed, as did many others, that the frontal ostium is a narrow opening and that its exposure, especially while infected, necessitates "drill-out" or aggressive curettage. As we have gained surgical experience, we have repeatedly noticed that as soon as a precise removal of a high terminal recess, an agger nasi cell, or a frontal cell is completed, a wide and roughly elliptical opening to the frontal sinus is exposed in most cases. The average dimensions that we measured in the current study (7.22-mm anterior–posterior dimension and 8.92-mm transverse dimension) give scientific proof to our subjective impression. Jacobs et al.[7] studied the anterior–posterior diameter only on sagittal CT scans and reported even larger diameter (i.e., 10 mm). Their results also indicate a trend of increasing anterior–posterior depth of the frontal sinus associated with larger agger nasi cells. These measurements imply that in most cases the available endoscopic frontal sinus instruments can be easily passed through the frontal ostium, as long as these are long enough. Consequently, based on our surgical experience, we find that an indication for drill-out or curettage (i.e., Draf II or Draf III surgery[12] or modified Lothrop procedure[13]) seldom exists.

The agger nasi cell is bordered by the frontal process of the maxilla anteriorly, the frontal sinus superiorly, the nasal bone anterolaterally, and the lacrimal bone inferolaterally.[14] The uncinate process forms its inferomedial border, and the frontal recess is its posterior border. During surgery, it is sometimes difficult to differentiate between an agger nasi cell and a high terminal recess because both appear as a superior–anterior dome-like structure. When both structures coexist, as in type 2 of the uncinate process, it is easy to miss the thin bony plate that separates the two. Clear identification of the agger nasi cell was challenging even with the studied CT three-dimensional planes. However, careful observation of the sagittal and coronal plains revealed agger nasi cells in 78% of the scans. In 1939, Van Alyea[15] reported their presence in 89% of specimens. Bolger et al.[16] and Zinreich et al.[17] noted these cells in "nearly all "CT scans they reviewed. We speculate that in these studies some of the terminal recesses were counted as agger nasi cells.

When comparing the sides in each scan, we found that the uncinate process configuration in one side would show an identical pattern contralaterally in most of the cases (93%). Similarly, identification of the agger nasi in one side would predict its presence contralaterally in most of the cases (94%). However, in more than 20% of the cases one should expect that the frontal ostium in the other side would have considerably different dimensions (more than 3 mm difference). In addition, while dissecting toward the frontal sinus, it must be kept in mind that in approximately 5% of cases there is no frontal sinus present.

In the current study we do not claim that image-guided surgery software could be a substitute for a cadaver dissection. However, we advocate this technique as a complementary tool to study anatomy and highly recommend its use for preoperative evaluation.

## CONCLUSION

The frontal sinus opens into the middle meatus medial to the uncinate process in 88% of the patients, and lateral to the uncinate process in 12% of the patients. The naturally wide dimensions of the frontal ostium help to explain why postoperative patency can be achieved merely by exposing the ostium without the need to enlarge it. The frontal ostium dimensions in one side may differ considerably from the contralateral side. An agger nasi cell or a terminal recess (or both) is found in most cases. Image-guided surgery software is a helpful new tool for anatomical studies and for preoperative evaluation.

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