FRONTAL SINUS SURGERY 2004: UPDATE OF CLINICAL ANATOMY AND SURGICAL TECHNIQUES

MICHAEL FRIEDMAN, MD, DARIUS BLIZNIKAS, MD,
RAMAKRISHNAN VIDYASAGAR, MBBS, MS, ROEE LANDSBERG, MD

Endoscopic frontal sinus surgery is still considered difficult, risky to perform, and likely to result in a high failure rate. We have previously reported on our technique of endoscopic frontal sinus surgery, stressing the importance of identification and preservation of natural outflow tract. Our study of frontal sinus anatomy shows that the mean frontal ostium anterior–posterior and transverse dimensions are 7.22 ± 2.78 mm and 8.92 ± 2.95 mm, respectively; therefore, dissection of obstructive structures in frontal recess leads to a wide opening of frontal sinus outflow. A key surgical landmark in our technique is the superior attachment of the uncinate process. This article provides an update of the surgical anatomy of the frontal recess region and our surgical technique, as well as a discussion of our approach to frontal sinus revision surgery.

The approach to the frontal sinus and the frontal recess is still considered the most difficult and challenging part of endoscopic sinus surgery. The obscure location of this area, its variable anatomy, and its intimate proximity to the eye and brain may prevent the surgeon from performing an adequate dissection and may expose the patient to major complications.

After a thorough review of the nasofrontal anatomy in the literature, and after studying this anatomy with axial, coronal, and saggital computed tomography (CT) scans and by operating on a large number of patients, we have developed a simplified endoscopic approach to the frontal sinus. Our technique has been previously reported and focuses on the uncinate process and its superior attachment as a key landmark.[1,2] Almost the entire procedure is performed with the microdebrider. The intraoperative and postoperative verification of frontal sinus patency is accomplished by transillumination[3] or with an image-guided surgery system. The key to surgical success is identification of the natural frontal sinus outflow tract and preservation of some of its mucosal lining.

RELEVANT ANATOMY

FRONTAL RECESS

The frontal ostium region in a sagittal section is an hourglass-shaped structure; the narrowest part is located at the frontal ostium, the upper part widens into the frontal sinus, and the lower parts open into frontal recess. Even though the frontal sinus ostium is the narrowest part of frontal sinus outflow tract, it is rarely a direct source of frontal sinus pathology (except in the case of the presence of Kuhn type 3 and 4 frontal cells). In most cases, as soon as obstruction caused by a high terminal recess, an agger nasi, or a frontal cell type 1 and 2 is removed, a wide and roughly elliptical opening to the frontal sinus is exposed. In our previous study with image-guided surgery software, we measured 288 frontal sinus sides. The mean anterior–posterior diameter was 7.22 ± 2.78 mm and transverse diameter was 8.92 ± 2.95 mm; mean frontal ostium sectional area was 50.5 mm^2.[4] Those findings led us to the assumption that most patients with frontal sinusitis can be treated with endoscopic sinusotomy via the natural outflow, without the need for drill-out procedures.

The frontal recess is a narrow cleft within the anterior ethmoid complex that forms an inverted funnel that widens in the inferior and posterior direction. This inferior third of the frontal sinus drainage pathway is the anatomical location responsible for most cases of frontal sinusitis. The position of the superior attachment of the uncinate process and extensive pneumatization of surrounding ethmoid cells such as the agger nasi and frontal cells anterolateral to the recess, supraorbital cells posterolateral to the recess, and the ethmoidal bulla posterior to the recess may all limit the shape and width of frontal recess and lead to frontal sinus disease.[5-7]

UNCINATE PROCESS AND ETHMOIDAL INFUNDIBULUM

A description of these structures is crucial to the understanding of our technique. Many surgeons analyzing coronal CT scans of paranasal sinuses focus on the easily identified posteroinferior segment of the uncinate process. The superior attachment of the uncinate process is often ignored or misnamed as anterior ethmoid cells, anterior ethmoid complex, or agger nasi cells. Intimate knowledge of this area shows that even though the anatomy is variable, it is also highly predictable.[8,9] Our experience

From the Department of Otolaryngology and Bronchoesophagology, Rush-Presbyterian–St. Luke's Medical Center, Chicago; Division of Otolaryngology, Advocate Illinois Masonic Medical Center, Chicago, IL; Department of Otolaryngology–Head and Neck Surgery, Sourasky Medical Center, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel.

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Address reprint requests to Michael Friedman, MD, Department of Otolaryngology and Bronchoesophagology, Rush-Presbyterian–St. Luke's Medical Center, 1653 West Congress Parkway, Chicago, IL 60612-3833.

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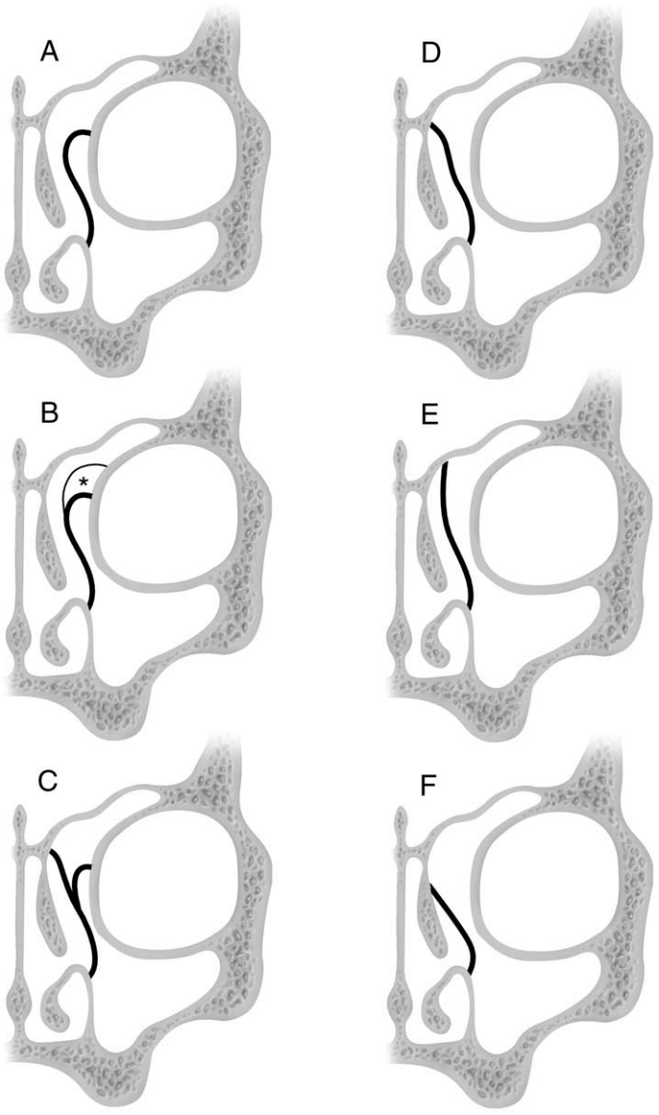

FIGURE 1. Schematic drawings of uncinate process superior attachment variations. (A) Insertion to the lamina papyracea. (B) Insertion to the posterior medial wall of the agger nasi cell. (C) Insertion to both the lamina paprycea and the junction of the middle turbinate with the cribriform plate. (D) Insertion to the junction of the middle turbinate with cribriform plate. (E) Insertion to the skull base. (F) Insertion to the middle turbinate. Reprinted with permission.[4]

led us to view the uncinate process superior attachment as the most important anatomical landmark in frontal sinus surgery.

The uncinate process is the first bony lamella, which is 1 of 4 lamellae that transverse the entire ethmoid (uncinate process, bulla lamella, basal lamella of middle turbinate, and basal lamella of the superior turbinate). The inferior portion of the uncinate process is well recognized and clearly visible. The uppermost segment of the uncinate process is no longer visible behind the insertion of the middle turbinate.

In our previous study with image-guided surgery software, we identified 6 types of superior attachment of the uncinate process:[4]

Type 1 (52%) is the most frequent (Figure 1A). The uncinate process bends laterally in its upper-most portion and inserts into lamina papyracea. Consequently, the blind pouch called terminal recess closes the ethmoidal infundibulum superiorly.

In type 2 (18.5%), the uncinate process confluences with the posterior–medial wall of the agger nasi (Figure 1B). In this case, the floor of the agger nasi closes the infundibulum superiorly.

Type 3 (17.5%) has 2 insertions; one forms the terminal recess and a second runs to the junction of the middle turbinate with the cribriform plate (Figure 1C).

These 3 types include the vast majority of cases (88%) and from a surgical standpoint mandate the same approach (ie, the frontal recess can be reached by dissecting medial or posteromedial to the uncinate process), because the frontal ostium outflow opens medial to the superior attachment of the uncinate process and directly into the meatus of medial turbinate.

Types 4 to 6 include only 12% of cases and mandate a different approach; ie, the frontal recess can be reached by dissecting lateral to the superior attachment of the uncinate process because the frontal ostium outflow opens lateral to the superior attachment of the uncinate process and directly into the ethmoid infundibulum (Figure 1D, E, and F).

Agger Nasi Cell

The agger nasi cell is the most anteriorly placed ethmoid cell. In the early 1900s, researchers reported the prevalence of the agger nasi cell to be 40% to 60%; in 1939, Van Aleya reported seeing this cell in 89% of anatomic specimens.[10,11] With the introduction of CT scans, the presence of the agger nasi cell was reported in up to 98.5% of cases by several authors.[12,13] In our previous study, we identified the agger nasi in 78% of 233 reviewed CT slides.[4]

The agger nasi cell is believed to originate from the pneumatized superior remnant of the first ethmoturbinal. It is bounded laterally by the nasal and lacrimal bones, anteriorly by the frontal process of the maxilla, superiorly by the frontal recess and frontal sinus, inferiorly and medially by the uncinate process, and posteriorly by the ethmoid infundibulum.[14]

Excessive pneumatization of the agger nasi cell may impinge on the frontal recess anterolaterally. The surgeon clearing the frontal recess of obstruction may mistakenly recognize the dome of this cell as frontal sinus and leave the frontal recess undissected. Because the posterior wall of the agger nasi cell has an intimate relationship with the upward extension of the uncinate process, removal of the superior attachment of the uncinate and posteromedial wall of the agger nasi gives a wide exposure of the frontal ostium.

Frontal Cells

Frontal cells are common in association with the agger nasi cells.[6] Kuhn classified those cells into types 1, 2, 3, and 4 (Table 1).

TABLE 1. Kuhn Classification of Frontal Cells

Cell Type	Anatomical Location
Type 1	Single frontal cell above agger nasi cell, but not extending above frontal beak
Type 2	Tier of cells in frontal recess above agger nasi cell, but not extending above frontal beak
Type 3	Single massive cell pneumatizing cephalid into frontal sinus
Type 4	Isolated cell in the frontal sinus

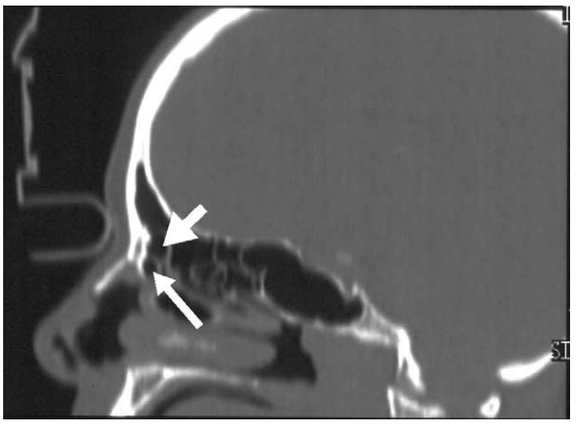

FIGURE 2. Kuhn type1 frontal cell. The bold arrow marks the frontal cell. The long tail arrow marks the agger nasi cell.

These additional cells can alter the anatomy of the frontal recess in a number of ways. If they sit directly above the agger nasi cell, then the insertion of the uncinate process may follow higher on the lamina papyracea (Figure 2). Types 1 and 2 frontal cells often form a cap that pushes up into the frontal recess, narrowing it in an anterolateral direction.[5] Removal of the superior attachment of the uncinate process and its extension to the posteromedial wall of the frontal cell leaves the frontal ostium wide open. In cases of the uncinate process inserting on the skull base or middle turbinate, fracture and removal of the posterior wall of frontal cells provides good access to the frontal ostium.

A more complex situation occurs in the presence of types 3 and 4 cells (Figure 3). These cells extend above the frontal beak, and in some cases reach the skull base laterally and therefore narrow the frontal ostium medially. If one of these frontal cells is adjacent to the middle turbinate and reaches the skull base medially, then the frontal ostium is narrowed laterally.[5,6] Regardless, a lateral or medial position of frontal sinus cells relative to the frontal recess and ostium inevitably causes narrowing of the frontal sinus outflow. If frontal sinusitis is present, then these frontal cells need to be removed to provide maximal opening of the frontal ostium

Supraorbital Ethmoid Cells

The supraorbital ethmoid cells typically arise from the anterior ethmoid cell group; they are present in up to 15% of patients. The degree of pneumatization of the cell may vary. On occasion, more than one supraorbital cell may be present. During pneumatization, it extends superolaterally between the usual boundaries of the lamina papyracea and the roof of the ethmoid to pneumatize the orbital plate of the frontal bone. The supraorbital cell may merely indent the frontal sinus or markedly obstruct the frontal recess.[7] Failure to identify this cell may lead to persistent frontal sinus disease after what was believed to be a successful frontal recess dissection. Differentiating a supraorbital cell opening in the frontal recess from the frontal sinus ostium is vital to prevent such errors.

Septation of the frontal sinus seen in coronal and axial CT images raises suspicion about the presence of frontal sinus cells (types 3 and 4) or supraorbital cells, making precise preoperative evaluation of coronal, axial, and reconstructed sagittal CT images or intraoperative use of an image-guided system advisable.

SURGICAL TECHNIQUE

Preoperatively, it is crucial to evaluate the frontoethmoid connection with 3-mm-section CT scans, paying special attention to the anatomy of the uncinate process. When a CT is inadequate, continuous tracking of image-guided scans provide clearer visualization of the uncinate; use of an image-guided system in preoperative evaluation also provides saggital views, which are essential for study of frontal sinus outflow tract. By so doing, the surgeon can easily plan the approach to the frontal sinus and predict the complexity of the procedure.

The early steps of the procedure are performed with a 0° endoscope. The first surgical maneuver is to gently displace the middle turbinate medially with a freer elevator. The uncinate process is identified and then medialized with the hooked end of a frontal sinus ostium seeker. Thereafter, almost the entire uncinectomy and frontal sinus surgery are performed with microdebrider blades. The visible inferior portion of the uncinate process is completely removed with a 40° curved microdebrider (Figure 4). At this point, if the maxillary natural ostium is free of disease, then it is preserved.

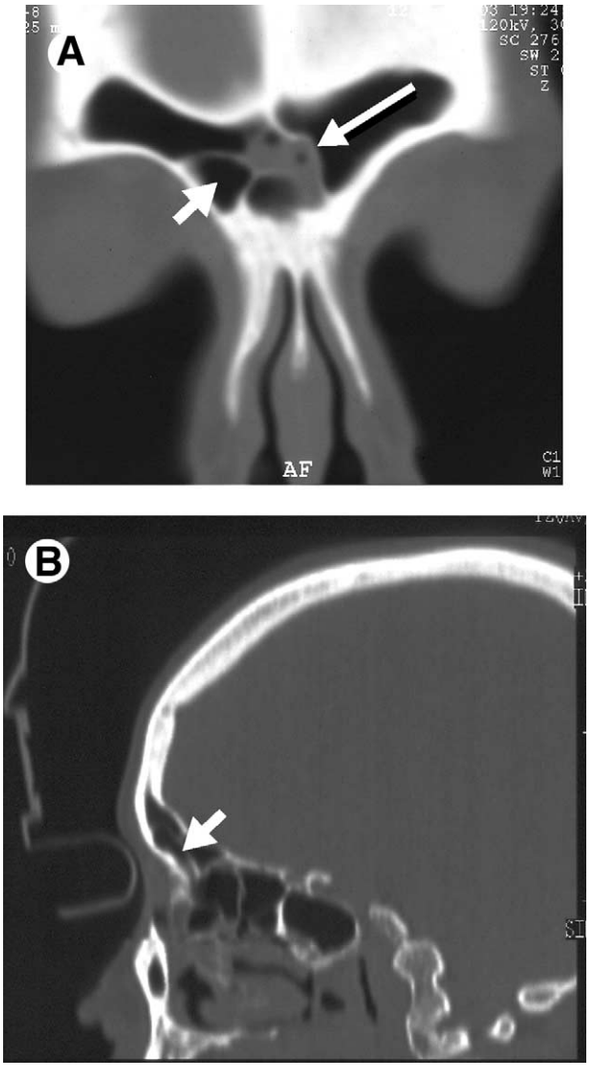

FIGURE 3. Kuhn type 3 frontal cell. (A) In the coronal view, the bold arrow marks the frontal cell, and the long tail arrow marks the septum between frontal sinuses. (B) In the sagittal view, the bold arrow marks the frontal cell.

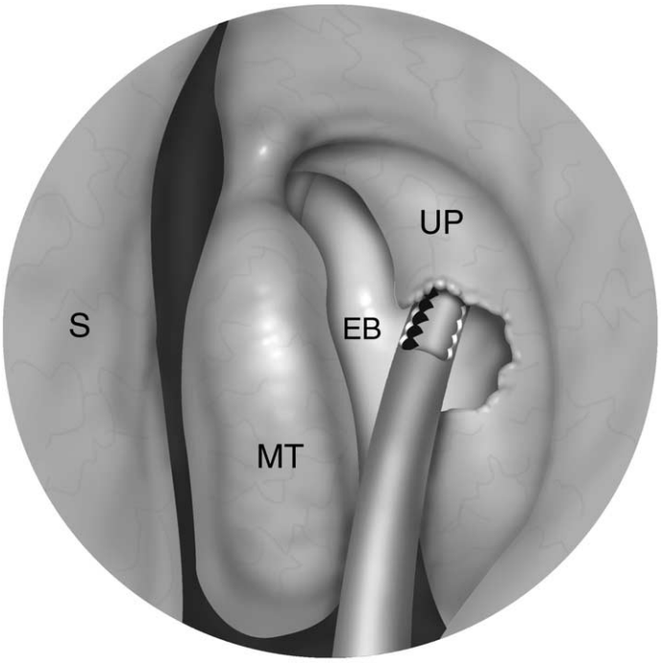

FIGURE 4. The visible inferior portion of the uncinate process is removed with a microdebrider. Great care is taken not to injure the middle turbinate. S, nasal septum; MT, middle turbinate; EB, ethmoid bulla; UP, uncinate process. Reprinted with permission.[1]

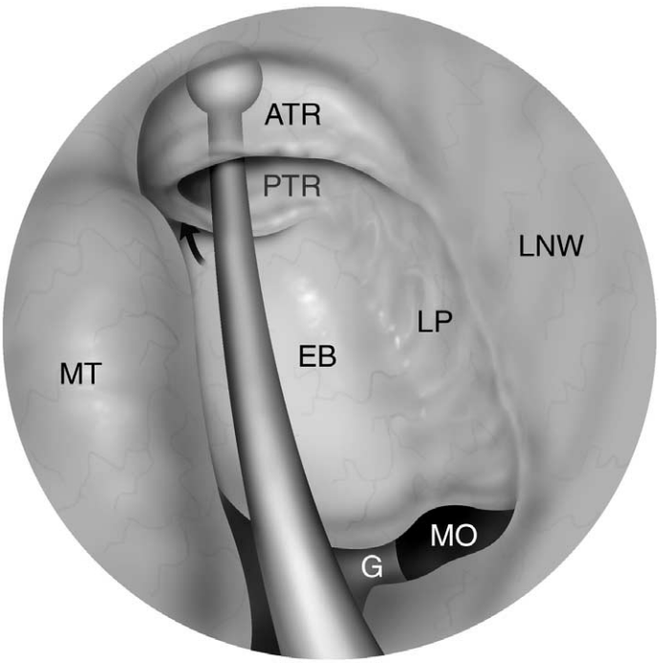

FIGURE 5. The terminal recess is exposed after removal of inferior portion of the visible uncinate process. The frontal seeker reaches the dome of the terminal recess. The frontal recess is found posteromedially to the posterior wall of the terminal recess (blue arrow). ATR, anterior wall of the terminal recess; PTR, posterior wall of the terminal recess; MT, middle turbinate; EB, ethmoid bulla; LP, lamina papyracea; LNW, lateral nasal wall; MO, maxillary ostium; G, groove representing the preserved natural outflow tract of the maxillary sinus. Reprinted with permission.[1]

ANATOMICAL SCENARIO TYPE 1

In the majority of cases, when the removal of the inferior portion of the visible uncinate process is accomplished, one will notice a dome-like structure that looks like an inferiorly opened anterior ethmoid cell (Figure 5). This structure is the superior dead end of the ethmoidal infundibulum, which is formed by the lateral attachment of the uncinate process to the lamina papyracea and is known as the terminal recess. It is not uncommon for surgeons to mistakenly identify it as an agger nasi cell or even a frontal sinus when the terminal recess is very high. For description purposes, the terminal recess has anterior and posterior walls. If one inserts a frontal seeker posteromedially to the posterior wall and advances it superiorly, it is most likely that the upper end of the instrument will reach the frontal sinus. However, this maneuver is rarely necessary because one can predict and visualize the exact location of the frontal sinus by following and resecting the uncinate process. We now switch to a 30° or 45° endoscope and use the curved microdebrider to completely remove the anterior wall of the terminal recess until the instrument meets the hard lacrimal bone superiorly, just lateral to its junction with the middle turbinate and medial to the lamina papyracea (Figures 6 and 7). The posterior wall of the terminal recess is now widely exposed and can be traced superiorly and removed with the curved microdebrider until resection of the superior attachment of the uncinate process is complete (Figures 8 and 9). This last step is usually all that is needed to obtain exposure of the frontal sinus (Figures 9 and 10). Often, only the posterior wall of the frontal sinus is exposed, making it is necessary to remove the posteromedial wall of a well-pneumatized agger nasi cell to achieve better visualization of the frontal sinus. Not infrequently, frontal cells may all need to be opened to achieve clear access to the frontal sinus (Figure

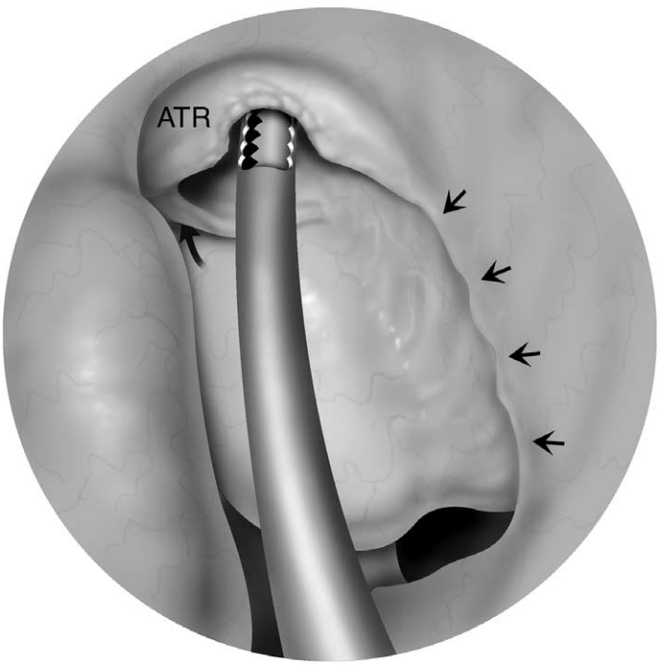

FIGURE 6. A 30° endoscope and a 40° curved microdebrider are used to remove the anterior wall of the terminal recess. Arrows mark the cut edge of the uncinate process after its removal. Reprinted with permission.[1]

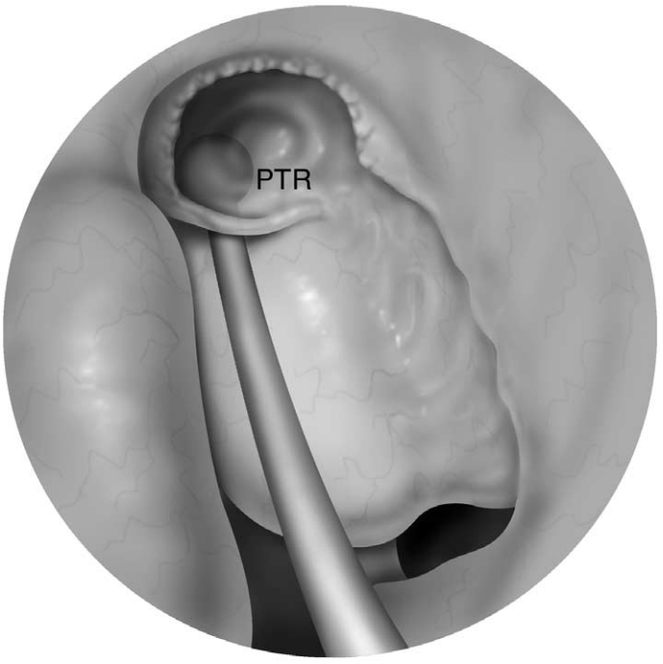

FIGURE 7. The anterior wall of the terminal recess has been completely removed, whereas the posterior wall is still intact. The frontal seeker is in the frontal recess. PTR, posterior wall of the terminal recess. Reprinted with permission.[1]

11). Because the terminal recess and the agger nasi cell commonly share the same posteromedial wall, removal of the agger nasi cell is similar to the removal of the terminal recess posterior wall, just more superior and anterior. Removal of the anteriorly placed agger nasi cell or frontal cell is safe because of its location away from eye and brain. Occasionally, a 60° microdebrider blade is helpful to open these cells. If dissection is performed as described, the

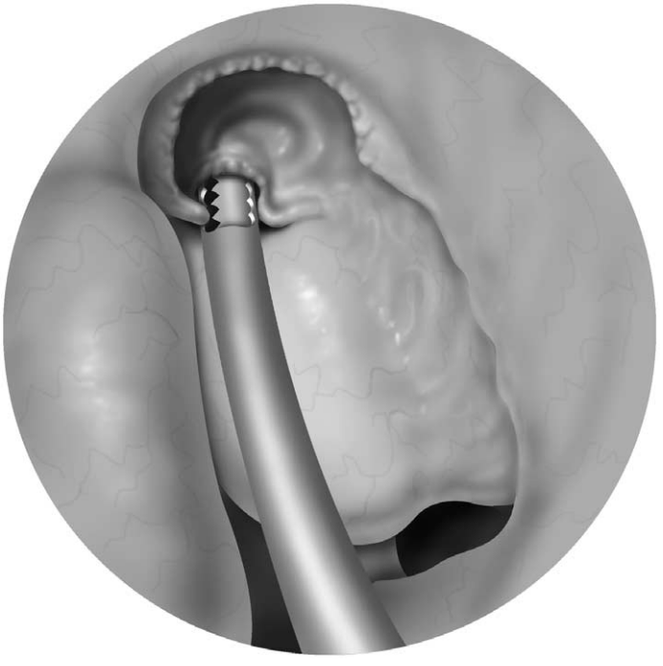

FIGURE 8. The posterior wall of the terminal recess is traced superiorly and removed with a 30° or 45° endoscope and a 40° curved microdebrider. Reprinted with permission.[1]

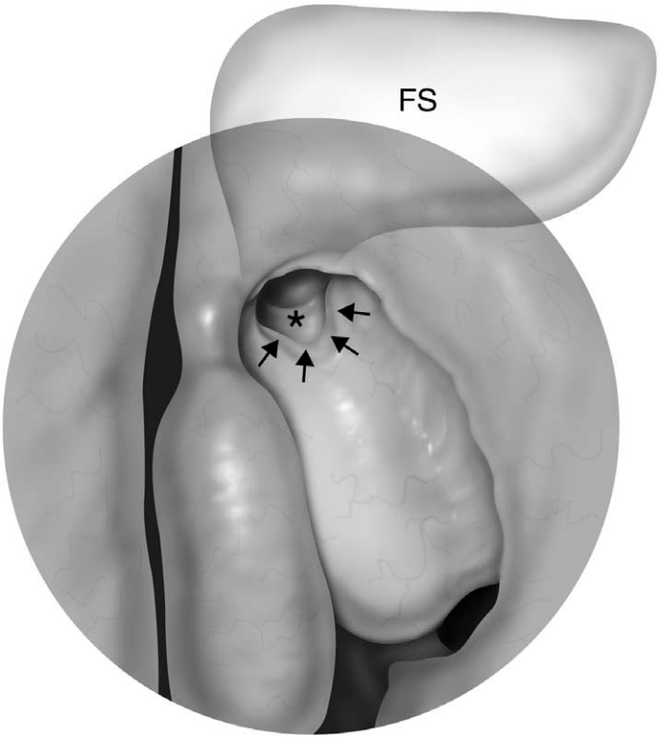

FIGURE 9. Complete resection of the uncinate process superior attachment has been accomplished. The posterior rim of the frontal ostium (arrows) and the posterior wall of the frontal sinus (asterisk) are exposed. The ethmoid bulla and its attachment to the skull base remain intact through the entire frontal recess surgery. FS, frontal sinus. Reprinted with permission.[1]

frontal ostium is often found to be very wide, with an approximate anteroposterior diameter of 7 mm and a transverse diameter of 9 mm. Although the superior portion of the frontal recess is higher and tighter, the surgery in this area is performed with the same instruments, ie, 30° or 45° endoscopes and 40° curved microdebrider blade. A 60° blade can be also useful for dissection in this area. Curved curettes and giraffe forceps are rarely needed.

ANATOMICAL SCENARIO TYPE 2

When the uncinate process attaches superiorly to the base of the skull or to the middle turbinate, frontal sinus exposure is almost immediate because the ethmoidal infundibulum and the frontal sinus share a common compartment. Because there is no terminal recess, the frontal sinus will be exposed soon after removal of the superior portion of the visible uncinate process. In these situations, dissecting medial to the superior attachment of the uncinate process is dangerous and may result in penetration of the thin lateral lamella of the cribriform plate. Again, it is sometimes necessary to remove the posterior wall of a well-pneumatized agger nasi or frontal cell to achieve better visualization of the frontal sinus.[2]

If frontal or supraorbital cells are present, then the common wall between the frontal sinus and the cell should be removed as high into frontal recess as possible. If these walls are not adequately removed, then they may become chronically edematous because of mucociliary clearance disruption, resulting in frontal sinus obstruction. Disruption of mucociliary flow patterns in partially removed cells leads to mucus recirculation and edema, which may close off the frontal sinus outflow.[15] Removal of the common

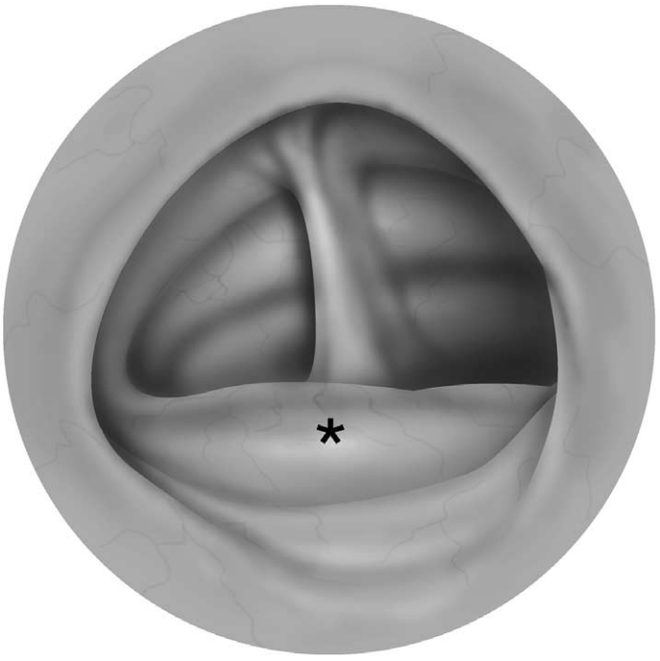

FIGURE 10. Intraoperative left frontal sinus as shown by a 30° or 45° endoscope. The bony ridge at the roof of the sinus is typical. Reprinted with permission.[1]

wall may be accomplished with a 60° microdebrider, but a frontal sinus curette and giraffe forceps may sometimes be necessary to reach the high-positioned bony wall. Types 3 and 4 frontal cells can be challenging to deal with; they may be unreachable endoscopically. In such situations, an external frontal sinus approach may be considered to work on the frontal recess simultaneously with intranasal dissection.

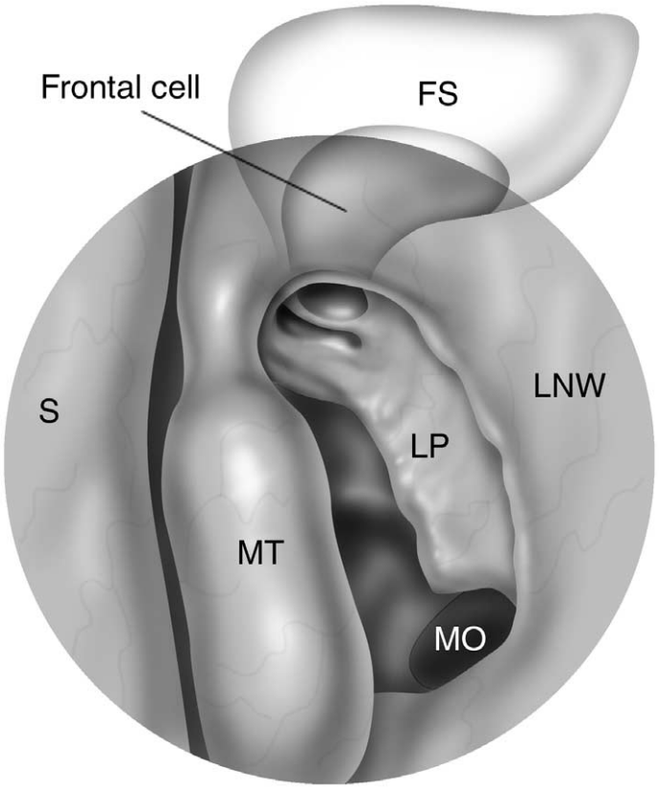

FIGURE 11. Frontal cell blocking the frontal sinus (FS) outflow and pushing it medially.

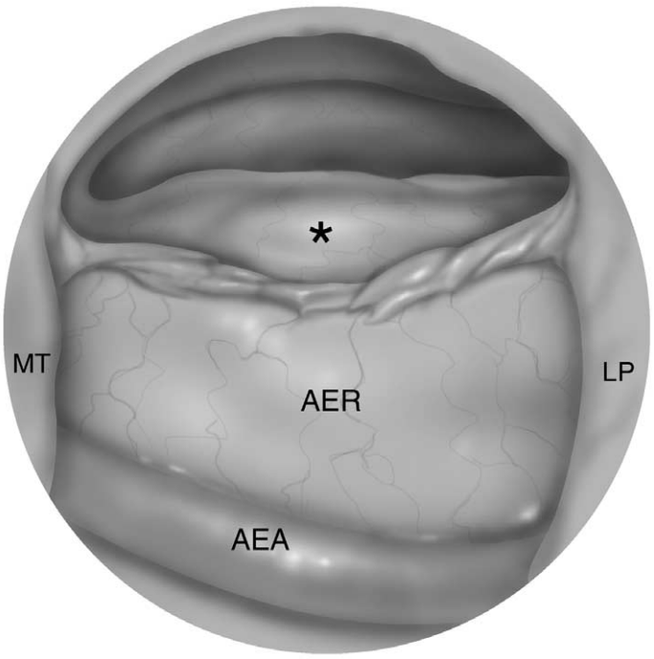

FIGURE 12. After completing anterior ethmoidectomy, the transitional area between the anterior ethmoid roof and the posterior wall of the frontal sinus is left smooth and continuous. AEA, anterior ethmoid artery; AER, anterior ethmoid roof; asterisk, posterior wall of frontal sinus; MT, anterosuperior attachment of middle turbinate; LP, lamina papyracea. Reprinted with permission.[1]

Verification of an open frontal sinus is accomplished by transillumination with a 30° endoscope or an image-guided system. The scope does not need to enter the frontal sinus. When the frontal sinus is wide open, placing the scope in the frontal recess below the frontal ostium will produce a bright red signal on the patient's forehead. The intensity of transillumination is inversely proportional to the extent of frontal sinus disease. The presence of transillumination does not guarantee an open frontal sinus (false positive) because light may transilluminate through thin bone plates or polyps. On the other hand, the absence of transillumination indicates that the frontal sinus is not opened; either the illuminated cell is a high-terminal recess, agger nasi cell, or the sinus obstructed by disease, or the sinus is hypoplastic.[3]

After frontal recess surgery is completed, the rest of the endoscopic procedure is performed as indicated. It is important to leave the transitional area between the anterior ethmoid roof and the posterior wall of the frontal sinus smooth to prevent scar-tissue formation and stenosis. Therefore, the ethmoid bulla and its superior attachment are completely removed. In most patients, the anterior ethmoid artery is clearly identified and preserved (Figure 12).

The middle turbinate is almost always preserved. With the straight microdebrider, medialization of the middle turbinate is achieved by debriding small areas of the mucosal surfaces at the medial surface of the middle turbinate and the opposing septum. The middle turbinate is pushed medially with a long nasal speculum, and we use absorbable packing (Merogel®) in the ethmoidal cavity to help

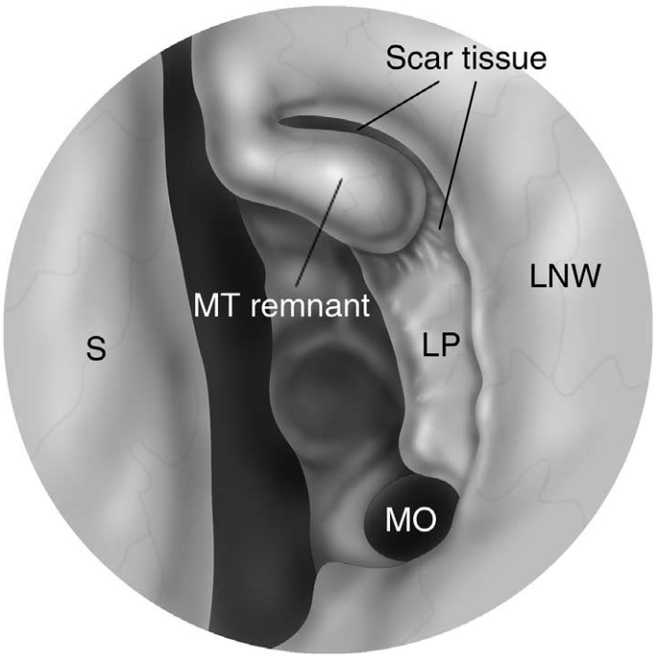

FIGURE 13. Middle turbinate collapse against lateral nasal wall blocking the frontal sinus outflow tract. S, septum; MT, middle turbinate; LNW, lateral nasal wall.

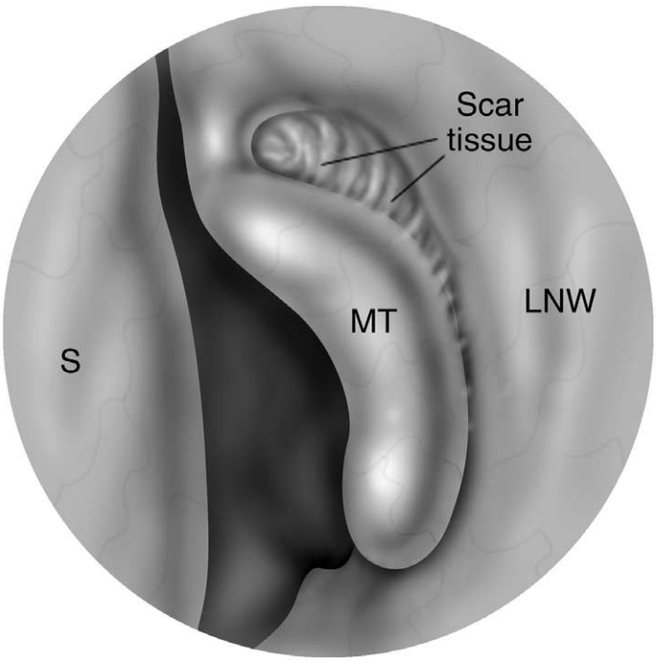

FIGURE 14. Lateralized middle turbinate remnant blocking the frontal sinus outflow tract. S, septum; LP, lamina papyracea; LNW, lateral nasal wall.

maintain the turbinate position.[16] This technique results in controlled synechia formation between the middle turbinate and the nasal septum. Medialization of the turbinate and meticulous care of the turbinate's lateral surface are essential to avoid lateralization with the potential result of frontal recess obstruction.[17]

REVISION SURGERY

Postoperative or iatrogenic frontal sinus obstruction after endoscopic ethmoidectomy or previous frontal recess dissection was reported in the 2% to 11% range by different authors.[22-26]

Failure to re-establish mucociliary clearance at any point along the frontal sinus outflow results in persistent frontal sinus disease. Obstruction of frontal sinus outflow may cause headache or facial pressure soon after surgery or may remain asymptomatic for a long period of time. Complete obstruction left untreated may cause mucocele formation and lead to intraorbital or intracranial extension. Often, patients require revision surgery because of a failure to respond to medical treatment.

Revision surgery by its nature is difficult to perform because normal anatomical landmarks are scared and distorted or absent. Although there is no uniform stepwise approach to revision surgery, common clinical situations may fall into 6 main scenarios:

1. A partially amputated middle turbinate or entire middle turbinate lateralizes and causes obstruction of frontal sinus outflow (Figures 13 and 14).

2. Patient underwent ethmoidectomy without frontal recess dissection and developed iatrogenic obstruction of frontal sinus outflow caused by adhesions and scar-tissue formation (Figure 15).

3. Frontal recess dissection where performed, but terminal recess mistakenly identified as frontal sinus.

4. Agger nasi or frontal cell left undissected, resulting in persistent frontal recess obstruction.

5. Recurrence of polyposis in the frontal outflow system.

6. Scarring, circumferential stenosis, and/or osteoneogenesis in frontal ostium area (Figure 16).

Careful and precise review of preoperative CT scans and/or use of the image-guided system to identify anatomical landmarks or their remnants is necessary for reestablishment of the frontal sinus outflow.

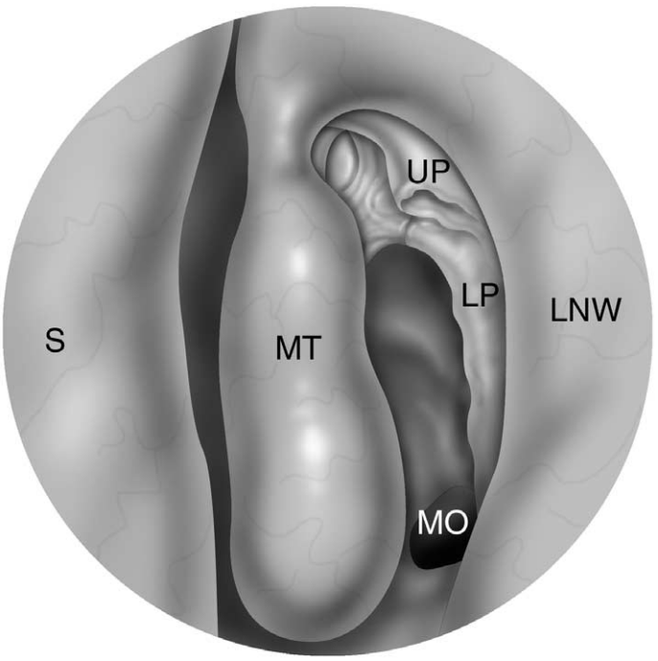

FIGURE 15. After anterior ethmoidectomy; superior attachment of the uncinate process is left undissected.

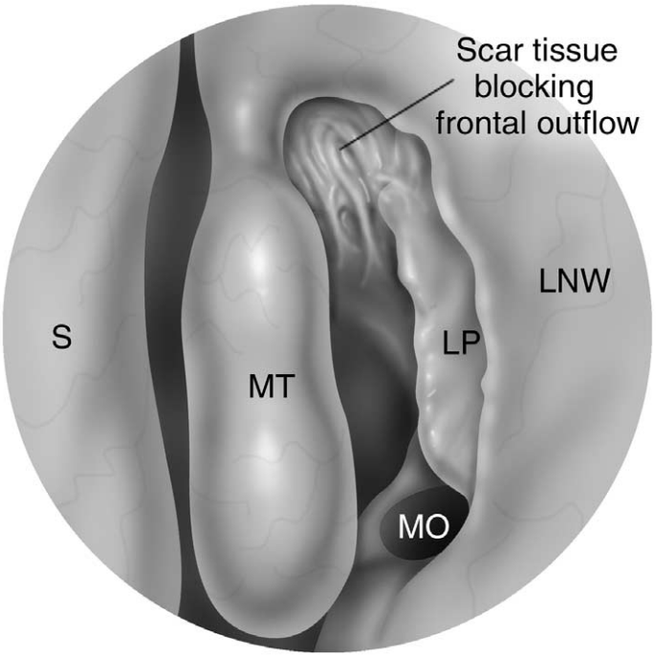

FIGURE 16. Circumferential scarring after frontal sinus surgery; scar tissue blocking the frontal sinus outflow tract.

Scenario 1

A frontal sinus rescue procedure can be performed if the middle turbinate remnant stump is obstructing the frontal recess.[18] This involves removal of the anterior middle turbinate stump together with mucus membrane on its medial aspect. The mucus membrane on its lateral aspect is carefully preserved and draped medially over the denuded area where the previous stump had been resected.[19] This allows for assessment of the frontal outflow tract and revision for possible causes of obstruction, which may fall into clinical scenarios 2 through 6.

Scenarios 2, 3, and 4

The surgical approach to revising the frontal recess may follow our previously described steps of primary frontal sinus surgery. The key structure remains the superior attachment of the uncinate process when it is present. In the absence of the uncinate process, the posterior wall of the agger nasi cell should be identified and dissected. This approach leads to good exposure of frontal sinus in the majority of cases.

Scenario 5

Recurrent frontal sinus mucosal disease (polypoid or hyperplastic) unresponsive to medical treatment requires repetitive frontal recess dissection with removal of polypoid tissue blocking frontal sinus outflow. Meticulous dissection with cutting instruments is necessary to prevent musoca striping, which may lead to scar- tissue formation.

Scenario 6

Circumferential mucosal injury often leads to frontal ostium stenosis and occlusion caused by circumferential scar-tissue formation in the frontal ostium area. Extensive bone exposure caused by mucosal denuding and injury to the periosteum leads to osteoneogenesis with subsequent frontal ostium stenosis. Revision of the frontal recess in such a case is inevitable; often it requires frontal ostium stenting. We use self-retaining Rains stents if the frontal ostium diameter is less than 5 mm or where there is evidence of circumferential scarring in the frontal ostium.[20] In the case of osteoneogenesis, the frontal sinus floor is drilled out[21] or an endoscopic modified Lothrop procedure is used to achieve frontal sinus outflow patency. However, even after the endoscopic modified Lothrop procedure, some patients may still have a narrow frontal sinus outflow tract, evidence of osteoneogenesis, and restenosis with bony tissue, and may require open frontal sinus surgery with sinus obliteration. Open frontal sinus obliteration is rare these days and should be considered as the last resort in surgical treatment of chronic frontal sinusitis.

CONCLUSION

Methodical evaluation of preoperative CT scans, familiarization with the anatomy of the frontal recess and surrounding structures, and the use of an image-guided system in more complicated cases is necessary to achieve success in primary frontal sinus surgery.

In-depth understanding of anatomical variations of the uncinate process and precise surgical removal of its superior attachment provide surgical access to the frontal sinus that is based on the natural ostium and is therefore more likely to remain patent. The use of powered dissection at the frontal recess allows for precise removal of the uncinate process, the agger nasi, and frontal cells, and can create a clean patent frontal recess that heals without granulation or scarring in most cases. Endoscopic transillumination of the frontal sinus intraoperatively and postoperatively is a simple and reliable way to help verify the patency of the frontal sinus.

In cases of frontal sinus revision surgery, precise evaluation of frontal recess anatomy and identification of the cause of obstruction in the frontal sinus outflow system is vital to achieve successful frontal recess dissection. In the majority of cases, frontal sinus patency may be restored via our surgical approach to the frontal recess. However, in isolated cases, circumferential scarring of frontal ostium, osteoneogenesis, and restenosis of the frontal sinus outflow tract with bony tissue may require frontal sinus stenting, frontal sinus floor drill out, or open frontal surgery with sinus obliteration.

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