

Imaging Anatomy in Revision Sinus Surgery

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Core Messages

- An intimate knowledge of sinus anatomy and a clear understanding of the baseline postsurgical anatomy are required for safe and effective revision sinus surgery.
- Appropriate utilization of computer-assisted surgical navigation with CT crossregistration improves safety margins on revision sinus surgery.
- Rhinologists should evaluate each side of the face as a completely independent anatomic, functional, and surgical entity.
- Familiarity with anatomic variants in the frontal recess is required for safe anterior skull base and frontal recess surgery.
- Persistent mucosal polypoid changes in a surgical site on follow-up postsurgical computed tomography, retained surgical surfaces (uncinate process, agger nasi, frontal bulla cells), or new bone formation are negative prognostic signs.

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Introduction

The resulting imaging anatomy of the paranasal sinuses following initial functional endoscopic sinus surgery (FESS) must be thoroughly evaluated to establish the new postsurgical baseline of the sinonasal anatomy. These postsurgical changes may vary from subtle remodeling of anatomy to extensive resection with loss of sinus landmarks, frequently resulting in widely open sinus spaces into the nasal cavity. The great variability of the postsurgical changes is a reflection of the variety of accepted surgical techniques, the surgeon's perception of the specific problem prior to FESS, and the individualized surgical approach to the resolution of the identified problem. The detailed assessment of the postsurgical changes must emphasize which structures have been resected and which

anatomy is still intact. In addition, it must identify the presence of any scar tissue formation, retraction of mucosal surfaces, and unresolved sinus drainage issues. In cases where revision surgery is needed to solve persistent sinus obstruction or postsurgical synechiae, a detailed presurgical mapping of the anatomy must be performed with emphasis on the identification of endoscopic landmarks related to the anatomic surgical targets, especially if the surgical target is close to the lamina papyracea, cribriform plate, or sphenoid sinus walls.

The recent introduction of multidetector helical scanning with its seamless high-resolution imaging databases and the wide availability of computer-assisted surgical navigation workstations allow today a real-time mapping of the progress through the surgical procedure, even in postsurgical fields devoid of residual endoscopic anatomic

landmarks. The combination of improved imaging clarity from surgical navigation with computed tomography (CT) crossregistration and recent development of new powered instruments and modern endoscopic devices is effectively extending the surgical safety margin, allowing the rhinologist to solve more complex sinonasal and skull-base problems.

Caldwell-Luc and Nasoantral Windows

The Caldwell-Luc operation, named after the American physician George Caldwell and the French laryngologist Henry Luc, was first described in the late nineteenth century as a surgical decompressive technique to remove diseased mucosa from the maxillary sinus, be it infectious or tumor [1]. The procedure is performed via direct trocar puncture through the anterior maxilla above the second molar tooth, allowing for initial decompression of the maxillary disease, followed by the opening of a nasoantral window at the inferior meatus to connect the maxillary sinus lumen to the nasal cavity. This procedure is recognized on sinus CT by the associated focal defect of the anterior maxillary wall above the alveolar process and the opening within the inferior meatus into the lumen of the maxillary sinus (Fig. 1.1). This operation, which has been used widely over the last century, is being performed with less frequency today, having been replaced by the more physiologic endoscopic middle meatal antrostomy. Still, this surgery is considered safe and effective when removal of all of the diseased maxillary sinus mucosa is desired.

Imaging Anatomy in Post-FESS Ostiomeatal Complex

The postsurgical CT anatomy of the ostiomeatal complex will reflect the presurgical anatomic problems leading to surgery combined with the surgical management chosen by the surgeon to address the patient's clinical problem. An almost infinite variety of surgical changes result from the appropriately tailored surgical approach selected by experienced rhinologists, who must carefully individualize the extent of the procedure to the specific patient's problem (Fig. 1.2). These surgical changes, alone or in combinations, may include septoplasty, turbinate remodeling/resection, uncinectomy, middle meatal antrostomy, internal ethmoidectomy, sphenoidotomy, and/or frontal recess/frontal bulla cell/agger nasi decompression [2, 3].

- The first step in a comprehensive evaluation of a post-surgical nasal cavity is to determine which structures have been previously resected and which structures remain, thus establishing the new anatomic baseline of the nasal cavity.
- The second step in this evaluation is to determine the relationship between the postsurgical changes and the patient's current symptoms.
- The third and final step is to review the danger zones of the nasal cavity in the light of the distorted postsurgical anatomy prior to any revision surgery.

This relationship is inferred by the presence of acute sinus fluid levels, sinus opacity, or persistent sinus mucosal dis-

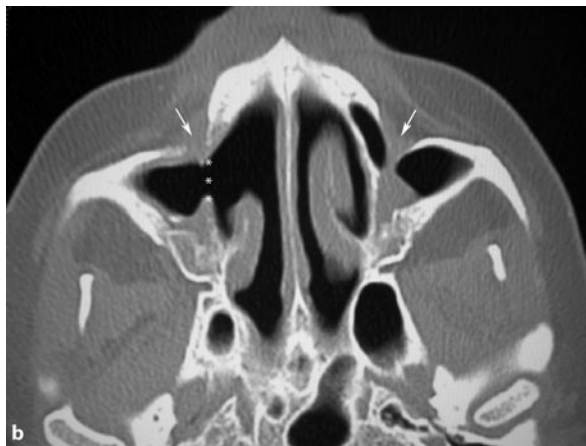


Fig. 1.1a,b Caldwell-Luc procedure. Coronal and axial computed tomography (CT) images at the level of the maxillary sinuses, showing bilateral anterior maxillary sinus-wall defects (arrows in

a and b) as a result of Caldwell-Luc surgery, combined with inferior meatal nasoantral windows (asterisks). Notice also the right middle meatal antrostomy and right inferior turbinectomy

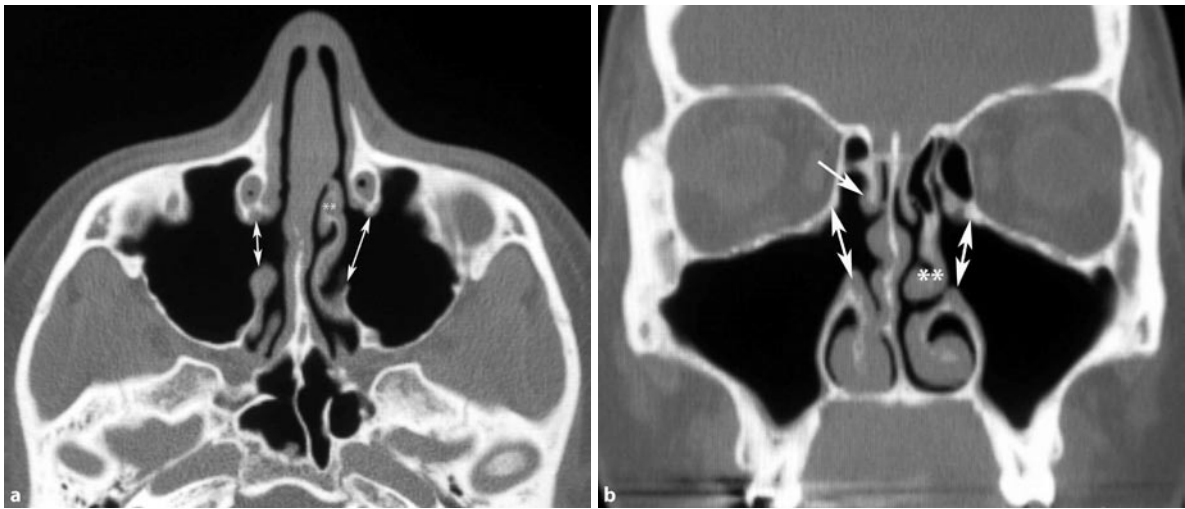


Fig. 1.2 a and b Middle meatal antrostomies. There are bilateral middle meatal antrostomies (*double-headed arrows*), with a right-sided middle turbinectomy (*arrow in b*). Notice the com-

plete resection of the uncinate processes and the wide pattern of communication with the middle meatus. There is also a left paradoxical middle turbinate

ease. Soft-tissue density within the surgical ostia is an important postsurgical finding, suggesting the presence of scar tissue formation, polyps and/or hyperplastic mucosal changes, all of which are indistinct by CT findings.

Septoplasty

Septoplasty is a common adjunct finding in FESS due to the frequency of septal deviations producing asymmetric nasal cavity narrowing, occasionally to the point of laterally deflecting the middle and/or inferior turbinates. After septoplasty, the nasal septum will appear unusually vertical and straight, with a thin mucosa and no apparent nasal spurs. Postsurgical complications such as septal hematomas or septal ischemia may lead to triangular cartilage chondronecrosis, resulting in nasal septal perforations or saddle-nose deformity.

Turbinectomies

Partial resection of the inferior turbinate is seen frequently in patients with symptoms of chronic nasal congestion and polyposis, with the reduction of turbinate surface increasing meatal diameters, thus increasing the total air volume through the nose. Inferior turbinectomy is recognized on coronal CT as a foreshortened “stumped” inferior turbinate (Fig. 1.3).

Partial or subtotal resection of the middle turbinate may be necessary whenever a concha bullosa or a lateralized middle turbinate is producing a mass effect toward the lateral nasal wall. Whenever truly indicated, middle turbinate surgical remodeling must be carefully performed to the minimal degree that solves the clinical problem, taking into consideration the fact that its mucosa is critical for olfactory function. Its basal lamella is one of the most important surgical landmarks for safe endonasal navigation, maintaining turbinate stability by function of its three-planar attachments (vertical attachment to the cribriform plate, coronal attachment to the lamina papyracea, and axial attachment to the medial maxillary sinus wall at the prechoanal level). The iatrogenic fracture of the middle turbinate vertical attachment is a dreaded complication, resulting in the risks of cerebrospinal fluid fistula at the cribriform plate, floppy middle turbinate behavior, and postsurgical lateralization and scarring. Thus, the resulting postsurgical appearance of the middle turbinate may vary from a barely perceptible thinning of its bulbous portion, to a small residual upper basal lamella stump in cases of subtotal resection.

- Lateralization of the middle turbinate is an important postsurgical finding, since it secondarily narrows the middle meatus, potentiates synechia formation, and predisposes to recurrent obstruction of the underlying drainage pathways by granulation tissue and scarring (Fig. 1.4).



Fig. 1.3a–d Inferior turbinectomies. **a** Coronal image showing extensive changes as a result of functional endoscopic sinus surgery (FESS), with subtotal right inferior turbinectomy (*arrow*) and partial left inferior turbinectomy (*asterisks*), wide bilateral middle meatal anastomoses, and left internal ethmoidectomies. Note the persistent polypoid mucosal disease in the right ante-

rior ethmoid sinus. **b** Coronal image of the selective right inferior turbinate prechoanal resection (*arrow*) showing prominent widening of the inferior meatal airway. **c,d** A different patient with extensive FESS showing by coronal (**c**) and axial CT (**d**), loss of all lateral wall landmarks bilaterally, except for the right middle turbinate (*MT*)

Uncinectomy and Maxillary Sinus Ostium Opening

Resection of the uncinate process is an important element in the performance of a functional maxillary sinusotomy. Its incomplete resection is recognized by CT as a visible uncinate process within the surgical field, usually surrounded by soft tissue from a scar/granulation reaction. This granulation and scar, a part of the postsurgical healing response, may contribute to recurrent obstruction at the natural ostium of the maxillary sinus, the ethmoidal infundibulum, or even toward the frontal sinus outflow tract, depending upon where the residual uncinate process is located (Fig. 1.5). Widening of the maxillary sinus ostium is also variable, depending on the uncinate resec-

tion, presence of Haller cells, large bulla ethmoidalis, or the configuration of the adjacent orbital wall. Any soft tissue within the natural ostium of the maxillary sinus or in the ethmoidal infundibulum must be identified due to its potential for impairment of the mucociliary clearance. The presence of a nasoastral window is a good clinical indicator for the surgeon to look for the phenomenon of mucus recirculation, where mucociliary clearance already in the middle meatus may return to the maxillary sinus lumen through a surgical nasoastral window, thus increasing the mucus load and potential for sinus colonization with nasal pathogens. Naturally occurring posterior fontanelles must also be taken into consideration during the planning for revision FESS to avoid mistaking this space endoscopically with the maxillary sinus os-



Fig. 1.4a,b Lateralized middle turbinate in a patient 4 months after FESS, with recurrent facial pain and fever. These sequential coronal images show lateralization of the right middle turbinate

(arrow) obstructing the middle meatal antrostomy, already with active mucosal disease in the right maxillary sinus. Note also subtotal resection of both inferior turbinates (asterisk)

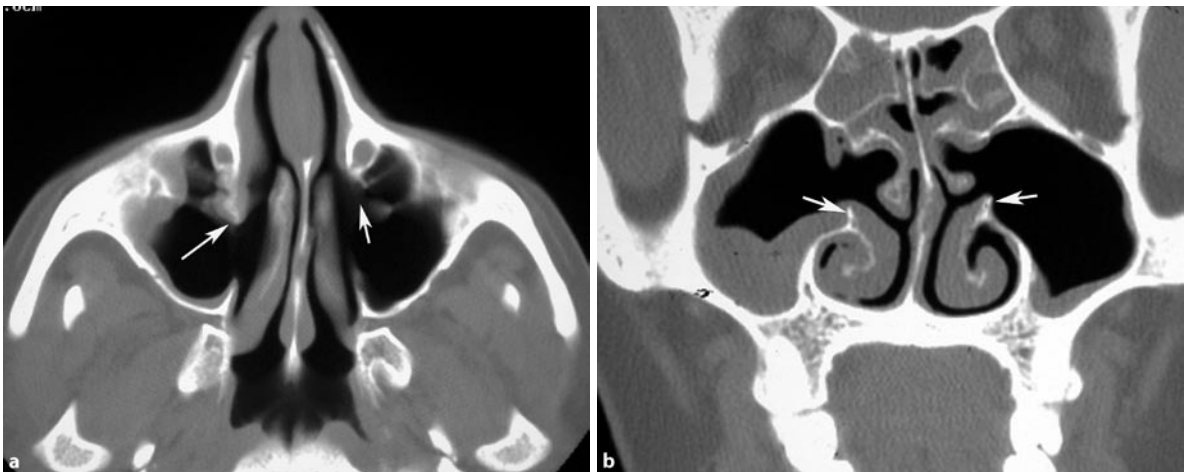


Fig. 1.5a,b Residual uncinate process. Axial (a) and coronal (b) CT images demonstrate persistent uncinate processes (arrows) bilaterally in spite of previous FESS. Note the persistent active

mucosal thickening in both maxillary sinuses, which is worse on the right side

tium, which would result in a maxillary sinusotomy not bearing mucociliary clearance.

Internal Ethmoidectomy

The internal ethmoidectomy is an intranasal endoscopic procedure that is performed to manage mucosal disease within the anterior ethmoidal air cells. It requires the ini-

tial resection of the bulla ethmoidalis followed by resection of the ethmoidal cells, located anterior and inferior to the basal lamella of the middle turbinate. If a posterior ethmoidectomy is also needed, the basal lamella of the middle turbinate is then penetrated to decompress the posterior ethmoidal air cells. This approach is also extendable to the sphenoid sinus (transethmoidal sphenoidotomy). An internal ethmoidectomy appears by CT as a wide ethmoidal cavity that is devoid of septations

(Fig. 1.6). It is important that residual opaque ethmoidal air cells are identified, since they may be an indicator for recurrent sinus disease. The presence of mucosal polypoid changes and mucosal congestion within any residual ethmoidal cells is also a concern as they obscure the underlying anatomic landmarks that are necessary for safe surgery near the skull base.

Frontal Sinus Drainage Surgery

The frontal sinus drainage pathway is one of the most complex anatomic areas of the skull base. Its drainage pathways, the frontal sinus ostium and the frontal recess, are modified, shifted, and narrowed by the pneumatized agger nasi, anterior ethmoid cells, frontal cells, supraorbital ethmoid cells, and the surrounding anatomic structures (vertical insertion of the uncinate process and bulla lamella) [4]. The complexity of the frontal sinus variable drainage pathway starts at the frontal sinus ostium, which is oriented nearly perpendicular to the posterior sinus wall, indented anteriorly by the nasal beak. Its caliber is modified by the presence and size of pneumatized agger nasi and/or frontal cells. When markedly pneumatized, agger nasi cells can cause obstruction of the frontal sinus drainage pathway and thus have surgical implications. A second group of frontal recess cells, the frontal cells, are superior to the agger nasi cells. Bent and Kuhn described the frontal cells grouping them into four patterns [5]:

1. Type 1: a single cell above the agger nasi.
2. Type 2: a tier of two or more cells above the agger cell.

3. Type 3: a single cell extending from the agger cell into the frontal sinus.
4. Type 4: an isolated cell within the frontal sinus.

The frontal sinus ostium may also be narrowed by supraorbital ethmoid cells arising posterior to the frontal sinus and pneumatizing the orbital plate of the frontal bone. The frontal sinus ostium communicates directly with the frontal recess inferiorly, a narrow passageway bounded anteriorly by the agger nasi, laterally by the orbit, and medially by the middle turbinate. The posterior limit of the frontal recess varies depending upon the ethmoid bulla or bulla lamella, reaching to the skull base. When the bulla lamella reaches the skull base, it provides a posterior wall to the frontal recess. When the bulla lamella fails to reach the skull base, the frontal recess communicates posteriorly, directly with the suprabullar recess, and the anterior ethmoidal artery may become its only discrete posterior margin. The frontal recess opens inferiorly to either the ethmoid infundibulum or the middle meatus depending on the uncinate process configuration. When the anterior portion of the uncinate process attaches to the skull base, the frontal recess opens to the ethmoid infundibulum, and from there to the middle meatus via the hiatus semilunaris. When the uncinate process attaches to the lamina papyracea instead of the skull base, the frontal recess opens directly to the middle meatus [6].

- Each pneumatized sinus space grows independently, with its rate of growth, final volume, and configuration being determined by its ventilation, drainage, and the

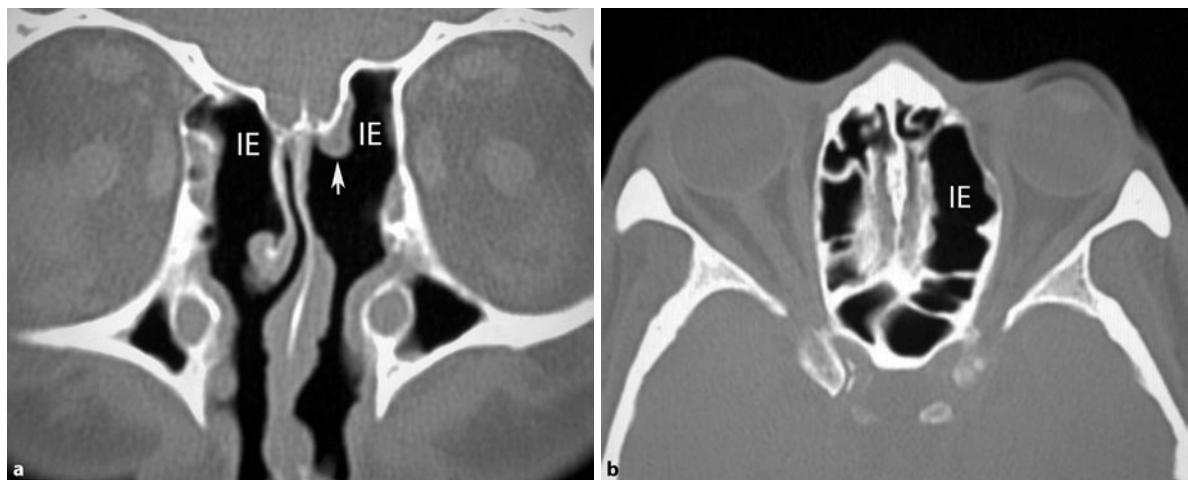


Fig. 1.6a,b Internal ethmoidectomy. **a** Coronal image showing bilateral internal ethmoidectomies (IE) and left middle turbinate resection (arrow). **b** Axial image at the level of the orbit shows

the asymmetric lack of internal septations in the left ethmoid labyrinth internal ethmoidectomy

corresponding growth (or lack of it) of the competing surrounding sinuses and skull base.

This independent and competing nature of the structures surrounding the frontal recess adds an additional dimension of complexity to the frontal sinus drainage pathway. It is thus understandable why chronic frontal sinusitis secondary to impaired frontal recess drainage is so difficult to manage surgically, as reflected by the wide range of surgical procedures devised for frontal sinus decompression over the years. The spectrum of treatment options ranges from surgical ostiomeatal complex decompression combined with conservative long-term medical management, to endoscopic frontal recess exploration, the more recent endoscopic frontal sinus modified Lothrop procedure, external frontal sinusotomy, osteoplastic fat obliteration, or multiple variations of all of these [7].

Most endoscopic frontal sinus procedures are performed in patients who had previous ostiomeatal complex surgery in whom long-term conservative medical management failed. In these patients, it is not uncommon to find frontal recess scarring, osteoneogenesis, and incompletely resected anatomic variants, particularly incomplete removal of obstructing agger nasi cells and/or frontal cells leading to chronic frontal sinusitis (Fig. 1.7). Modern endoscopic surgical techniques and instruments, combined with image-guided three-dimensional navigation techniques have resulted in increased endoscopic management of most frontal sinus pathology. Endoscopic approaches tend to preserve the sinus mucosa, with less scar tissue than external approaches, resulting in

less mucosal shrinkage and secondary obstruction. If the endoscopic approach fails to provide long-term drainage of the frontal sinus, then an external approach with obliteration of the frontal sinus still remains as a viable surgical alternative.

Endoscopic Frontal Recess Approach (Draf I Procedure)

Dr. Wolfgang Draf popularized a progressive three-stage endoscopic approach to the management of chronic frontal sinus drainage problems for patients in whom classic ostiomeatal endoscopic sinus surgery is unsuccessful [8]. The Draf type I procedure, or endoscopic frontal recess approach, is indicated when frontal sinus disease persists in spite of more conservative ostiomeatal and anterior ethmoid endoscopic approaches. The Draf I procedure involves complete removal of the anterior ethmoid cells and the uncinate process up to the frontal sinus ostium, including the removal of any frontal cells or other obstructing structures to assure the patency of the frontal sinus ostium.

Endoscopic Frontal Sinusotomy (Draf II Procedure)

The endoscopic frontal sinusotomy, or Draf II procedure, is performed in severe forms of chronic frontal sinusitis for which the endoscopic frontal recess approach was un-

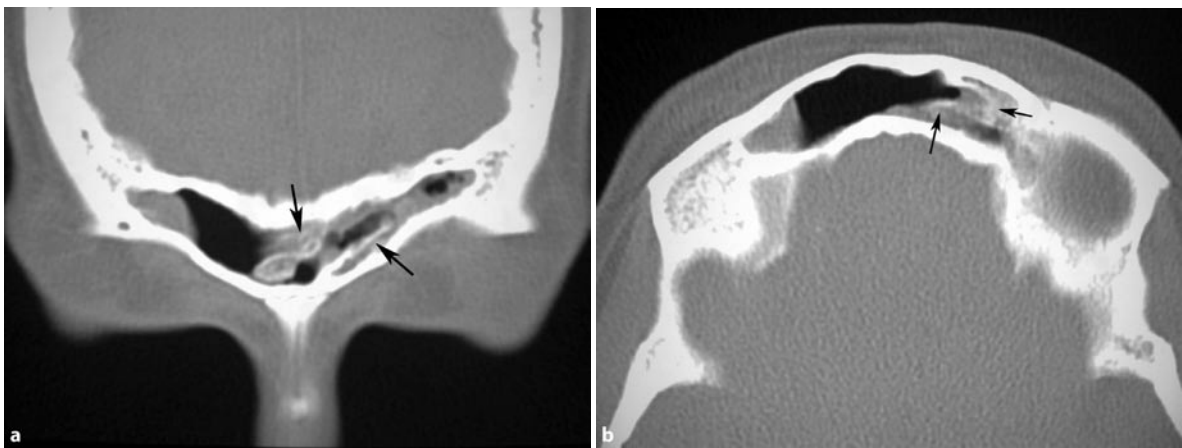


Fig. 1.7a,b Postinflammatory osteoneogenesis. Coronal (a) and axial (b) sinus CT sections at the level of the frontal sinuses show osteoneogenesis with persistent frontal sinus inflammatory mucosal engorgement (black arrows)

successful. The previous endoscopic drainage procedure is extended by resecting the frontal sinus floor from the nasal septum to the lamina papyracea. The dissection also removes the anterior face of the frontal recess to enlarge the frontal sinus ostium to its maximum dimension. The Draf II procedure looks very similar to the Draf I procedure on coronal images, requiring the evaluation of sequential axial or sagittal images to allow the extensive removal of the anterior face of the frontal recess and the frontal sinus floor. Endoscopic frontal sinusotomy (Draf II) procedure can also be easily distinguished from the Draf III procedure (see below) by the lack of resection of the superior nasal septum and the entire frontal sinus floor.

Median Frontal Drainage (Modified Lothrop Procedure or Draf III)

The modified Lothrop procedure, or Draf III procedure, first described in the mid-1990s, is indicated for the most severe forms of chronic frontal sinusitis, where the only other choice is an osteoplastic flap with frontal sinus obliteration. This procedure involves the removal of the inferior portion of the interfrontal septum, the superior part of the nasal septum, and both frontal sinus floors. The lamina papyracea and posterior walls of each frontal sinus remain intact. This procedure results in a wide opening into both frontal sinuses (Fig. 1.8).



Fig. 1.8a–d Draf III (modified Lothrop) procedure. Axial (a,b), coronal (c), and sagittal CT images

- The surgical defect component in the superior nasal septum after a Draf III procedure should not be mistaken for an unintended postoperative septal perforation.

Frontal Sinus Trephination

The trephination procedure is a limited external approach for frontal sinus drainage. An incision is made above the brow and a hole is drilled through the anterior wall of the frontal sinus taking care to avoid the supratrochlear and supraorbital neurovascular bundles (see Chap. 33). The inferior wall of the frontal sinus is devoid of bone marrow, which may lessen the risk of developing osteomyelitis. Frontal sinus trephination is indicated in complicated acute frontal sinusitis to allow the release of pus and irrigation of the sinus to prevent impending intracranial complications. It can also be used in conjunction with endoscopic approaches to the frontal sinus in chronic frontal sinusitis or frontal sinus mucocoeles, where the trephination helps to identify the frontal recess by passing a catheter down the frontal recess, also allowing it to be stented and to prevent its stenosis. This approach provides fast and easy access to the frontal sinus to place an irrigation drain in the sinus. Its main disadvantages are the risks of associated scarring, sinocutaneous fistula formation, and injury to the supraorbital nerve bundle and the trochlea, which can cause diplopia [9]. Image guidance is critical for accurate trephine placement in particularly small frontal sinuses or to gain access to isolated type 4 frontal sinus disease.

Osteoplastic Flap with Frontal Sinus Obliteration

- Long-term stability of the mucociliary clearance of the frontal sinus must be maintained for endoscopic surgery of the frontal sinus to be successful. If this is not achieved, an osteoplastic flap procedure with sinus obliteration may be the only remaining option.

The indications for this procedure include chronic frontal sinusitis in spite of prior endoscopic surgery, mucopycocele, frontal bone trauma with fractures involving the drainage pathways, and resection of frontal tumors near the frontal recess. The outline of the sinus can be determined by using a cut template made from a 6-foot (1.83 m) Caldwell x-ray, which approaches the exact size of the frontal sinus. Other methods include the use of a wire thorough an image-guidance-placed frontal sinus trephination to palpate the extent of the sinus. Beveled

osteotomy cuts through the frontal bone prevent collapse of the anterior table into the sinus lumen upon postoperative closure. Frontal sinus obliteration requires all of the mucosa to be drill-removed and the frontal recess occluded. The sinus is then packed with fat, bone marrow, pericranial flaps, or synthetic materials, and then the bony flap is replaced.

The postoperative imaging appearance by CT and/or magnetic resonance imaging (MRI) is highly variable due to the spectrum of tissues used for sinus packing, with imaging behavior reflecting fat, chronic inflammatory changes, retained secretions, granulation tissue, and fibrosis. MRI may be of limited utility in distinguishing symptomatic patients with recurrent disease from asymptomatic patients with imaging findings related to scar tissue. Imaging is useful for the early detection of postoperative mucocoele formation, which is recognized by its mass effect and signal behavior of inspissated secretions [10, 11].

Endoscopic Sphenoidotomy

The postsurgical appearance of the sphenoethmoidal recess following endoscopic sphenoidotomy varies depending upon whether the sphenoidotomy was transnasal, transethmoidal, or transseptal. Transnasal sphenoidotomy may be performed as a selective procedure, where the only subtle finding may be a selective expansion of the sphenoid sinus ostium in the sphenoethmoid recess. Transethmoidal sphenoidotomies, on the other hand, are performed in the realm of a complete functional endoscopic surgery, where middle meatal antrostomy changes, internal ethmoidectomy changes, and sphenoid sinus rostrum defects ipsilateral to the ethmoidectomy defects become parts of the imaging constellation (Fig. 1.9). Finally, transseptal sphenoidotomy changes are a combination of septal remodeling with occasional residual septal split appearance combined with a midline sphenoid rostrum defect and variable resection of the sphenoid intersinus septum. These changes are seen typically in the realm of more extensive sphenoid sinus explorations or surgical exposures for transsphenoidal pituitary surgery. The accurate imaging identification of the optic nerves, internal carotid arteries, maxillary division of the trigeminal nerve, and the vidian neurovascular package in reference to the pneumatized sphenoid sinus is even more important in postsurgical sphenoid re-exploration, since the usual anatomic and endoscopic sinus appearance may be significantly distorted by previous procedures, postsurgical scar and/or persistent inflammatory changes. Imaging guidance is thus critical for the safe and accurate depiction of all of neighboring structures of the sphenoid sinus.

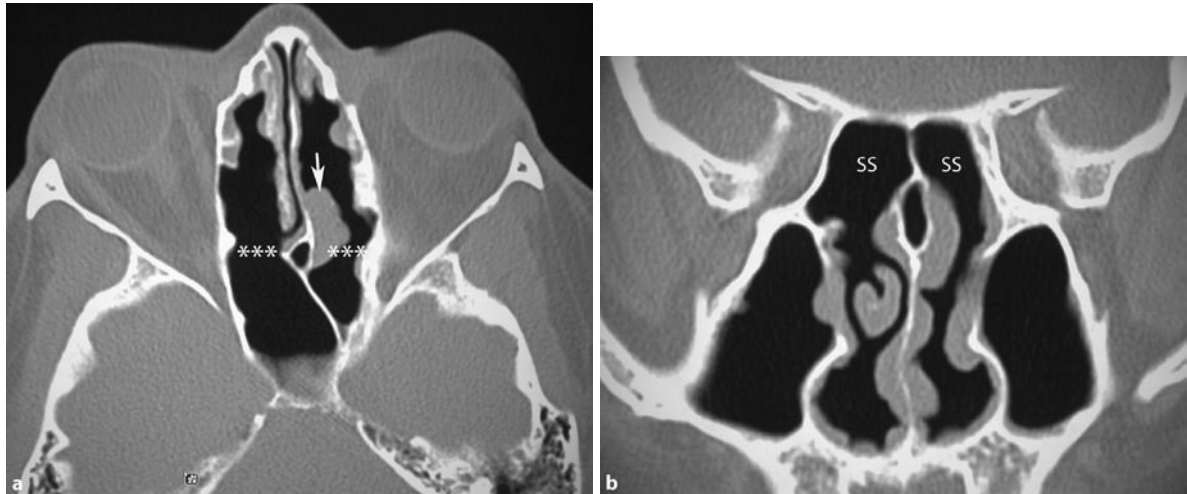


Fig. 1.9a,b Sphenoidotomy. **a** Axial CT showing bilateral internal ethmoidectomies and transtethmoidal sphenoidotomies (asterisks). Note the persistent polypoid disease (arrow) in the left posterior ethmoid sinus. **b** Coronal CT at the level

of the rostrum of the sphenoid showing open communication into the sphenoid sinus (SS), with no residual sphenothmoid recess components. Note the absent left-middle and bilateral inferior turbinates from prior turbinectomies

Negative Prognostic Findings Post-FESS

There is a series of postsurgical imaging findings that imply a persistent underlying physiologic problem, with poor prognostic implications for recurrence of sinus disease. These CT findings may include a wide range of elements, such as incomplete resection of surgical structures (especially uncinate process, agger nasi, or frontal bulla cells), mucosal nodular changes at areas of prior surgical manipulation (mucosal stripping, granulation tissue, mucosal scarring, synechiae formation, polyposis), or postinflammatory increased bone formation (osteoneogenesis). All of these changes should be detectable in a good-quality postsurgical sinus CT, which should be performed ideally at least 8 weeks after the surgical trauma to allow for reversible inflammatory changes to resolve. These changes result in recurrent or persistent obstruction of the mucociliary drainage at the affected points, with increased potential for recurrent symptoms. Persistent nasal septal deviation leading to a narrowed nasal cavity and lateralization of the middle turbinate against the lateral nasal wall are two additional factors with poor prognostic implications for recurrent sinus disease. The relevance of these CT findings must be judged by the rhinologist based on the presence of mucosal congestion and/or fluid accumulation in the affected sinus space in combination with assessment of the patient's clinical behavior (persistent sinus pressure, pain and/or fever).

Conclusion

The postsurgical anatomy of the paranasal sinus drainage pathways and their surrounding structures must be evaluated in an integrated fashion, emphasizing the interrelationship between sinus anatomy and function. The presence of residual surgical structures, mucosal nodular changes at areas of prior surgical manipulation or postinflammatory new bone formation are poor prognostic factors for recurrent postsurgical sinus disease.

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Revision Sinus Surgery

Kountakis, S.E.; Jacobs, J.; Gosepath, J. (Eds.)

2008, XVIII, 353 p. With DVD., Hardcover

ISBN: 978-3-540-78930-7