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Modern Concepts of Frontal Sinus Surgery

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Objectives/Hypothesis: **To validate the endonasal surgical approach to frontal sinus in inflammatory sinus disease, trauma, and selective tumor surgery, and to define the role of external approaches to the frontal sinus. Endonasal frontal sinusotomy can range from endoscopic removal of obstructing frontal recess cells or uncinate process to the more complex unilateral or bilateral removal of the frontal sinus floor as described in the Draf II–III drainage procedures. In contrast, the osteoplastic frontal sinusotomy remains the "gold standard" for external approaches to frontal sinus disease.** ***Methods:*** **A retrospective review of 1286 patients undergoing either endonasal or external frontal sinusotomy by the authors at four university teaching programs from 1977. Prior author reports were updated and previously unreported patient series were combined.** ***Results:*** **Six hundred thirty-five patients underwent type I frontal sinusotomy, 312 type II sinusotomy, and 156 type III sinusotomy. A successful result was seen in these groups, 85.2% to 99.3%, 79% to 93.3%, and 91.5% to 95%, respectively. External frontal sinusotomy or osteoplastic frontal sinusotomy was successfully performed in 187 of 194 patients. Clinical symptoms, endoscopic findings, computed tomography, and magnetic resonance image scanning, and reoperation rate measured postoperative success.** ***Conclusions:*** **A stepwise approach to the surgical treatment of frontal sinusitis, trauma, and selective benign tumors yields successful results as defined by specific criteria which vary from 79% to 97.8%. The details of specific techniques are discussed, essential points emphasized, and author variations noted.** ***Key Words:*** **Frontal sinus surgery, osteoplastic frontal sinus surgery, endonasal frontal sinusotomy, type I drainage, type II drainage, type III drainage.**

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INTRODUCTION

In principle, surgery of the frontal sinus can be performed endonasally or through an external approach. The endonasal approach for surgical treatment of frontal sinusitis has become increasingly established in the last few years.[1–14] This follows developments in knowledge of sinus pathophysiology,[15,16] optical aids,[2,3,17–20] and modern instrumentation (Table I).[21,22] With increasing surgical experience, selective tumor and trauma cases are managed successfully with the endonasal approach.[8,23,24]

A wide spectrum of defined endonasal surgical procedures of the frontal sinus has been developed. These are based on the drainage or sinusotomy classification of Draf.[2,4,13] May and Schaitkin developed a similar classification based on the Draf system (Table II; Figs. 1–3).[10]

Draf Type I Frontal Sinusotomy

Draf type I frontal sinusotomy consists of removal of obstructing disease inferior to the frontal ostium. The term ostium is used to simplify the description of the surgical procedures. It means the drainage area between the frontal infundibulum from above and the frontal recess from below. The anterosuperior ethmoidal cells obstructing the frontonasal outflow tract are removed without altering the frontal sinus ostium. This least invasive technique serves to expose the frontal ostium (Draf type I, NF 1).

Draf Type II Frontal Sinusotomy

Draf type II frontal sinusotomy consists of enlargement of the frontal sinus drainage or outflow tract. Draf type IIA is removal of ethmoidal cells protruding into the frontal sinus (similar to the so-called "uncapping the egg" as described by Kuhn et al.[25] and Stammberger[26]). This results in a larger opening of the frontal sinus floor between the lamina papyracea and the middle turbinate. Draf type IIB drainage (NF 3) is resection of the frontal sinus floor between the lamina papyracea and the nasal septum to provide a maximal opening on one side.

Draf Type III Frontal Sinusotomy

Draf type III frontal sinusotomy consists of contiguous bilateral enlargement of frontal sinus drainage. Maximum access is provided by a median drainage procedure with removal of the frontal sinus floor on both sides and removal of adjacent parts of the intrafrontal and nasal septum (Draf type III, NF 4).

TABLE I.
Reasons for Renaissance of Endonasal Frontal Sinus Surgery.

Pathophysiology	Importance of free ventilation and drainage; obstruction of the ostiomeatal complex may lead to chronic inflammation; obstruction of the frontal recess by special anterior superior ethmoidal cells
Optical aids	Endoscope
	Microscope
	Microscope and endoscope
Instrumentation	Powered instruments
	Curved instruments
	Through-cutting instruments

Despite the recent enthusiasm for endonasal approaches to the sinuses, external or open frontal sinusotomy remains an important procedure in the care of selected patients. Of the various open techniques, the osteoplastic flap procedure with fat obliteration has been hailed as the "gold standard" of definitive frontal sinus procedures.[27–29] As disease or trauma extends intracranially, the osteoplastic approach to the frontal sinus may be modified to include removal of the posterior wall of the sinus or marsupialization of the sinus into the nose.[30,31]

Because the success of frontal sinus surgery must be judged over time and in sufficient numbers of patients, the authors report their combined experience over a period of 24 years with endonasal and open approaches to frontal sinusotomy. This reports seeks to: 1) offer specific indications for the various endonasal and open frontal sinusotomy techniques, 2) describe highlights of surgical procedures and note technical variations between authors, and 3) validate the patient selection and techniques through examination of results.

Methodology

A retrospective review of patients treated at the Departments of Otolaryngology at Fulda Hospital (Academic Teaching Hospital of the University of Marburg), Otto-von-Guericke-University Magdeburg, Regensburg University Hospital, and the New York Eye & Ear Infirmary (New York Medical College) over a period of up to 24 years (range, 18–24 y) was conducted. Indications and surgical technique are as follows:

Type I frontal sinusotomy indications and technique. Type I frontal sinusotomy is indicated for establishing drainage of the frontal sinus when the history, physical examination, and computed tomography (CT) scan suggest that chronic frontal sinusitis is the result of sinus outflow tract obstruction at the level of the frontal recess. This procedure begins with careful medial mobilization of the middle turbinate. In cases of a concha bullosa or polypoid turbinate, the obstructing portion of the turbinate can be resected. The uncinate process is completely removed. If only the frontal sinus is diseased, it is possible to preserve the bulla ethmoidalis. If other sinuses are diseased, surgery on those sinuses can be performed and the frontal sinus surgery undertaken as the last step of the procedure. Anterior frontal recess cells obstructing the frontonasal outflow tract are removed, preserving the mucosa of the outflow tract without altering the frontal sinus ostium. Because the etiology of the frontal sinusitis in these patients is not within the sinus or its ostium, these structures are left intact. Much of the frontal recess can be visualized with either the operating microscope using the 250–300-mm lens with a self-retaining nasal speculum (Cholewa speculum, Karl Storz, Germany) or the 0° endoscope. Direct visualization of the frontal sinus requires a 30° or 45° endoscope.

Type II frontal sinusotomy indications and technique. An endonasal type II sinusotomy should be performed if the history, physical examination, and CT scan suggest complicated frontal sinusitis or as a revision procedure for failed type I frontal sinusotomy resulting from

TABLE II.
Endonasal Frontal Sinus Drainage Type I–III According to Draf[2,4,13] and Nasofrontal Approach NFA I–IV According to May and Schaitkin.[10]

Classification Type by Draf		Nasofrontal Approach	Extent of Surgery
I		I	Anterior ethmoidectomy with drainage of the frontal recess without touching the frontal sinus outflow tract
II	A	II	Removal of ethmoidal cells protruding into the frontal sinus ("uncapping the egg" [25,26]) creating an opening between the middle turbinate medially and the lamina papyracea laterally
	B	III	Removal of the frontal sinus floor between the nasal septum medially and the lamina papyracea laterally
III		IV	Type II drainage on both sides and removal of the upper part of the nasal septum and the lower part of the frontal sinus septum

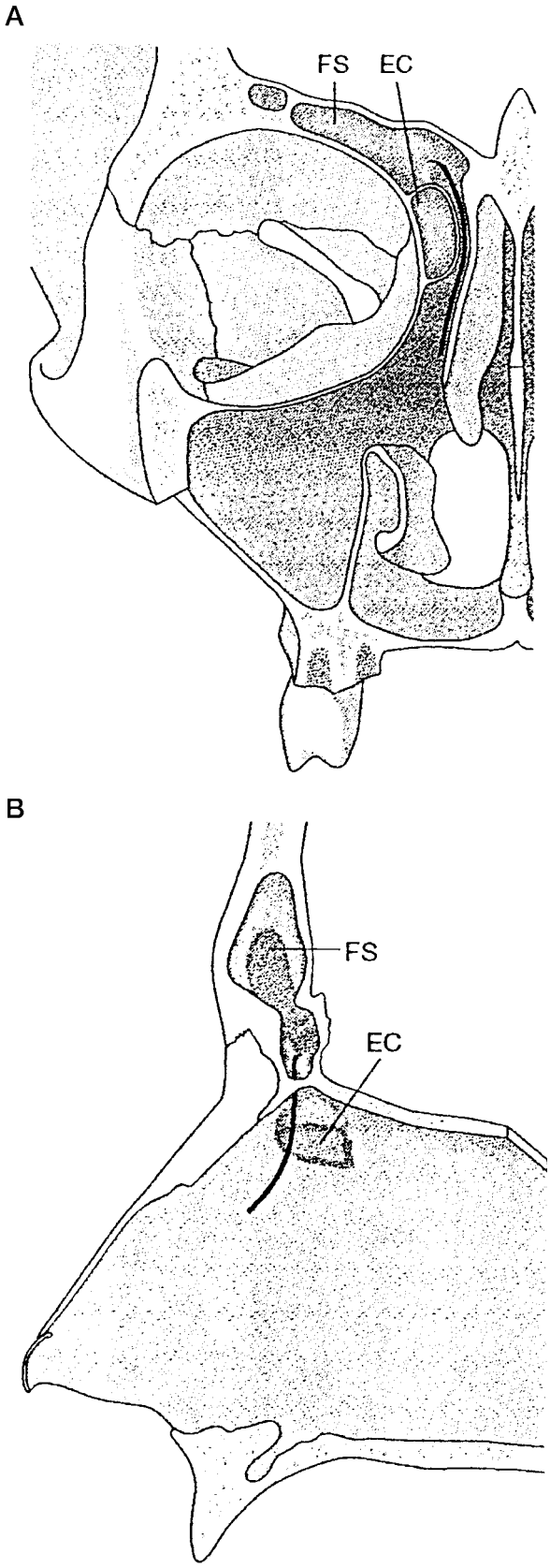

Fig. 1. Type IIA drainage according to Draf with endoscopic removal of eggshell-like ethmoidal cells (EC) obstructing the frontal sinus (FS) drainage. (**A**) coronal view, (**B**) right-sided anatomical specimen, oblique view from below.

significant frontal sinus pathology (scarring, polyps, viscous secretion). A type II drainage procedure is recommended in frontal sinuses with a large anterior–posterior (A–P) diameter (anticipated minimum diameter of frontal neo-ostium 5 mm or more),[12] hypoplastic internal nasal spine, and a broad ethmoid. Type IIA sinusotomy is indicated when the removal of ethmoidal cells yields a wide natural frontonasal outflow tract ("uncapping the egg").[25,26] In all other cases, type IIB or type III drainage is recommended. In frontal sinuses with a small A–P diameter, a hyperplastic internal nasal spine, or a narrow ethmoid, and in revision cases after type II drainage, a type III drainage is recommended. In cases with severe polyposis, a type III drainage procedure is preferable to a type II sinusotomy. Other indications include removal of osteomas, inverting papillomas with minimal frontal sinus involvement, and following limited frontal sinus trauma. Fractures of the inferior posterior wall of the frontal sinus with or without involvement of the ethmoid roof can be reduced and an endonasal duraplasty can be performed in cases with a large A–P diameter. In performing a type II drainage procedure, the agger nasi, uncinate process, and frontal process of the maxilla form important landmarks. The initial steps of this procedure are the same as the type I sinusotomy which exposes the ostium of the frontal sinus. The ostium may be identified by direct visualization, probing using variation of frontal sinus seekers (Karl Storz; Xomed, Jacksonville, FL), or, more recently, computer image-guided stereotatic techniques (Visualization Technologies Incorporated, Boston, MA; Xomed). The removal of the fragile or eggshell-like ethmoidal cells (described under various names, including *none frontal cells*)[25] protruding into the floor of the frontal

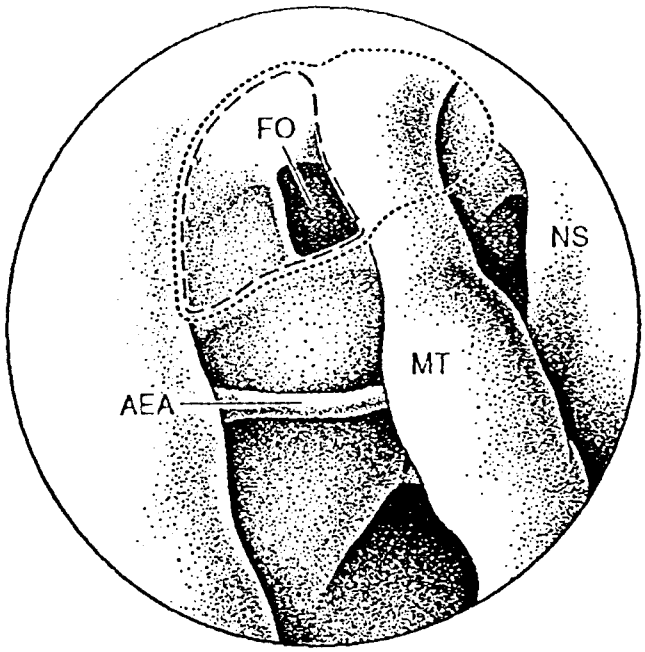

Fig. 2. Frontal sinus drainage type IIB according to Draf, endoscopic view. Broken line = area of resection for Type IIB drainage. FO = frontal ostium; AEA = anterior ethmoidal artery; MT = middle turbinate; NS = nasal septum.

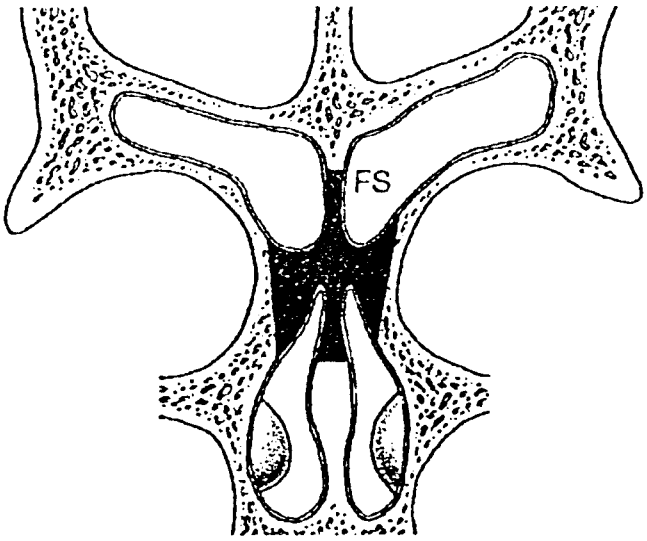

Fig. 3. Frontal sinus drainage type III according to Draf, coronal projection. Dark underlay = necessary removal of bone. FS = frontal sinus.

sinus and its ostium, are removed primarily using frontal sinus curettes. If the above-described removal of cells in a type IIA frontal sinusotomy floor does not enlarge the frontal sinus outflow or ostium to greater than 5 mm, then punches or burrs must be used to remove the sinus floor from the lamina papyracea to the middle turbinate. A type IIB frontal is performed by extending the frontal sinus floor removal medially to the nasal septum using punches or burrs. When using burrs, the authors differ in that only two (W.H., S.D.S.) primarily use the endoscope for surgical visualization. In revision cases, it may be necessary to expose the lacrimal sac for anatomic orientation. In both forms of a type II drainage procedure, it is essential to minimize trauma and to maximize mucous membrane preservation.

Endonasal duraplasty at the posterior wall of the frontal sinus is usually performed using the underlay technique.[23] The intact dura is detached from the edge of the bony defect to create an adequate buttress for stable graft insertion. The graft, a layer of connective tissue such as autogenic or allogenic fascia lata, is cut to a size sufficient for it to be pushed a few millimeters between the bone and the raised intact dura on all sides of the defect. After insertion, the graft is additionally fixed with fibrin glue (Tisseel®, Immuno AG, Vienna). The graft is covered with a free mucosal flap from the middle or inferior turbinate, which is also fixed with fibrin glue.

Type III frontal sinusotomy indications and technique. A type III drainage procedure is indicated after failure of a prior type II sinusotomy or a prior Lynch procedure, limited inverting papillomas, and selected trauma cases. This procedure yields a maximal communication of the frontal sinus to the nose by removing the superior nasal septum and inferior frontal sinus septum in continuity with a bilateral type IIB sinusotomy. Although there are minor variations between the authors in performing this procedure, the important elements of the technique are the same. First, the above-described steps of the type IIB permit the initial opening of the lateral frontal sinus floor. Second, the removal of a 2- to 3-cm rectangle of the superior nasal septum at the junction of the quadrangular cartilage and perpendicular plate of the ethmoid is both necessary to the medial removal of the frontal sinus floor and assists in widening the surgical field to permit simultaneous visualization and removal of the medial floor of both sides of the frontal sinus. Third, the triangle of bone formed by the anterior frontal sinus floor (referred to by May as the *beak*)[10] in the midline forms a landmark and must be removed with a burr to obtain maximal ventilation of the sinus. Fourth, in special cases, identification of the most anterior olfactory fiber forms the posterior boundary of the sinusotomy to avoid perforation of the cribriform plate as removal of the frontal floor precedes anteriorly along the attachment of the middle turbinate (Draf W, personal communication, 1996). Variations between the authors include the insertion of a rubber finger packing (Rhinotamp®, Vostra, Aachen, Germany) at the end of the procedure versus a synthetic sponge (Merocel®, Xomed) into the nose and ethmoidal cavity for 3 to 7 days for postoperative hemostasis, moistening the wound, and promoting re-epithelization; and, the use of stents. Those using stents (R.W.) think the insertion of stents into the frontal sinus outflow tract for 6 months in special cases with a narrow drainage passage may significantly improve the postoperative patency of the frontal sinus neo-ostium.[32] Stents have included a prototype soft silicone (Vostra, Aachen, Germany) which is not yet commercially available. The Rains Frontal Sinus Stent® (Smith & Nephew, Memphis, TN) or the Parell T-Stent® (Xomed) are available alternatives. Clear indications for stenting still have to be developed.

Postoperative care consists of careful mechanical cleaning of the operative site without injury to regenerating tissue. The nose should not bleed after the procedure. Crusts are removed only if they obstruct nasal breathing or hinder sinus drainage. Topical steroids may be applied to reduce postoperative edema and hasten the healing process.[33–37] Steroids should be applied until the mucosa is well healed or at least for 6 months. In some cases, application over years is necessary. Nasal irrigation with saline solution both moisturizes and atraumatically cleans the nose. The use of special nasal douche (Rhinocare®, Siemens & Co.; Bad Ems, Germany; Grossand irrigator®, Hydromed; Culver City, CO) is recommended for effective irrigation.[38] Systemic steroids are prescribed in cases of recurrent nasal polyps, including those patients with asthma, aspirin sensitivity, and nasal polyposis. Systemic antibiotics are not used routinely. Antibiotics are used in cases of acute sinusitis or superinfection of chronic sinusitis.

Osteoplastic obliterative frontal sinusotomy indications and technique. Endonasal frontal sinus surgery fails when the specific sinus pathology is beyond the operative field or a stable drainage cannot be established despite a wide intraoperative opening of the frontal sinus floor through a type II or III sinusotomy or long-term stenting of the neo-ostium.[13,32] In these cases, an external approach is necessary. Indications for an osteoplastic

obliterative frontal sinusotomy include chronic frontal sinusitis after endonasal surgery, mucopyoceles caused by occlusion of the frontal sinus outflow tract after a prior Lynch operation, severe frontal sinus fractures including those which involve the drainage pathway, and tumors such as large osteomas.[39–46] Essential steps of the operation are:[44–46]

- Coronal incision without having shaved hair or use of a forehead crease;
- Development of the scalp flap up to the supraorbital rim with preservation of the supraorbital nerves;
- Using a 6-ft occipitofrontal (Caldwell) x-ray template;
- Opening of the sinus with a saw and chisel;
- Complete removal of the pathological process and sinus mucous membrane using a cutting or diamond burr drill under microscopic control or loupe magnification, and endoscopic control, if necessary. When sinus mucosa cannot be removed or disease extents into the epidural space, involved dura should be removed or the sinus permanently drained into the nose (marsupialization)[30,31]:
- Eversion of the nasal mucosa toward the nose;
- Sealing of the frontonasal duct with a layer of connective tissue (temporalis fascia, galea periost, allogenic fascia lata (Tutoplast^{R}, Tutogen Medical; Erlangen, Germany) and fixation with fibrin glue (Tisseel, Immuno, Wien). Tissue glue was not used by one of the authors (S.D.S.). One author (W.D.) likes to place conchal cartilage between the everted nasal mucosa and the connective tissue to obtain a stable layer;
- Filling the sinus cavity with freshly harvested abdominal fat. This can be performed through a preexisting or umbilical incision;
- Wire or plate fixation of the anterior table of the sinus bony flap with preservation of the periosteal blood supply if the bony template does not remain in a stable position after replacement. In some cases, concurrent reconstruction of defects of the anterior frontal sinus wall can be performed using split calvarian bone from the parietal region; and
- Periosteal stitching, suction drainage, and scalp closure.

RESULTS

Endonasal Surgery

The success of all non-obliterative surgical procedures of the frontal sinus is measured by persistent patency of the nasofrontal duct or neo-ostium. In both endonasal and external procedures, one might assume that the more extended procedure is the most likely operation to result in ventilation of the frontal sinus. However, any endonasal surgical access may give rise to significant tissue trauma and inflammation following bone removal with a drill to enlarge the communication of the frontal sinus to the nose. An impressively wide opening at surgery does not guarantee patency weeks or months after the procedure. In a l995 retrospective study, the authors evaluated all patients who underwent endonasal frontal sinus drainage at the ENT clinic in Fulda (471 type I, 128 type II, 57 type III).[4] Referring to these patients, random individuals were selected for special postoperative follow-up examination (42 type I, 43 type II, 47 type III). Surgery was for chronic sinusitis and polyps, with orbital complications of acute sinusitis in five cases (type III). The follow-up period was 1 to 12 years (average, 5 y). In a 1990 study, one of the authors (S.D.S.) reported 36 patients undergoing 57 type I or IIA sinusotomy (27 patients type I and 9 patients type IIA sinusotomy) with an original follow-up period of 9 to 26 months (average, 16.4 mo).[12] Subjectively, 32 of the 36 (88,8%) patients were significantly improved. However, 11 patients did have one episode of sinusitis requiring antibiotics and two required further surgery. A previously unpublished 3-year follow-up after this report found that one additional patient had persistent sinusitis and would benefit from further surgery. This patient was then lost to follow-up. In an additional population of 182 patients treated at the New York Eye & Ear Infirmary, 288 type I or IIA and two type IIB drainage procedures were performed between l992 and l997 (137 type I, 43 type IIA, and 2 type IIB sinusotomy). Four of these patients (1 type I sinusotomy, 3 type IIA sinusotomy) required further surgery for recurrent sinusitis clinically and on CT scanning. Follow-up varied so much within this group that it is difficult to further estimate surgical success. In the 1995 study, subjective estimation of operative results by the patients showed a significant improvement or complete eradication of symptoms in 85.7% (type I drainage), 83.8% (type II drainage), and 91.5% (type III drainage).[4] Individual symptoms had improved to various extents.

Applying a subjective/objective grading system (grade 1 = endoscopically normal mucosa independent of the subjective picture of complaints; grade 2 = subjective freedom from symptoms with endoscopically visible inflammatory mucosal changes still present; grade 3 = no improvement subjectively and pathological changes in the mucosa (failure), the authors were able to achieve in Fulda population a success rate (grade 1 or 2) of 83.4% for the type I drainage, 83.7% for the type II drainage, and 89.4% for the type III drainage. These results imply that despite many prognostically unfavorable cases, the type III sinusotomy shows the best results.

In another study by the authors, endoscopic and computed tomographic examinations were systematically carried out postoperatively.[13] Twelve to 98 months after type II sinusotomy, 79% (37 of 48) patients were free of symptoms or had only minor problems. Fifty-eight percent (71 of 83) frontal sinuses were ventilated and on endoscopy showed normal mucosa. A ventilated frontal sinus with hyperplastic mucosa was seen in 12% (10 of 83). Occlusion of the frontal sinus communication with the nose, and total opacification on CT, was obvious in 15% (12 of 83). An additional 16% (13 of 83) of the patients undergoing type II drainage procedure showed total frontal sinus opacification resulting from recurrent polyposis. Twelve to 89 months after type III drainage, 59% (48 of 81) frontal sinuses were ventilated and normal. A ventilated frontal

sinus with hyperplastic mucosa was seen in 17% (14 of 81). Scarred occlusion with total opacification on CT was obvious in 7% (6 of 81). An additional 16% (13 of 81) showed total opacification resulting from recurrent polyposis. The patients were free of symptoms or had only minor problems in 95% (41 of 43) patients. Recent endoscopic follow-up, including this patient population, reveals that 70.5% (86 of 122) type II sinusotomies were patent as a result of direct endoscopic visualization (32.8%) or probing (37.7%). Scarred occlusion and occlusion because of severe polyposis was obvious each in 14.8% (18 of 122). Following type III sinusotomy, 65 of 112 drainages were endoscopically patent (58.0%). Probing in the presence of recurrent polyposis was possible in 23.2%. Scars preventing endoscopy and probing were found in 18.8%.

Tables III and IV summarize the authors previously published and now updated results, and those of others for type I to III sinusotomy.[1–14,47–53] Despite the difficulty in comparing data because of different indications for surgery, different follow-up times and methods, it seems to be obvious that a bigger drainage procedure leads to a greater probability of an endoscopically open frontal sinus neo-ostium.

In one prospective report by the authors, Weber et al. found that long-term stenting of the frontal sinus significantly reduces the rate of re-stenosis of the frontal sinus neo-ostium (Table IV).[32] Endonasal sinus surgery was performed with extended Draf type II (NFA II according to May) sinusotomy for chronic polypoid sinusitis with and without long-term stenting of the neo-ostium for 6 months using a silicone rubber spacer. Twelve to 16 months postoperatively, the neo-ostium was endoscopically patent in 80% and the frontal sinus aerated in 93.3% with use of a stent. In the group without stenting, the neo-ostium was endoscopically patent in 33% and the frontal sinus aerated in 71.4%. The difference was statistically significant ($P = .0416$).

Summarizing all our data, 635 patients underwent type I frontal sinusotomy, 312 type II sinusotomy, and 156 type III sinusotomy. An overall successful result, which means significant improvement or free of symptoms and no revision surgery, was seen in these groups, 85.2%–99.3%, 79%–93.3%, and 91.5%–95%, respectively. Scarred occlusion of the frontal neo-ostium was documented using endoscopy and CT/MRI in 6.7% to 30% of type II sinusotomies and 7% to 18.8% of type III sinusotomies.

Results of osteoplastic obliterative frontal sinus surgery. In a previously published report based on the experience at Fulda, the authors reviewed 31 osteoplastic obliterative frontal sinus operations with fat obliteration and 44 osteoplastic procedures without obliteration.[44] Average follow-up was 3.8 years (range, 0.5–14 y). The over-

TABLE III.
Results of Endoscopic Enlargement of the Frontal Sinus Ostium.

Author(s)	No. of Frontal Sinuses	Postoperative Interval	Results	Remarks
Draf et al. (Draf type I)[4]	42 (471)	5 y	Mucosa: 55.6% normal, 11.1% polyps, 33.3% "pathological"	
Friedrich[48]	7	13 mo	7/7 frontal sinuses normal	Silastic stenting of the nasofrontal recess through small external opening
Hosemann et al.[9]	201	13 mo	81% ostia patent by probing	Ostia <5 mm have poorer prognosis
			71% frontal sinuses opacified postop	
Metson[11]	7	19–24 mo	6/7 ostia remained patent	
			1/7 ostia stenosed	
Moriyama et al.[49]	105	6–42 mo	73.4% ostia widely patent	No bony occlusion of ostium observed
			17.1% ostia narrowed	
			9.5% ostia occluded by polyps/granulation tissue patent rate of 90.1%	
Otori et al.[50]	172	>1 y		Abstract: Significant lower rates of patency in cases with preoperative severe lesion of frontal sinus and with small ostium
Perko[51]	7	11 mo	6/7 patients symptom-free	Isolated cases of frontal sinusitis
			7/7 ostia patent	
Schaefer and Close[12]	36	16 mo	58% symptom-free	Placement of silastic tube in ostia of less than 6 mm
			31% one recurrence of sinusitis	
			3% unchanged	
			8% worse	
Wigand and Hosemann[14]	162	3.5 y	40% ostia patent by endoscopy	
			28% ostia patent by probing	
			32% ostia closed by probing	

TABLE IV.
Results of Extended Endonasal Frontal Sinus Surgery: Draf Type II (Extended Drainage) and III (Median Drainage)

Author(s)	Technique	No. of Operations	Follow-up Period	Healing of Frontal Sinus Ostium	Remarks
Becker et al.[52]	Median drainage	14	9 mo	100%	Special drill system
Close et al.[1]	Median drainage	11	5.8 mo	100%	In 5/11 patients, additional small external incision
Draf et al.[4]	Type II	128 patients	5 y	Normal/polyps/pathological: 61.7%/14.8%/23.5%	
	Type III	57	5 y	Normal/polyps/pathological: 67%, 9.1%, 23.9%	
Gross et al.[5]	Median drainage ("endonasal Lothrop procedure")	10	7 mo	100%	
Har-El and Lucente[6]	Simple drainage	16	10–50 mo	1/22 patients with ostium occlusion	In 1/22 patients, additional small external incision
	Extended drainage	5		2/22 patients with CT opacification but patent ostium	
	Median drainage	1			
Rudert et al.[53]	Type II and III	40	1–3 y (?)	Restenosis in 3 cases	
Simmen[54]	Type II and III	55	23 mo (mean)	62% symptom-free	No data on endoscopic result
				29% improved	
Weber et al.[13]	Type II	96	51 mo (mean)	70% reventilation	
	Type III	43	34 mo (mean)	76% reventilation	
Weber et al.[33]	Type II	21	12–16 mo	33% endoscopically patent, 71.4% aerated frontal sinus	
	Type II with silicone spacer for 6 mo	15	12–16 mo	80% endoscopically patent, 93.3% aerated frontal sinus	Prospective study, statistically significant difference
Weber et al.	Type IIB	122	12–98 mo	Patent ostium: 70.5%	Endoscopy (32.8%) and probing
				Scarred occlusion: 14.8%	
				Occlusion by polyps: 14.8%	
	Type III	56 (112 sinuses)	12–89 mo	Patent ostium: 81.2%	Endoscopy (51.0%) and probing
				Scarred occlusion: 18.8%	

all esthetic and functional outcome was very good. Revision was necessary in only one case. No serious complications, such as impaired vision or meningitis, occurred. In a previously unpublished review from one of the authors (S.D.S.), 99 patients underwent bilateral osteoplastic obliterative frontal sinusotomy for primarily chronic sinusitis over a 15-year period. Other indications include displaced fractures of the frontal sinus and acute frontal sinusitis refractive to intravenous antibiotics and trephination. Fat was not placed within acutely infected sinuses, but was successfully used in chronic sinusitis with purulent secretions in the sinus. Complications included laceration of the dura in one patient resulting from an incorrectly performed radiographic template, and transient ptosis of the upper eyelid in another patient from removal of disease extending into the orbit. Early in this period, one patient presented with a large epidural extension of a mucopyocele. All mucous membrane was carefully dissected away from the dura. Within weeks of obliteration of the frontal sinus, the patient represented with a fronto-cutaneous fistula. Recurrent infection was thought to be the result of an inability to completely remove mucous membrane from the dura. At the second surgery, the entire floor of the frontal sinus and superior nasal septum were removed to marsupialize the sinus into the nose. The concept of *sinus marsupialization* for extensive epidural mucopyoceles was then used successfully in more than a dozen patients over the next 13 years.[30,31] An alternative procedure was resection of the involved dura in three patients. One of these patients required drainage of an epidural effusion on the tenth postoperative day. Seven of the frontal sinus marsupialized patients were reported by Schaefer in 1988, with follow up as long as 8 years.[31] The entire group of patients remained well over a 12-year period.

During the past 20 years, CT scanning was the primary technique used to evaluate potentially infected obliterated frontal sinuses.[46,54] More recently, MRI has become the definitive imaging method to postoperatively investigate the obliterated frontal sinus cavity. T_1- and T_2- weighted spin echo images and *fat suppression* (STIR sequences) are necessary to differentiate the soft tissue inside the frontal sinus.[46,55] The authors first investigated using MRI in 11 Fulda patients, aged 22–65 years, who had previously undergone an osteoplastic frontal sinus operation with fat obliteration 4 to 24 months earlier.[56,57] In six of 11 cases so far, vital fatty tissue was found. Partial fat necrosis occurred five times, whereas transformation into granulation tissue (N = 4) or mature connective tissue (N = 1) could be seen additionally. All 11 patients were complaint-free.

Currently we evaluated 91 MRI scans performed in 53 patients after surgery. Time between surgery and the last MRI scan was 24 months on average (range, 1–12 y). Outcome parameters were time-dependent changes in the distribution of adipose or connective tissue, development of necroses or oil cysts, recurrences, inflammatory complications, or mucoceles.

We found five mucoceles (9.4%). The amount of adipose tissue depicted on the last scan was less than 20% in the majority of cases (51%) and more than 60% in only 21% of cases.

Therefore, fat decreases significantly with time. Necrotic cells will be absorbed and replaced by granulation and later on fibrous tissue or will form oil cysts (foreign-body reaction).[32] Clinically, patient outcome did not correlate with the decrease of fatty tissue and remained good despite scanning results.

DISCUSSION

Improvements in optical aids, instrumentation, and knowledge of pathophysiology are essential steps in establishing endonasal sinus surgery. With increasing experience, endonasal frontal sinus surgery can be performed safely and successfully for most indications.[2,8,12,13,39] According to the extent and pathophysiology of the disease process, the authors recommend a stepwise endonasal treatment approach from clearance of the frontal recess (type I drainage procedure or sinusotomy) to partial removal of the frontal sinus floor (type II) to bilateral removal of the sinus floor and frontal/nasal septums (type III).

In the patients reported by the authors, endonasal frontal sinus surgery failed when the pathology could not be surgically approach or a permanent drainage could not be established despite temporarily widening the outflow tract, the frontal sinus, or long-term stenting of the neoostium.[32] In these cases, the authors do not recommend the Lynch procedure because the classic operation leads to partial removal of the lateral aspect of the bony frontal sinus outflow tract with subsequent narrowing by scarring or prolapse of the orbital soft tissue.[58,59] This prolapse then leads to obstructions of the nasofrontal communication and development of mucoceles. The incidence of mucoceles has been reported to be more than 30%.[39,60,61] Additionally, some patients develop problems with numbness in the N-V1 region, neuralgiform pain, and a visible facial scar. The authors do recommend the osteoplastic obliterative frontal sinusotomy. Hardy and Montgomery first reported a comprehensive series on this technique in 1976.[62] Two-hundred fifty patients were investigated with a median follow-up of 8 years (range, 3–19 y). The overall complication rate was 18%: 5.2% abdominal wound complications, 3% acute postoperative infections with necrosis of implanted fat, and 3% recurrent chronic sinusitis. The occurrence of mucoceles was not reported. Four percent of 208 patients with obliteration of the frontal sinus were revised. Ninety-three percent of the patients had no significant symptoms, whereas 6% had persistent pain and 1% persistent neuralgia. An important limitation of this series of obliterative frontal sinusotomies, and other studies, was the inability to sufficiently image the sinus contents.

At present, MR is the best imaging method for postoperative investigation of the obliterated frontal sinus, CT the second one.[46] On MR, fat typically has a high signal intensity on T_1-weighted images and an intermediate signal intensity on T_2-weighted images.[54,63,64] The areas of fibrosis have low to intermediate signal intensity on both T_1-weighted and T_2-weighted scans.[54,63] To limit comparable further processes with short T_1 times (e.g., subacute bleeding), fat suppressant techniques can be used to se-

lectively suppress signals from lipid-bound protons.[65–67] The signal characteristics of mucoceles are variable according to the protein concentration of the secretions.[63,68] The appearance of transplanted fat on MR imaging is changing. Fat often forms often round structures, which could be lobules of viable fat or small oily cysts or some granulation areas. Because of the varying signal intensities of both mucoceles and fat, early mucoceles are sometimes masked and may be diagnosed with some delay. Furthermore, there is no evidence in any study that the clinical outcome is influenced by the degree of surviving fat cells. The clinical result appears to be independent of the viability of the implanted fat.[32] Nevertheless, MRI is the most valuable method of examination following frontal sinus obliteration with fat. The experience we have gained leads us to recommend postoperative MRI scans 1, 2, and 5 years after surgery.

CONCLUSIONS

Modern surgical treatment of frontal sinus disease now ranges from endonasal to external approaches. The majority of inflammatory and infectious frontal sinusitis can be successfully treated through an endonasal approach with results varying from 79% to 97.8% as measured by various criteria. An endoscopically visible frontal sinus drainage pathway could be seen in 30% to 80%, and frontal sinus re-ventilation according to CT and MRI in up to 93%. Type I sinusotomy with removal of obstructing disease in the frontal recess is sufficient when major disease is not within the frontal sinus. Depending on the individual anatomy, removal of protruding ethmoidal cells (type IIA) or the whole nasal part of the frontal sinus floor on one side (type IIB), or a contiguous bilateral enlargement of frontal sinus drainage (type III), is indicated if the frontal sinus shows severe disease. If the specific sinus pathology is beyond the operative field or a stable drainage cannot be established, an osteoplastic obliterative approach should be performed. The classic Lynch operation is not recommend because it leads to partial removal of the lateral aspect of the bony frontal sinus outflow tract with subsequent narrowing by scarring or prolapse of the orbital soft tissue and the development of mucoceles. Long-term follow-up showed a recurrence rate of mucoceles after osteoplastic obliterative frontal sinus surgery in approximately 10%. Follow-up has to include magnetic resonance imaging 1, 2, and 5 years postoperatively.

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