Frontal Sinus Surgery

A Systematic Approach

Devyani Lal
Peter H. Hwang
Editors

Springer

EXTRAS ONLINE

Frontal Sinus Surgery

Devyani Lal • Peter H. Hwang
Editors

Frontal Sinus Surgery

A Systematic Approach

Foreword by
Valerie J. Lund, CBE, MB, BS, FRCS, FRCSEd

Springer

Editors

Devyani Lal, MD, FARS
Professor of Otolaryngology,
Mayo Clinic College of Medicine and Science,
Associate Dean, Mayo Clinic School of Continuous Professional Development,
Consultant, Department of Otolaryngology – Head and Neck Surgery,
Consultant (Joint),
Department of Neurological Surgery,
Mayo Clinic,
Phoenix, AZ,
USA

Peter H. Hwang, MD, FARS
Professor and Chief,
Division of Rhinology and Endoscopic Skull Base Surgery,
Department of Otolaryngology – Head and Neck Surgery,
Stanford University School of Medicine,
Stanford, CA,
USA

ISBN 978-3-319-97021-9 ISBN 978-3-319-97022-6 (eBook)
https://doi.org/10.1007/978-3-319-97022-6

Library of Congress Control Number: 2018965169

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

I dedicate this book to my parents, Krishna Murari and Sarita Rani Lal. Their unequivocal love has brought me zest for life, learning and sharing.

This book was only possible with the loving support of my husband, Niresh Pande and my siblings, Ritu and Abhiroop.

Devyani Lal

To my many superb teachers, who have instilled in me a desire to pursue excellence in teaching; and to my students and trainees, who on a daily basis sustain my love for teaching and inspire me to continually sharpen my craft.

Peter H. Hwang

Foreword

Since the inception of endoscopic sinus surgery, it has been widely acknowledged that the frontal sinus provides the greatest challenges to rhinologists. Even prior to endoscopic approaches, the complex outflow anatomy of the frontal sinus and its proximity to the orbit and brain has always made it a potent source of acute and chronic complications which often demanded radical solutions. The proliferation of surgical procedures, devices, and drug delivery systems is indicative of the problems in maintaining mucociliary clearance and patency of the system. For these reasons, it is entirely appropriate for a book such as this to be entirely devoted to this topic, particularly one which adopts a systematic and practical approach.

The editors and senior authors, Dr. Lal and Dr. Hwang, have amassed an impressive array of the "great and the good" to explore all aspects from anatomy, physiology, and pathology through the range of medical management, the many surgical approaches, complications, and associated topics, concluding with a highly instructive step-by-step video demonstrations.

This comprehensive and insightful book is indispensable to all rhinologists at any stage of their careers, but above all, it is a surgeon's book, by surgeons sharing a unique cumulative expertise.

Valerie J. Lund, CBE, MB, BS, FRCS, FRCSEd
Professor of Rhinology, University College London
Honorary Consultant ENT Surgeon
Royal National Throat Nose and Ear Hospital (Royal Free Trust)
Moorfields Eye Hospital
University College Hospital and Imperial College
London, UK

Preface

Frontal sinus surgery is one of the most exacting procedures undertaken by the Otolaryngologist. Surgery in proximity to the eye and brain requires fortitude, and surgery within the convoluted frontal outflow tract requires exquisite delicacy and restraint. Seasoned surgeons approach the frontal sinus with reverence, while learners consider it with trepidation. The editors present a systematic approach to frontal sinus surgery through simplified discussions of critical concepts. A thoughtful, personalized approach optimizes patient outcomes; we therefore discuss all aspects of frontal anatomy, pathology, and surgical approaches. The editors thank the authors of all chapters, each led by global experts on the subject matter. Chapters are richly illustrated with figures and surgical videos, replete with practical pearls and tips. It is the editors' goal to provide this compendium as an aid to the sincere surgeon aspiring to attain expertise in frontal sinus surgery.

Phoenix, AZ, USA — Devyani Lal
Stanford, CA, USA — Peter H. Hwang

Contents

Contributors

Nithin D. Adappa, MD Department of Otorhinolaryngology – Head and Neck Surgery, University of Pennsylvania, Perelman School of Medicine, Philadelphia, PA, USA

Fahad Al-Asousi, MB BCh, BAO, SB-ORL St. Paul's Sinus Centre, St. Paul's Hospital, Department of Otolaryngology – Head and Neck Surgery, Vancouver, BC, Canada

Jeremiah A. Alt, MD, PhD Division of Otolaryngology – Head and Neck Surgery, University of Utah School of Medicine, Salt Lake City, UT, USA

Samantha Anne, MD, MS Pediatric Otolaryngology, Head and Neck Institute, Cleveland Clinic, Cleveland, OH, USA

Rami James N. Aoun, MD, MPH Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Pete S. Batra, MD, FACS Department of Otorhinolaryngology – Head and Neck Surgery and Rush Sinus Program, Rush University Medical Center, Chicago, IL, USA

Vidur Bhalla, MD University of Kansas Medical Center, Department of Otolaryngology – Head and Neck Surgery, Kansas City, KS, USA

Benjamin S. Bleier, MD Massachusetts Eye and Ear Infirmary, Harvard Medical School, Department of Otolaryngology, Boston, MA, USA

Christopher D. Brook, MD Boston University Medical Center, Department of Otolaryngology, Boston, MA, USA

Mohamad Raafat Chaaban, MD, MSCR, MBA Department of Otolaryngology, University of Texas Medical Branch, Galveston, TX, USA

Alexander Chiu, MD University of Kansas Medical Center, Department of Otolaryngology – Head and Neck Surgery, Kansas City, KS, USA

Garret W. Choby, MD Division of Rhinology and Endoscopic Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, Stanford University School of Medicine, Stanford, CA, USA

Division of Rhinology and Endoscopic Skull Base Surgery, Department of Otorhinolaryngology – Head and Neck Surgery, Mayo Clinic, Rochester, MN, USA

Brian D'Anza, MD Division of Rhinology, Allergy, and Skull Base Surgery, Department of Otolaryngology, University Hospitals – Case Western Reserve University, Cleveland, OH, USA

Anali Dadgostar, MD, MPH, FRCSC St. Paul's Sinus Centre, St. Paul's Hospital, Department of Otolaryngology – Head and Neck Surgery, Vancouver, BC, Canada

John M. DelGaudio, MD Department of Otolaryngology – Head and Neck Surgery, Emory University School of Medicine, Atlanta, GA, USA

Rohit Divekar, MBBS PhD Division of Allergic Diseases, Mayo Clinic, Rochester, MN, USA

D. David Beahm, MD University of Kansas Medical Center, Department of Otolaryngology – Head and Neck Surgery, Kansas City, KS, USA

Jean Anderson Eloy, MD, FACS Department of Otolaryngology – Head and Neck Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Center for Skull Base and Pituitary Surgery, Neurological Institute of New Jersey, Rutgers New Jersey Medical School, Newark, NJ, USA

Department of Neurological Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Department of Ophthalmology and Visual Science, Rutgers New Jersey Medical School, Newark, NJ, USA

Marco Ferrari, MD Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

Richard J. Harvey, MD, PhD, FRACS Rhinology and Skull Base, Applied Medical Research Centre, UNSW, Sydney, NSW, Australia

Faculty of Medicine and Health Sciences, Macquarie University, Sydney, NSW, Australia

Joseph M. Hoxworth, MD Neuroradiology Division, Department of Radiology, Mayo Clinic, Phoenix, AZ, USA

Mayo Clinic College of Medicine and Sciences, Phoenix, AZ, USA

Peter H. Hwang, MD, FARS Department of Otolaryngology – Head and Neck Surgery, Stanford University School of Medicine, Stanford, CA, USA

Amin R. Javer, MD, FRCSC St. Paul's Sinus Centre, St. Paul's Hospital, Department of Otolaryngology – Head and Neck Surgery, Vancouver, BC, Canada

David W. Kennedy, MD Department of Otorhinolaryngology – Head and Neck Surgery, The University of Pennsylvania, Philadelphia, PA, USA

Suat Kilic, BA Department of Otolaryngology – Head and Neck Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Devyani Lal, MD, FARS Department of Otolaryngology – Head and Neck Surgery, Mayo Clinic College of Medicine and Science, Mayo Clinic, Phoenix, AZ, USA

Adrienne M. Laury, MD Otolaryngology, South Texas Veterans Health Care System, San Antonio, TX, USA

Jivianne T. Lee, MD Department of Head and Neck Surgery, University of California Los Angeles David Geffen School of Medicine, Los Angeles, CA, USA

Todd A. Loehrl, MD Department of Otolaryngology, Medical College of Wisconsin, Milwaukee, WI, USA

Division of Surgery, Zablocki VA Medical Center, Milwaukee, WI, USA

Conner J. Massey, MD University of Colorado School of Medicine, Department of Otolaryngology, Aurora, CO, USA

Jose Luis Mattos, MD, MPH Division of Rhinology and Sinus Surgery, Department of Otolaryngology – Head and Neck Surgery, Medical University of South Carolina, Charleston, SC, USA

Ben McArdle, MBBS, FRACS Department of Otolaryngology, Sunshine Coast University Hospital, Birtinya, Qld, Australia

Kevin C. McMains, MD Otolaryngology, South Texas Veterans Health Care System, San Antonio, TX, USA

Lester E. Mertz, MD Division of Rheumatology, Department of Medicine, Mayo Clinic, Scottsdale, AZ, USA

Jayakar V. Nayak, MD, PhD Division of Rhinology and Endoscopic Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, Stanford University School of Medicine, Stanford, CA, USA

Piero Nicolai, MD Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

Erin K. O'Brien, MD Department of Otorhinolaryngology, Mayo Clinic Rochester, Rochester, MN, USA

Richard R. Orlandi, MD Division of Otolaryngology – Head and Neck Surgery, University of Utah School of Medicine, Salt Lake City, UT, USA

James N. Palmer, MD Division of Rhinology, Department of Otorhinolaryngology – Head and Neck Surgery, Hospital of the University of Pennsylvania, Philadelphia, PA, USA

Peter Papagiannopoulos, MD Department of Otorhinolaryngology – Head and Neck Surgery and Rush Sinus Program, Rush University Medical Center, Chicago, IL, USA

Arjun K. Parasher, MD Division of Rhinology and Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, University of South Florida, Tampa, FL, USA

Department of Health Policy and Management, University of South Florida, Tampa, FL, USA

Chirag Rajan Patel, MD Department of Otolaryngology – Head and Neck Surgery, Loyola University Medical Center, Maywood, IL, USA

Naresh P. Patel Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Zara M. Patel, MD Department of Otolaryngology – Head and Neck Surgery, Stanford University School of Medicine, Stanford, CA, USA

David M. Poetker, MD, MA Division of Surgery, Zablocki VA Medical Center, Milwaukee, WI, USA

Department of Otolaryngology, Medical College of Wisconsin, Milwaukee, WI, USA

Alkis James Psaltis, MBBS(hons), PhD, FRACS Department of Otolaryngology Head and Neck Surgery, The University of Adelaide, Adelaide, SA, Australia

Vijay R. Ramakrishnan, MD University of Colorado School of Medicine, Department of Otolaryngology, Aurora, CO, USA

Matthew A. Rank, MD Division of Allergy, Asthma, and Clinical Immunology, Mayo Clinic, Scottsdale, AZ, USA

E. Ritter Sansoni, MD Division of Rhinology and Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, St Vincent's Hospital, Sydney, NSW, Australia

Luigi Fabrizio Rodella, MD Section of Anatomy and Physiopathology, University of Brescia, Brescia, Italy

Raymond Sacks, MBBCh, FCS (SA) ORL, FRACS Department of Otolaryngology, Macquarie University, Sydney, NSW, Australia

The University of Sydney, Sydney, NSW, Australia

Alberto Schreiber, MD Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

Theodore A. Schuman, MD Rhinology and Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Joseph S. Schwartz, MD, FRCSC Department of Otolaryngology – Head and Neck Surgery, McGill University, Montreal, QC, Canada

Brent A. Senior, MD Division of Rhinology, Allergy, and Endoscopic Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Dongho Shin, BHSc, MD University of Toronto, Faculty of Medicine, Toronto, ON, Canada

Kristine A. Smith, MD Division of Otolaryngology – Head and Neck Surgery, Department of Surgery, University of Calgary, Calgary, AB, USA

Zachary M. Soler, MD, MSc Division of Rhinology and Sinus Surgery, Department of Otolaryngology – Head and Neck Surgery, Medical University of South Carolina, Charleston, SC, USA

Jessica E. Southwood, MD Department of Otolaryngology, Medical College of Wisconsin, Milwaukee, WI, USA

James A. Stankiewicz, MD Department of Otolaryngology – Head and Neck Surgery, Loyola University Medical Center, Maywood, IL, USA

Janalee K. Stokken, MD Department of Otorhinolaryngology, Mayo Clinic, Rochester, MN, USA

Peter F. Svider, MD Department of Otolaryngology – Head and Neck Surgery, Wayne State University School of Medicine, Detroit, MI, USA

Bobby A. Tajudeen, MD Department of Otorhinolaryngology – Head and Neck Surgery and Rush Sinus Program, Rush University Medical Center, Chicago, IL, USA

Andrew Thamboo, MD, MHSc, FRCSC Department of Otolaryngology – Head and Neck Surgery, Stanford University School of Medicine, Stanford, CA, USA

Aykut A. Unsal, DO Department of Otolaryngology – Head and Neck Surgery, Medical College of Georgia – Augusta University, Augusta, GA, USA

Rickul Varshney, MD, MSc, FRCSC Department of Otolaryngology, McGill University, Montreal, QC, Canada

Ian Witterick, MD, MSc, FRCSC Department of Otolaryngology – Head and Neck Surgery, University of Toronto, Sinai Health System, Toronto, ON, Canada

Bradford A. Woodworth, MD, FACS Department of Otolaryngology, University of Alabama at Birmingham, Gregory Fleming James Cystic Fibrosis Research Center, Birmingham, AL, USA

Alan D. Workman, BA, MD/MTR Department of Otolaryngology, Massachusetts Eye and Ear Infirmary, Boston, MA, USA

Peter-John Wormald, MD, FRACS Department of Otolaryngology Head and Neck Surgery, The University of Adelaide, Adelaide, SA, Australia

Carol H. Yan, MD Department of Otolaryngology – Head and Neck Surgery, Stanford University, Stanford, CA, USA

Shiayin F. Yang, MD Department of Otolaryngology – Head and Neck Surgery, Loyola University Medical Center, Maywood, IL, USA

1 Evolution and Challenges in Frontal Sinus Surgery

Carol H. Yan and David W. Kennedy

Introduction

The frontal sinuses and their complex anatomy have long challenged surgeons and triggered controversies in their surgical management. The relatively narrow frontal sinus drainage pathway, critical adjacent structures, and high long-term failure rate, combined with relatively difficult angled intranasal access, have created a broad swathe of surgical approaches with initial enthusiasm and subsequent abandonment. More recent attempts at frontal sinus surgery originated in the early eighteenth century with the initial reported cases wrought with morbidity and mortality. Subsequently, a spectrum of frontal sinus surgical techniques evolved. These include external approaches such as the osteoplastic flap, obliteration, cranialization, trephination, and external frontoethmoidectomy. More recently, endoscopic visualization created renewed potential for endonasal techniques, and combined endonasal and external approaches as well as purely endoscopic endonasal approaches have been popularized. The trend of frontal sinus surgery has transitioned from ablative intentions with closure of the frontal ostium, to restorative ones with enlargement of the frontal outflow tract [1]. In this section, we briefly highlight the advances in techniques and resources that have allowed us to evolve frontal sinus surgery. The overarching goals of surgery include the eradication of disease, the resolution of symptoms, and the restoration of a nasofrontal outflow tract.

Historic Procedures

Early management of frontal sinus surgery from the early eighteenth century to the late twentieth century was predominantly external and focused on obliteration of disease. Some of these procedures still have indications today and will be discussed later in the chapter.

Trephination

The earliest frontal obliteration with a trephine was performed in 1750 by Runge as recorded by Donald [2]. The first published report of frontal sinus surgery with drainage of a mucocele has been credited to Seolberg Wells who conducted a trephine with tube placement [3]. Soon after in 1884, Alexander Ogston described a trephination procedure through the frontal sinus with curettage of mucosa and communication with the ethmoidal sinus for treatment of sinus infection. Luc described a very similar procedure, and in 1896, the Ogston-Luc technique was developed [1, 4]. However, the technique of trephination with frontal mucosal stripping did not gain

C. H. Yan
Department of Otolaryngology – Head and Neck Surgery, Stanford University, Stanford, CA, USA

D. W. Kennedy (✉)
Department of Otorhinolaryngology – Head and Neck Surgery, The University of Pennsylvania, Philadelphia, PA, USA

D. Lal, P. H. Hwang (eds.), *Frontal Sinus Surgery*, https://doi.org/10.1007/978-3-319-97022-6_1

popularity due to a high rate of nasofrontal outflow tract stenosis [5].

Radical Ablation

Frontal sinus obliteration was first introduced as an alternative to the Ogston-Luc procedure. In 1898, Riedel described obliteration of the frontal sinus with complete removal of the anterior table and floor of frontal sinus, stripping of all mucosa, and redraping of forehead skin [4]. This procedure, now known as frontal sinus collapse or the Riedel procedure, was associated with significant cosmetic deformity but improved disease control compared to the Ogston-Luc procedure. In those times, frontal sinusotomies were performed with chisels. Killian modified this technique by preserving a rim of mucosa and bone across the supraorbital ridge in an effort to decrease cosmetic deformity (Fig. 1.1). This technique too, was abandoned due to its high morbidity, post-operative infections, and failure rates [6]. However, frontal sinus collapse still remains a viable option today for some cases of osteomyelitis. In a small frontal sinus with narrow anterior-posterior (A-P) diameter and with careful drill feathering of the sinus margins, the cosmetic deformity can be minimal. In other cases, a delayed reconstruction can be performed.

External Frontoethmoidectomy

Following disenchantment with disfiguring obliterative procedures, the surgical community explored the option of enlarging the nasofrontal outflow tract through external access to the frontal sinus. Knapp in 1908 entered the frontal sinus via a frontoethmoidectomy through the medial orbital wall. He continued to remove all mucosa of the frontal sinus and also enlarged the frontal outflow tract after addressing the disease. In 1914, Lothrop made the enlargement of the frontal outflow tract a priority and accomplished this via a combined external and intranasal approach to remove the ethmoidal cells, bilateral frontal sinus floors, the superior nasal septum and intersinus septum [7]. Resection of the frontal floor and medial orbital wall caused collapse of orbital soft tissue into the ethmoidal area and subsequent stenosis of the frontal drainage pathway [8]. The

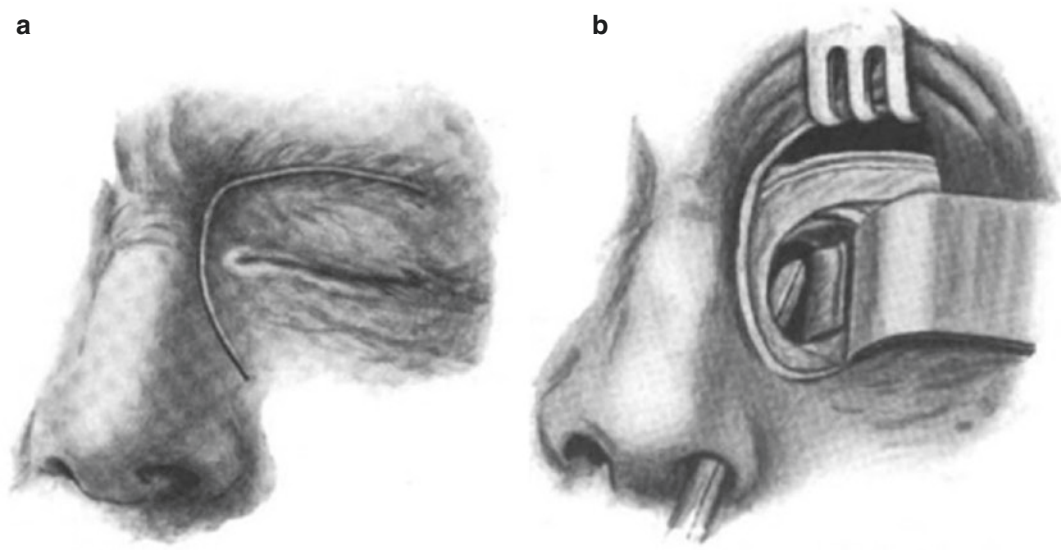

Fig. 1.1 The Killian technique for radical frontal sinus obliteration (**a**) as depicted in "the catarrhal and suppurative diseases of the accessory sinuses of the nose" by Ross Hall Skillern, 1913 [6]. The anterior frontal sinus table bone was removed with the exception of a 1 cm bar of supraorbital rim to decrease deformity, and a mucosal nasal flap was rotated laterally to cover the frontal recess (**b**). This technique was complicated by high restenosis rates, supraorbital rim necrosis, and mucocele formation

removal of bone without adequate visualization made the procedure dangerous and technically difficult. Its eventual revival and popularization as an intranasal endoscopic operation by Draf was aided by multiple technological advances [9].

Lynch and Howarth in the United States described other modifications of external frontoethmoidectomy resulting in improved cosmetic outcome in 1921. This operation was conducted through a medial periorbital incision and proceeded to remove ethmoidal cells as well as a portion of the frontal sinus floor along with a stent placement to ensure adequate drainage. This frontoethmoidectomy technique became known as the Lynch procedure, and its modifications have included the addition of a septal flap (Sewall-Boyden) and use of Silastic stents (Neel-Lake) [10, 11]. These additions improved early patency rates up to 85%, but poor long-term results led to its eventual abandonment [10].

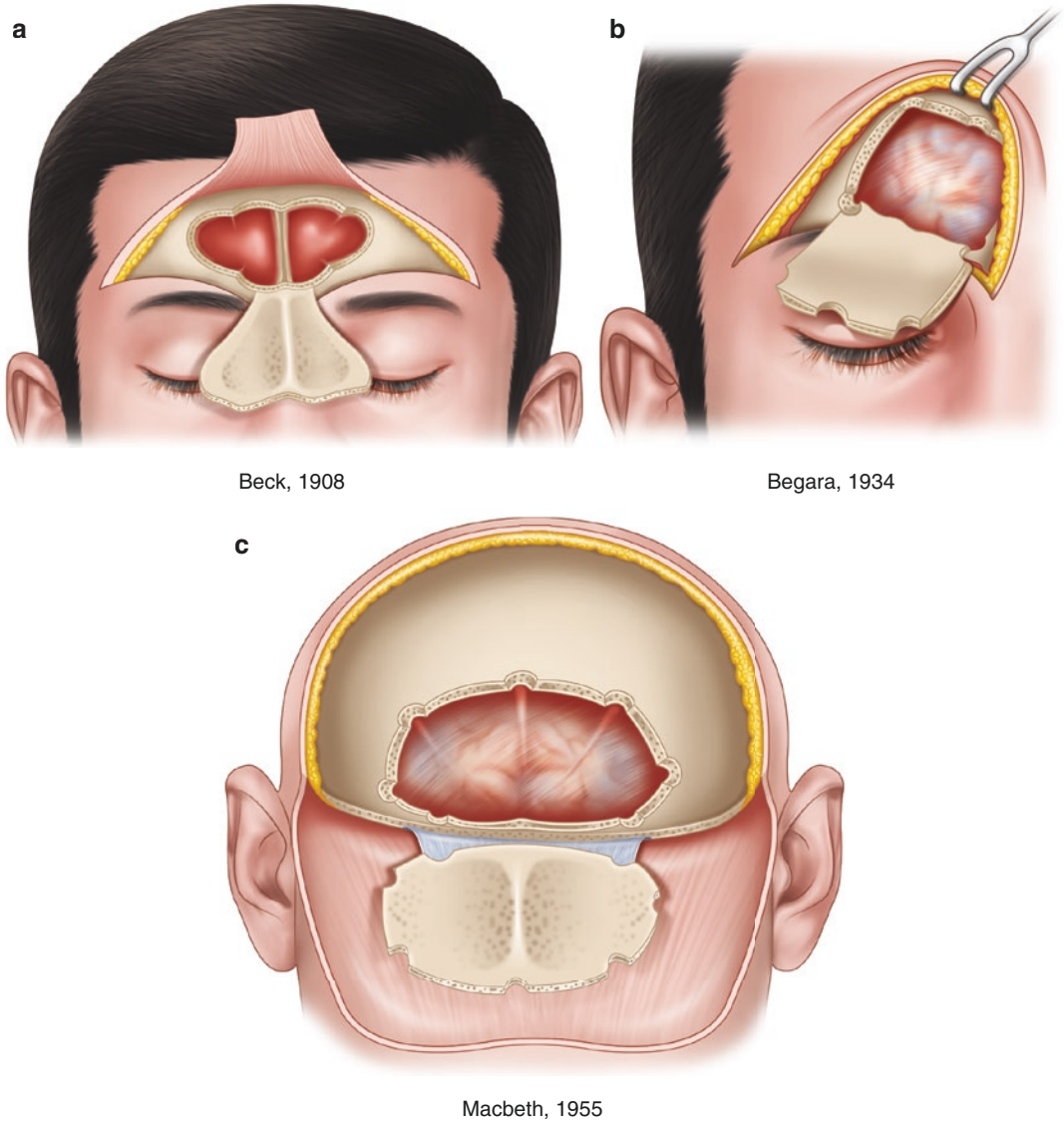

Fig. 1.2 Osteoplastic flap techniques as described in J. Dawes in *The Management of Frontal Sinusitis and its Complications*, J. Laryngology and Otology, 1961 [13]. Beck described in 1908 the use of radiographic guidance in his osteoplastic flaps with an incision along the upper margins of the eyebrows (**a**). In 1934, Bergara depicted his flap through the eyebrow incision (**b**) versus Macbeth, who adopted the bicoronal incision for a larger osteoplastic flap (**c**)

Osteoplastic Flaps

Osteoplastic flaps were separately described by Schonborn in 1894 and Brieger in 1895 [12]. Beck in 1908 used radiographic guidance to plan the incision of the flap (Fig. 1.2a). However, technical challenges and concerns of osteomyelitis prevented the flap from gaining popularity until Bergara introduced the eyebrow incision in 1934 (Fig. 1.2b) followed by Macbeth's adoption of the bicoronal incision for a large osteoplastic flap (Fig. 1.2c) [13]. In 1958, Goodale and Montgomery published their series of patients treated with an osteoplastic flap with fat obliteration and reported good success rates. By 1960, the osteoplastic flap, typically with but sometimes without obliteration, became the standard of care. In the 1960s, Becker developed the concept of using a template cut out of the patient's radiographic plate to outline the frontal sinus, allowing for a safer entry into the frontal sinus. The flap avoided significant facial deformity by replacing the bone plate and newer obliteration techniques. However, long-term follow-up demonstrated an increasing failure rate, and even using modern MRI, evaluating for recurrent disease has remained a challenge.

Early Adoption of Endoscopic Techniques

The use of external ablative procedures was limited by recurrent infections and disease due to the closure of the nasofrontal outflow tract, significant scarring and poor cosmetic outcomes. Even with the popular Lynch procedure, over 30% of patients required revision surgery. With these complications, the surgical community became more conservative in use of these approaches. Intranasal approaches were introduced in the beginning of the twentieth century but experienced high morbidity and mortality as the lack of visualization was troublesome.

Early endoscopic techniques were developed by Messerklinger, Wigand, and Draf. The initial work by Messerklinger incorporated the diagnostic use of the endoscope in analyzing mucociliary patterns of the paranasal sinuses. Mucosal apposition in the region of the frontal recess was noted to be the precursor of frontal sinusitis [14]. Wigand described the anatomic landmarks important for identifying the frontal ostium including the anterior ethmoidal artery, middle turbinate, and orbital wall.

In 1985, Kennedy made modifications to the Messerklinger technique and coined the term "functional endoscopic sinus surgery" [15]. Zinreich introduced CT imaging visualization of endoscopic sinus surgery to improve anatomic detail and decrease the very high radiation dose associated with polytomography [16]. Early functional endoscopic surgery also included treatment of mucoceles through marsupialization; approaches that were confronted with significant criticism [17]. Unlike the Lynch procedure, the endoscopic technique focuses on the preservation of as much mucosa as possible within the bony framework of the nasofrontal recess area. Kennedy and colleagues further described the valuable use of endoscopes to visualize the internal lining of the frontal sinus and maintain patency during post-operative surveillance.

Stammberger further popularized the Messerklinger approach, expanded indications for endoscopic disease management and made significant additional contributions to the technique and to the understanding of the regional anatomy [18]. Other early descriptions of endoscopic frontal sinus surgery for chronic sinusitis were described by Schaefer and Close who adopted the combined Messerklinger and Wigand technique along with placement of a Silastic tube if the ostioplasty was less than 6 mm [19]. The authors proposed that patients with frontal sinus ostia less than 4 mm or obstructive hypertrophic mucosa would not be good candidates for endoscopic surgery.

An improved understanding of frontal sinus anatomy facilitated the rapid adoption of endoscopic sinus surgery. Van Alyea's prior work was critical in describing supraorbital ethmoid, agger nasi, intersinus septal cells, and frontal recess cells as potential impediments to drainage of the frontal sinus [20]. The detailed anatomy and technique of removing agger nasi cells in frontal obstruction was further elaborated by Kuhn and colleagues [21].

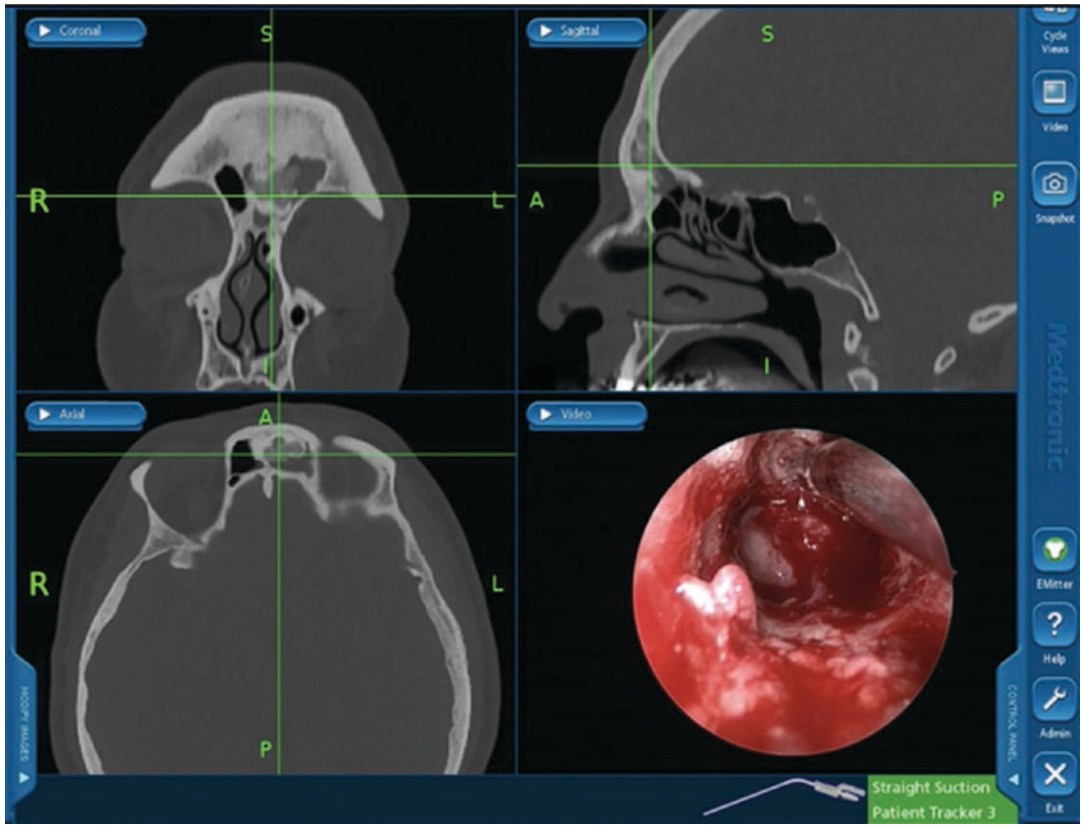

Fig. 1.3 An "outside-in" Draf III procedure being performed for a left-sided frontal osteoma with the help of CT image navigation using the Medtronic fusion navigation system (Minneapolis, MN, USA)

Advent of Modern Endoscopic Frontal Sinus Surgery

Variations of endoscopic frontal sinus surgery were described by Wolfgang Draf in the 1990s as type I, IIa and IIb, and III [9, 22]. Type I involves clearance of the frontal recess with anterior ethmoidectomy but no manipulation of the frontal ostium, type IIa and b involve an extended dissection of the frontal outflow tract with unilateral resection of the frontal sinus floor, while type III involves median drainage and bilateral resection of the frontal floor with removal of the intersinus septum. The Draf III technique, also known as the endoscopic modified Lothrop procedure, was detailed in 1994 in tribute to the original drill out procedure described by Lothrop in 1899 [23]. Close and colleagues warned fellow surgeons that circumferential stripping of frontal recess leads to stenosis and stressed the importance of radiographic image guidance [23]. Interestingly, both Lothrop and Draf described the procedure to be especially challenging and cautioned against using it as a primary procedure. The availability of high-speed curved drills and image-guided surgery has allowed the Draf III to gain popularity (Fig. 1.3). Promising long-term follow-up data have encouraged expansion of indications for this procedure, most commonly used for chronic frontal sinusitis, for use in surgery for mucoceles and tumors [24]. A meta-analysis reported partial or complete frontal sinus patency to be 95.9% with an overall failure rate (defined as requiring further surgery) to be 13.9% [25]. Subsequently, the re-stenosis rate had been further reduced by the introduction of mucosal grafts or regional mucosal flaps to cover the exposed bone created when the drainage pathway is extended anteriorly and laterally by the drill out.

An important turning point in frontal sinus surgery was the advent of mucosal-sparing techniques. Hilding had previously demonstrated in animals that the removal of mucosa of the maxillary sinus led to accumulation of secretions distally and increased chances of infections [26]. Walsh's Triologic thesis in 1943 suggested that removing diseased frontal sinus mucosa but preserving the frontal outflow tract led to improved outcomes [27]. Multiple studies using animal models demonstrated that a patent, well-mucosalized frontal outflow tract was critical to proper frontal sinus function [28, 47]. Furthermore, the presence of disease in the frontal recess does not mandate revision surgery if the patient is asymptomatic [26, 29]. In a series of 440 subjects who underwent endoscopic sinus surgeries, most of the patients who were noted to have persistent mucosal disease remained asymptomatic [30].

Improvements and Tools in Endoscopic Frontal Sinus Surgery

Improvements in optical aids, instrumentation, and knowledge of pathophysiology have been the critical developments in establishing endoscopic sinus surgery as standard of care for frontal sinus disorders [31].

Frontal Sinus Stents

The use of frontal stents has waxed and waned in the history of frontal sinus surgery. Stents, consisting of a firm rubber tube, were used with Lynch's external frontoethmoidectomy, which employed placement of a firm rubber tube in the nasofrontal tract to maintain patency. However, the stenosis rate remained high at 30%. Neel and colleagues described a modified Lynch (Neel-Lake) operation in 1976 which used silicone (Silastic) rubber sheets to stent the nasofrontal passage with more promising long-term outcomes [11, 32]. In animal studies, stents created from Silastic sheets resulted in improved mucosal regeneration and decreased inflammation [32]. Schaefer and Close used Silastic tubing to stent small endoscopic frontal sinusotomies less than 6 mm [19]. More recently, steroid-eluting bioabsorbable implants placed in the frontal ostioplasty have been shown to be advantageous in several clinical trials. Murr and colleagues performed the original safety and efficacy study for an ethmoid mometasone-eluting implant. In a prospective double-blind, randomized study, they demonstrated decreased inflammation, adhesion, and polyp formation [33]. More recently, a smaller implant placed into the frontal sinus has also been demonstrated to reduce the need for postoperative frontal ostial debridement and to reduce the incidence of stenosis (Propel, Intersect ENT, Menlo Park, CA, USA) (Fig. 1.4c). An office-based corticosteroid-eluting implant (mometasone-furoate impregnated implant, SINUVA, Intersect ENT, Menlo Park, CA, USA) has recently been approved for treatment of recurrent nasal polyps in adult patients who have undergone prior ethmoidectomy.

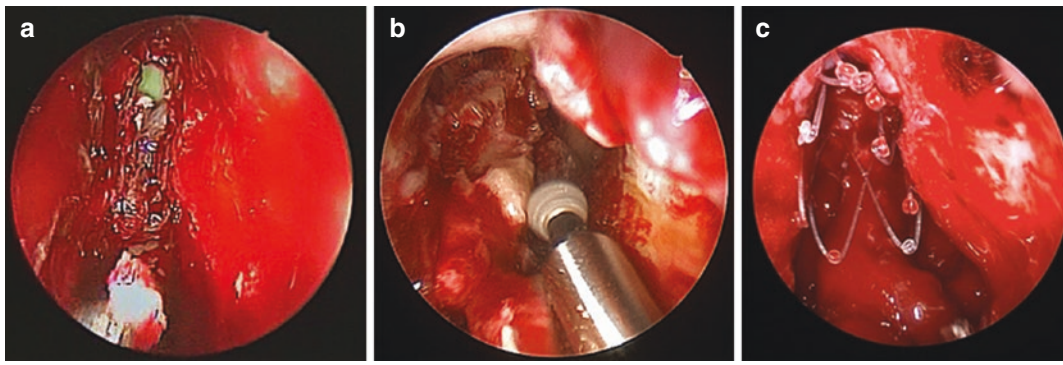

Fig. 1.4 A mucocele of the frontal sinus (**a**) in the process of being opened through a Draf III procedure using a 60,000 rpm high-speed drill, the Medtronic Mini-Midas (Minneapolis, MN, USA) (**b**). A mometasone-eluting stent is placed after completion of the Draf III (Propel, Intersect ENT, Menlo Park, CA, USA) (**c**)

Frontal Sinus Balloon Catheters

Catheter dilation of the paranasal sinuses was inspired by successes in cardiac and vascular procedures. Brown and Bolger performed the first paranasal sinus balloon dilations in 10 patients in 2006 and described a satisfying ease of cannulation while preserving mucosa [34]. Early on, cannulation was performed under fluoroscopic guidance prior to balloon inflation. While studies indicated symptomatic improvement in patients following fluoroscopy-directed balloon dilations, there were concerns regarding patient and physician radiation exposure [35]. Subsequently, light-guided catheters were introduced to utilize transillumination as an alternative method of catheter placement verification. More recently, the addition of image guidance has added additional precision to the catheterization procedure. Balloon catheter dilation can safely be used in the office setting by experienced surgeons for isolated frontal sinus ostium stenosis [36].

There are three current manufactures of frontal sinus balloon devices that have US Food and Drug Administration approval: Acclarent (Irvine, CA, USA), Entellus (Plymouth, MN, USA), and Medtronic (Minneapolis, MN, USA) [37]. Entellus produces XprESS, a device with a malleable tip (Fig. 1.5c), and Path Assist, which acts as a frontal seeker. Working with Fiagon (Berlin, Germany), they have also introduced a computer-assisted image guidance wire, providing accurate tracking of the catheter tip. SpinPlus by Acclarent allows surgeons to navigate multiple frontal sinus ostia by spinning and changing the frontal guidewire trajectory. NuVent, manufactured by Medtronic (Minneapolis, MN, USA), offers surgical navigation with the Medtronic Fusion surgical navigation system (Minneapolis, MN, USA).

Powered Instruments

Powered instrumentation, including microdebriders and drills, have greatly improved the ability to perform mucosa-sparing techniques, particularly in extended frontal dissections. In 1995, Gross and colleagues demonstrated the use of an endonasal soft tissue shaver to perform the Lothrop procedure endonasally without complications [8]. Curved shaver blades and burrs allow for improved visualization and access to the frontal ostia. Microdebriders are available in different sizes and angulations with rotating tips, while various drills can be attached to the microdebrider platform. High-speed drills (60,000 rpm and higher) allow for very fast removal of frontal recess bone but are only available as straight drills (Fig. 1.4b). Angled drill systems running at 12,000 rpm (Diego Elite, Olympus America) and 15,000 rpm (Medtronic Straightshot, Medtronic, Minneapolis, MN, USA) that have built-in suction irrigation systems are available widely. More recently developed, the Medtronic Straightshot M5 Microdebrider functions at 30,000 rpm, allowing for rapid bone removal. Greater mucosal sparing is facilitated through a variety of angled diamond and cutting burrs.

Modern Indications for External Frontal Sinus Surgery

Although endoscopic sinus surgery has become the default approach, there still certain indications that require external frontal sinus surgery. A review of 683 patients with chronic sinusitis showed that external procedures were performed in 5.3% of the cases with the majority being either osteoplastic flaps for neo-osteogenesis of the frontal recess or adjunct trephination [38]. The combination of trephination and endoscopic techniques, known as the "above and below" approach, can be helpful in cases of difficult to reach, laterally based inflammatory and non-inflammatory pathology [39, 40]. Mini-trephinations can also guide us in finding difficult type III or IV frontal cells [41]. The ideal location for trephination has been described as 10 mm from a line passing through the crista galli [42].

There are almost no indications for an external frontoethmoidectomy in today's era. The risk of fibrosis and closure of the frontal ostium with this procedure can result in high rates of recurrent infection and mucocele formation. The Neel-Lake modification of the original Lynch procedure utilizes techniques of mucosa preservation and frontal stenting [11, 32].

In contrast, there is still a role for the osteoplastic flap procedure, such as contemporary indications of tumors, recurring failure from endoscopic approaches for chronic sinusitis,

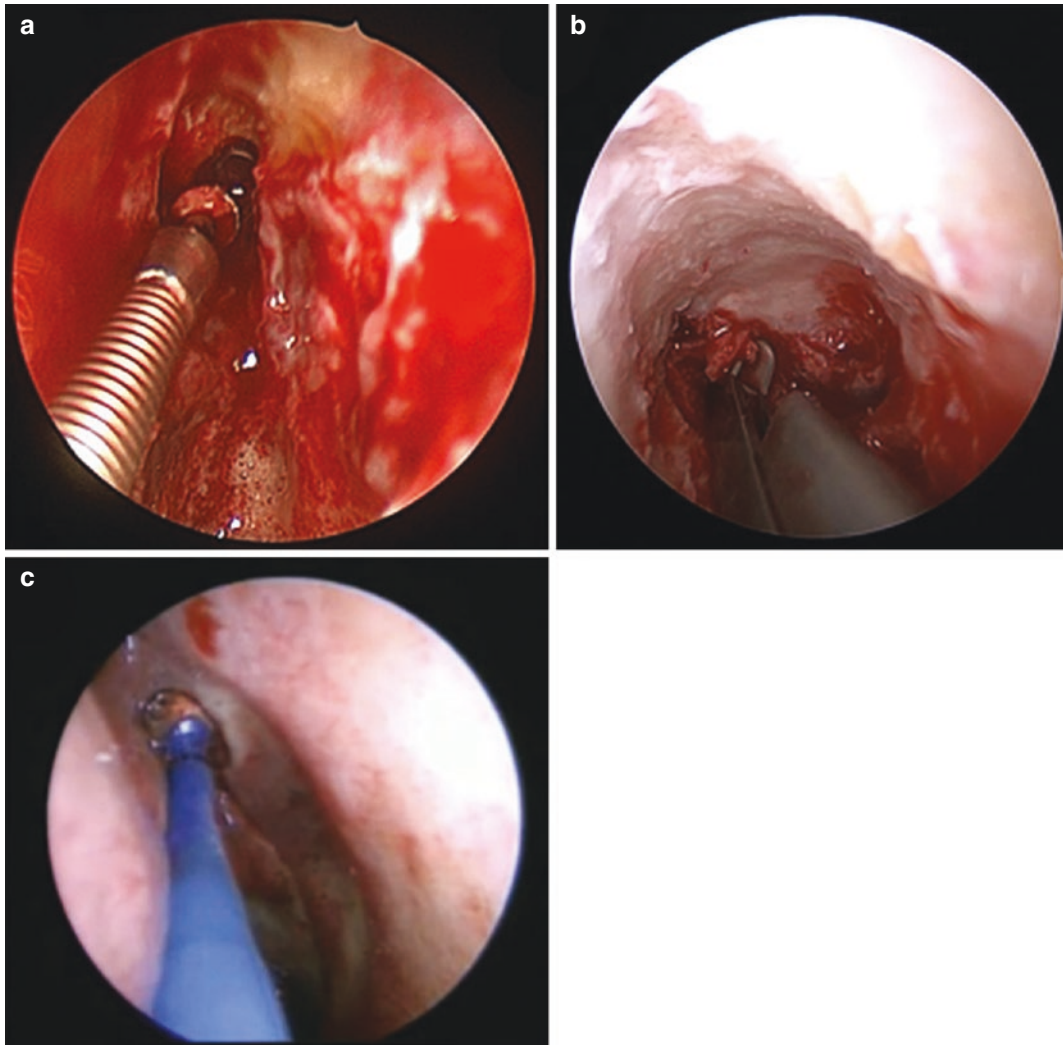

Fig. 1.5 Frontal sinus ostia have been more easily widened with mucosal-sparing techniques due to advancements in frontal sinus instruments including the frontal sinus angled (Hosemann) punch (**a**) and the forward-cutting (cobra) punch (**b**). Frontal sinus balloon catheter dilation (**c**) provides another way of cannulating the frontal ostium while preserving mucosa as shown here with one of the FDA-approved devices XprESS from Entellus (Plymouth, MN, USA)

lesions inaccessible endoscopically, and in some cases of frontal sinus trauma. Osteoplastic flaps today far more likely to be performed in combination with a Draf 3 procedure and without obliteration. This enhances both endoscopic visualization and post surgical radiographic surveillance, although the approach lengthens surgical time. Obliteration techniques are associated with long-term failures. Hardy and Montgomery reported a complication rate of 18% with significant morbidity. Recent studies with longer term follow-up clearly suggest that the failure rate continues to increase significantly over time [43].

New Techniques and Thoughts in Frontal Sinus Surgery

A recurrent challenge for frontal sinus surgery has been narrow frontal ostia and post-operative re-stenosis. While creation of osteoplastic flaps with obliteration is a possible solution, the long-term failure rate and morbidity associated with the procedure prompted the development of advanced endoscopic extended frontal sinusotomy techniques. Woodworth introduced free mucosal grafts to cover the exposed bony surface of the nasofron-

tal beak following Draf III surgery with promising long-term results, and this has now become standard in our practice [44]. Free septal mucosa grafts are harvested from the anterosuperior septectomy or the posterior third of the inferior turbinate [45]. In Woodworth and colleagues' study, 97% of patients maintained an ostioplasty that was at least 50% of the intraoperative diameter at three years postoperatively. If the septal mucosa is very polypoid, grafts may also be harvested from the nasal floor with minimal or no post-operative morbidity. The graft may be held in place with a mometasone-eluting or a Silastic stent. Mucosal flaps created from the lateral nasal wall can also be rotated to cover the bone exposed during the surgery and have demonstrated significant utility in reducing postoperative crusting.

A long-term study of the Draf III procedure suggested that allergy might be associated with increased re-stenosis rates post-operatively causing some to advocate for primary Draf III procedures in certain patients, particularly those with aspirin-exacerbated respiratory disease (AERD) [24]. On the other hand, Hwang and colleagues have advocated performing only Draf I or total ethmoidectomies in select patients with chronic frontal sinusitis without polyposis to minimize iatrogenic insults to the frontal recess [46].

Summary

Surgical management of frontal sinus disease has shifted dramatically over the last century from external extirpative techniques towards endoscopic surgery that aspires to restore physiological drainage of the frontal outflow tract through mucosal preservation and wide ostioplasties. History cautions us against adopting a one-size fits all approach. Longer term follow up is mandated to evaluate the results of newer techniques. The Draf III procedure does appear to be a very viable approach in long-term management recalcitrant inflammatory disease. The field of frontal sinus surgery continues to evolve rapidly. An adequate A-P diameter was considered paramount for both performing drillout procedures and maintaining long-term patency. However, novel solutions such as the "outside-in" drill out technique now overcome the problems posed by narrow AP width in small frontal sinuses that could not be tackled with the traditional "inside-out" drill out procedure. External approaches, particularly the osteoplastic flap and frontal sinus trephine, still have critical select cases. However, external techniques are now are more likely to be combined with a functional endoscopic approach, thus avoiding extensive mucosal stripping and fat obliteration. New research with longer-term and meticulous follow-up to thoughtfully assess frontal sinus surgery outcomes will guide us in refining and developing indications, techniques and technology.

References

1. Ramadan HH. History of frontal sinus surgery. Arch Otolaryngol Head Neck Surg. 2000;126(1):98–9.
2. Donald P. Surgical management of frontal sinus infections. In: The Sinuses. New York: Raven Press; 1995. p. 201–32.
3. Wells S. Abscess of the frontal sinus. Lancet. 1870;1:694–5.
4. McLaughlin RB. History of surgical approaches to the frontal sinus. Otolaryngol Clin N Am. 2001;34(1):49–58.
5. Coakley C. Frontal sinusitis: diagnosis, treatment, and results. Trans Am Laryngol Rhinol Otol Soc. 1905;11:101.
6. Skillern RH. The catarrhal and suppurative diseases of the accessory sinuses of the nose, vol. 1. Philadelphia and London: J. B. Lippincott Co.; 1913. p. 389.
7. Lothrop HA. XIV. Frontal sinus suppuration: the establishment of permanent nasal drainage; the closure of external fistulae; epidermization of sinus. Ann Surg. 1914;59(6):937–57.
8. Gross WE, Gross CW, Becker D, Moore D, Phillips D. Modified transnasal endoscopic Lothrop procedure as an alternative to frontal sinus obliteration. Otolaryngol Head Neck Surg. 1995;113(4):427–34.
9. Draf W. Endonasal micro-endoscopic frontal sinus surgery: the fulda concept. Oper Tech Otolaryngol Head Neck Surg. 1991;2(4):234–40.
10. Murr AH, Dedo HH. Frontoethmoidectomy with Sewall-Boyden reconstruction: indications, technique, and philosophy. Otolaryngol Clin N Am. 2001;34(1):153–65.
11. Neel HB, McDonald TJ, Facer GW. Modified Lynch procedure for chronic frontal sinus diseases: rationale, technique, and long-term results. Laryngoscope. 1987;97(11):1274–9.
12. Friedman WH. External approaches to the frontal sinuses. In: Diseases of the sinuses: diagnosis and management. 1st ed. PMPH–USA. p. 391–403.
13. Dawes JD. The management of frontal sinusitis and its complications. J Laryngol Otol. 1961;75:297–344.

14. Messerklinger W. On the drainage of the normal frontal sinus of man. Acta Otolaryngol. 1967;63(2):176–81.
15. Kennedy DW, Zinreich SJ, Rosenbaum AE, Johns ME. Functional endoscopic sinus surgery. Theory and diagnostic evaluation. Arch Otolaryngol. 1985;111(9):576–82.
16. Zinreich SJ, Kennedy DW, Rosenbaum AE, Gayler BW, Kumar AJ, Stammberger H. Paranasal sinuses: CT imaging requirements for endoscopic surgery. Radiology. 1987;163(3):769–75.
17. Kennedy DW, Josephson JS, Zinreich SJ, Mattox DE, Goldsmith MM. Endoscopic sinus surgery for mucoceles: a viable alternative. Laryngoscope. 1989;99(9):885–95.
18. Stammberger H. Nasal and paranasal sinus endoscopy. A diagnostic and surgical approach to recurrent sinusitis. Endoscopy. 1986;18(6):213–8.
19. Schaefer SD, Close LG. Endoscopic management of frontal sinus disease. Laryngoscope. 1990;100(2 Pt 1):155–60.
20. Alyea OEV. Frontal cells: an anatomic study of these cells with consideration of their clinical significance. Arch Otolaryngol. 1941;34(1):11–23.
21. Kuhn FA, Bolger WE, Tisdal RG. The agger nasi cell in frontal recess obstruction: an anatomic, radiologic and clinical correlation. Oper Tech Otolaryngol Head Neck Surg. 1991;2(4):226–31.
22. Draf W. Endonasal frontal sinus drainage type I–III according to Draf. In: Kountakis SE, Senior BA, Draf W, editors. The frontal sinus [Internet]. Berlin, Heidelberg: Springer; 2016. p. 337–55. https://doi.org/10.1007/978-3-662-48523-1_25.
23. Close LG, Lee NK, Leach JL, Manning SC. Endoscopic resection of the intranasal frontal sinus floor. Ann Otol Rhinol Laryngol. 1994;103(12):952–8.
24. Georgalas C, Hansen F, Videler WJM, Fokkens WJ. Long terms results of Draf type III (modified endoscopic Lothrop) frontal sinus drainage procedure in 122 patients: a single centre experience. Rhinology. 2011;49(2):195–201.
25. Anderson P, Sindwani R. Safety and efficacy of the endoscopic modified Lothrop procedure: a systematic review and meta-analysis. Laryngoscope. 2009;119(9):1828–33.
26. Jacobs JB. 100 years of frontal sinus surgery. Laryngoscope. 1997;107(11 Pt 2):1–36.
27. Walsh TE. Experimental surgery of the frontal sinus The role of the ostium and nasofrontal duct in postoperative healing. Laryngoscope. 1943;53(2):75–92.
28. Schenck NL. Frontal sinus disease: III. Experimental and clinical factors in failure of the frontal osteoplastic operation. Laryngoscope. 1975;85(1):76–92.
29. Friedman WH, Katsantonis GP. Intranasal and transantral ethmoidectomy: a 20-year experience. Laryngoscope. 1990;100(4):343–8.
30. Wigand ME, Hosemann WG. Endoscopic surgery for frontal sinusitis and its complications. Am J Rhinol. 1991;5(3):85–9.
31. Weber R, Draf W, Kratzsch B, Hosemann W, Schaefer SD. Modern concepts of frontal sinus surgery. Laryngoscope. 2001;111(1):137–46.
32. Neel HB, Whicker JH, Lake CF. Thin rubber sheeting in frontal sinus surgery: animal and clinical studies. Laryngoscope. 1976;86(4):524–36.
33. Murr AH, Smith TL, Hwang PH, Bhattacharyya N, Lanier BJ, Stambaugh JW, et al. Safety and efficacy of a novel bioabsorbable, steroid-eluting sinus stent. Int Forum Allergy Rhinol. 2011;1(1):23–32.
34. Brown CL, Bolger WE. Safety and feasibility of balloon catheter dilation of paranasal sinus ostia: a preliminary investigation. Ann Otol Rhinol Laryngol. 2006;115(4):293–9. discussion 300-301.
35. Bolger WE, Brown CL, Church CA, Goldberg AN, Karanfilov B, Kuhn FA, et al. Safety and outcomes of balloon catheter sinusotomy: a multicenter 24-week analysis in 115 patients. Otolaryngol Head Neck Surg. 2007;137(1):10–20.
36. Luong A, Batra PS, Fakhri S, Citardi MJ. Balloon catheter dilatation for frontal sinus ostium stenosis in the office setting. Am J Rhinol. 2008;22(6):621–4.
37. Sillers MJ, Lay KF. Balloon catheter dilation of the frontal sinus ostium. Otolaryngol Clin N Am. 2016;49(4):965–74.
38. Hahn S, Palmer JN, Purkey MT, Kennedy DW, Chiu AG. Indications for external frontal sinus procedures for inflammatory sinus disease. Am J Rhinol Allergy. 2009;23(3):342–7.
39. Batra PS, Citardi MJ, Lanza DC. Combined endoscopic trephination and endoscopic frontal sinusotomy for management of complex frontal sinus pathology. Am J Rhinol. 2005;19(5):435–41.
40. Patel AB, Cain RB, Lal D. Contemporary applications of frontal sinus trephination: A systematic review of the literature. Laryngoscope. 2015;125(9):2046–53.
41. Seiberling K, Jardeleza C, Wormald P-J. Minitrephination of the frontal sinus: indications and uses in today's era of sinus surgery. Am J Rhinol Allergy. 2009;23(2):229–31.
42. Piltcher OB, Antunes M, Monteiro F, Schweiger C, Schatkin B. Is there a reason for performing frontal sinus trephination at 1 cm from midline? A tomographic study. Braz J Otorhinolaryngol. 2006;72(4):505–7.
43. Hardy JM, Montgomery WW. Osteoplastic frontal sinusotomy: an analysis of 250 operations. Ann Otol Rhinol Laryngol. 1976;85(4 Pt 1):523–32.
44. Illing EA, Cho DY, Riley KO, Woodworth BA. Draf III mucosal graft technique: long-term results. Int Forum Allergy Rhinol. 2016;6(5):514–7.
45. Conger BT, Riley K, Woodworth BA. The Draf III mucosal grafting technique: a prospective study. Otolaryngol Head Neck Surg. 2012;146(4):664–8.
46. Abuzeid WM, Mace JC, Costa ML, Rudmik L, Soler ZM, Kim GS, et al. Outcomes of chronic frontal sinusitis treated with ethmoidectomy: a prospective study. Int Forum Allergy Rhinol. 2016;6(6):597–604.
47. Hilding A. Experimental surgery of the nose and sinuses: II. Gross results following the removal of the intersinus septum and of strips of mucous membrane from the frontal sinus of the dog. Arch Otolaryngol. 1933;17(3):321–27.

Anatomy of the Frontal Sinus and Recess

2

Alberto Schreiber, Marco Ferrari,
Luigi Fabrizio Rodella, and Piero Nicolai

Introduction

The anatomy of the frontal sinus and frontal recess has garnered considerable interest due to its complexity and exceeding interindividual variability. Since most surgical procedures addressing the frontal sinus are nowadays performed via an endoscopic approach, the surgical anatomy of the frontal recess and surrounding structures should be analyzed in an endoscopic-oriented perspective. On the other hand, anatomy can be difficult to understand in a bidimensional endoscopic view through a narrow corridor without the ability to perceive depth and surrounding structures. The purpose of this chapter is to provide the reader with a multi-perspective view of the frontal recess anatomy so to precisely explain the complex relationship between the uncinate process and surrounding structures, moving from an endoscopic view (both from anterior and posterior perspectives) to gross external anatomy of the lateral nasal wall and frontal sinuses. Step-by-step dissection through such a multi-perspective viewpoint will clarifying the technical surgical concepts that will be discussed in the following chapters. Moreover, detailed multiplanar analysis with high-definition CT images will be utilized to depict the entire three-dimensional architecture of the frontal recess.

A. Schreiber · M. Ferrari · P. Nicolai (✉)
Unit of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Brescia, Italy

L. F. Rodella
Section of Anatomy and Physiopathology, University of Brescia, Brescia, Italy

Frontal Bone

The frontal bone contributes to make up the bony framework of the face and anterior skull base. It is composed of three portions: squamous, orbital, and nasal. The squamous part is the largest and forms the skeleton of the forehead. As seen from outside, it shows two prominences, called frontal eminences, which correspond to the frontal sinuses. The orbital part forms the orbital roof and, together with ethmoid and sphenoid bones, makes up the anterior skull base. The nasal part is a small portion joining the nasal and maxillary bones.

The frontal sinus is an air space lined by mucoperiosteum that lies within the squamous part of the frontal bone. It shows different grades of pneumatization, ranging from hypoplasia/agenesis to enormous sinuses extending into the nasal part, orbital part, or adjacent bones. On average, the frontal sinus is 24.3 mm in height, 29.0 mm wide (from the midline to the lateral border), and 16.8 mm deep [1].

D. Lal, P. H. Hwang (eds.), *Frontal Sinus Surgery*, https://doi.org/10.1007/978-3-319-97022-6_2