Stilianos E. Kountakis
T. Metin Önerci
Editors

Rhinologic and Sleep Apnea Surgical Techniques

Second Edition

Springer

MOREMEDIA

Rhinologic and Sleep Apnea Surgical Techniques

Stilianos E. Kountakis • T. Metin Önerci
Editors

Rhinologic and Sleep Apnea Surgical Techniques

Second Edition

Springer

Editors
Stilianos E. Kountakis
Department of Otolaryngology–Head and Neck Surgery
Medical College of Georgia–Augusta University
Augusta, GA, USA

T. Metin Önerci
Department of Otorhinolaryngology–Head and Neck Surgery
Hacettepe University Faculty of Medicine
Ankara, Türkiye

ISBN 978-3-031-27135-9 ISBN 978-3-031-27136-6 (eBook)
https://doi.org/10.1007/978-3-031-27136-6

© Springer Nature Switzerland AG 2007, 2025

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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

If disposing of this product, please recycle the paper.

Dedications and Acknowledgements

To my grandchildren Freyja Eleni Maile, Stilianos Emmanuel Kountakis, Yngvar Mihalis Maile, Christopher John Kountakis, Yiannis Kavousanakis and Sophia Elizabeth Kountakis for providing meaning.

Stil Kountakis

To my father for his great teachings for life, to my wife Semra for her continuous support, to our teachers to whom we owe all our knowledge and the way to think scientifically, to our colleagues who shared their experience and inspired us to learn, to our students who inspired us to teach, to my daughters Özlem and Zeynep and my grandchildren Elif and Selin for giving me the energy and hope for the future.

Özlem Önerci Çelebi

T. Metin Önerci

Preface

Technology to assist in the diagnosis and treatment of rhinologic and sleep apnea diseases continues to evolve and improve, as the prevalence of these diseases continues to increase. As a result, the number of surgeons treating sinus and sleep apnea disorders has increased, along with the need for educational platforms and laboratory workshops that provide the information required for the training of these surgeons. The first edition of the *Rhinologic and Sleep Apnea Surgical Techniques* textbook served to assist learners and practicing surgeons by offering a single concise surgical atlas like book containing information published by world experts on sinonasal and sleep apnea surgery.

The second edition uses the same format of chapters organized and arranged in a logical fashion, from anatomic and basic surgical techniques to more advanced surgical principles and eventually revision surgery. The chapters were updated with the latest information, especially with new instrumentation and surgical techniques. The surgical descriptions are illustrated and chapters contain information about the work-up of the pathology that is described followed by indications of surgery and tips and pearls to avoid complications. All authors share their secrets that lead to successful and uncomplicated surgical outcomes.

The second edition of *Rhinologic and Sleep Apnea Surgical Techniques* contains video files of actual procedures performed, so that once readers review a chapter, they can reinforce their learning experience by viewing the video of an actual surgical case.

To honor the late Professor Wolfgang Draf, we have kept chapter 8 of the first edition of the book, titled “Endonasal Micro-endoscopic Frontal Sinus Surgery”, in exactly the same format.

The result is a comprehensive volume of surgical information that can be used by all practicing and in-training otolaryngologists as a reference source and to augment their surgical education.

Augusta, Georgia, USA — Stilianos E. Kountakis
Ankara, Türkiye — T. Metin Onerci

Foreword by David W. Kennedy

After a successful first edition, the editors have put together a comprehensive revision and update of their prior text on the surgical management of sinonasal disorders, sleep apnea, and snoring. Utilizing a broad selection of well-known leaders within their fields, the book focuses on surgical techniques and approaches, and in so doing provides an excellent and comprehensive text on the surgical techniques involved in the management of these disorders.

The book is divided into two sections. The first section covers sinonasal disorders and covers essentially all of the more common procedures in this area, as well as important topics such as radiologic anatomy. The second section deals with surgical procedures which have been, or still are, utilized in the surgical management of sleep apnea and snoring. It also has a chapter on drug induced sleep endoscopy (DISE), although there is not a chapter on hypoglossal nerve stimulation in this edition.

This text will be very useful for otolaryngology residents as well as practicing otolaryngologists wishing to keep up to date in surgical rhinologic and sleep apnea management techniques, both as an introduction to the procedures and as a reference text in surgical practice.

Professor Emeritus, Perelman School of Medicine
University of Pennsylvania
Philadelphia, PA, USA

David W. Kennedy

Foreword by B. Tucker Woodson

The second edition of *Rhinologic and Sleep Apnea Surgical Techniques* has significant additions since its first edition. As with the previous edition, this book is focused on suture techniques presented in a clear and practical fashion and is valuable addition to the practitioner's library. The editors have recruited an international group of exceptional expert contributors.

Like the previous edition, it covers a wide variety of topics relevant to the general sleep surgeon. It does not attempt to be encyclopedic but rather focus on those topics that are truly relevant to the daily practicing surgeon. While primarily a surgical technique book, it also provides a solid base in medical issues relevant to the sleep surgeon including sleep diagnostics, airway evaluation, and polysomnography for both adults and children. Updates on nasal CPAP and oral appliances are included. New chapters on drug-induced sleep endoscopy and positional therapy are also included. Consistent with the editors' backgrounds, there is excellent and comprehensive coverage of nasal issues relevant to sleep disordered breathing and sleep apnea. The book provides palatal surgeries ranging from implants, barbed suture, anterior palatoplasty, expansion techniques, and palatal advancement. Finally, the book addresses maxillofacial surgical procedures for sleep apnea. Noteworthy are recent advancements in rapid maxillary expansion and distraction osteogenesis techniques for sleep apnea. The book is a focused and worthwhile addition to the library of the specialist and generalist who address the upper airway.

Professor
Medical College Wisconsin
Milwaukee, WI, USA

B. Tucker Woodson

Contents

Contributors

Selen Adiloğlu Hacettepe University, Ankara, Turkey

Zeynep Onerci Altunay Department of Otorhinolaryngology, KENT ENT Hospital, Ankara, Türkiye

Raghu S. Athre Department of Otolaryngology-Head and Neck Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Pete S. Batra Department of Otorhinolaryngology-Head and Neck Surgery, Rush University Medical Center, Chicago, IL, USA

John Behnke Department of Otolaryngology-Head and Neck Surgery, West Virginia University, Morgantown, WV, USA

Peter A. Benedict NYU Otolaryngology Associates, New York, NY, USA

Bernard Bertrand Department of Otorhinolaryngology, Clinique Universitaires Saint-Luc, Brussels, Belgium

Institute of Neuroscience, Université catholique de Louvain, Brussels, Belgium

Benjamin Bleier Department of Otorhinolaryngology, Head and Neck Surgery, Mass Eye and Ear, Boston, MA, USA

Marina Boruk Department of Otolaryngology – Head and Neck Surgery, State University of New York at Downstate Medical Center, Brooklyn, NY, USA

Pien Bosschieter Department of Otorhinolaryngology Head and Neck Surgery, OLVG, Amsterdam, The Netherlands

Jean M. Bruch Otolaryngology-Head & Neck Surgery, CHA Cambridge Hospital, Boston, MA, USA

Nicolas Y. Busaba Snoring and Sleep Apnea Center, Massachusetts Eye and Ear, Boston, MA, USA

Department of Otolaryngology–Head and Neck Surgery, Harvard Medical School, Boston, MA, USA

Giovanni Cammaroto Department of Head-Neck Surgery, Otolaryngology, Head-Neck and Oral Surgery Unit, Morgagni Pierantoni Hospital, Forlì, Italy

Head and Neck Department, ENT Unit, Morgagni-Pierantoni Hospital, AUSL of Romagna, Forlì, Italy

Roy R. Casiano Department of Otolaryngology, University of Miami – Leonard Miller School of Medicine, Miami, FL, USA

Peter Catalano ANFAS Medical Center, Tufts University School of Medicine, Riyadh, KSA, Saudi Arabia

Ozlem Onerci Celebi Department of Otorhinolaryngology, Faculty of Medicine, Koç University, Istanbul, Türkiye

Samantha Cerasiello Department of Otolaryngology – Head & Neck Surgery, Loyola University Health System, Maywood, IL, USA

Khai Beng Chong Department of Otorhinolaryngology, Tan Tock Seng Hospital, Singapore, Singapore

Bülent Çiftçi Faculty of Medicine, Department of Internal Medical Sciences, Yozgat Bozok University, Yozgat, Türkiye

Tansu Ulukavak Çiftçi Faculty of Medicine, Gazi University, Ankara, Türkiye

Martin J. Citardi Department of Otorhinolaryngology-Head and Neck Surgery, McGovern Medical School, University of Texas Health Science Center at Houston, Houston, TX, USA

Brett T. Comer Department of Otolaryngology-Head and Neck Surgery, University of Kentucky, Lexington, KY, USA

Subinoy Das U.S. Institute for Advanced Sinus Care and Research, Columbus, OH, USA

Ahmet U. Demir Faculty of Medicine, Department of Chest Diseases, Hacettepe University, Ankara, Türkiye

Christel de Raaff Department of General Surgery, OLVG, Amsterdam, The Netherlands

Nico de Vries Department of Otorhinolaryngology Head and Neck Surgery, OLVG, Amsterdam, The Netherlands

Department of Oral Kinesiology, ACTA, MOVE Research Institute Amsterdam, University of Amsterdam and VU University Amsterdam, Amsterdam, The Netherlands

Faculty of Medicine and Health Sciences, Department of Otorhinolaryngology, Head and Neck Surgery Antwerp University Hospital (UZA), Antwerp, Belgium

Wolfgang Draf Department for ENT-Diseases, Head-, Neck- and Facial Plastic Surgery, Fulda, Germany

Ramon E. Figueroa Department of Radiology, Medical College of Georgia – Augusta University, Augusta, GA, USA

Peter Filip Department of Otorhinolaryngology, Rush University Medical Center, Chicago, IL, USA

Logan G. Fluty Department of Otolaryngology-Head and Neck Surgery, University of Kentucky, Lexington, KY, USA

Michael Friedman Department of Otolaryngology, Division of Sleep Surgery, Rush University Medical Center, Chicago, IL, USA

Department of Otolaryngology, Advanced Center for Specialty Care, Advocate Illinois Masonic Medical Center, Chicago, IL, USA

Oren Friedman Facial Plastic Surgery, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA

Otorhinolaryngology – Head and Neck Surgery, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA

Mustafa Gerek Ear Nose and Throat Department, Gülhane School of Medicine, Health Sciences University, Ankara, Turkey

Satish Govindaraj Department of Otolaryngology-HNS, Icahn School of Medicine at Mount Sinai, New York, NY, USA

Parul Goyal Syracuse Otolaryngology, Nasal & Sinus Center, Syracuse, NY, USA

T. Graham Norwood Department of Otolaryngology, University of Alabama at Birmingham, Birmingham, AL, USA

Ralph Abi Hachem Division of Rhinology and Endoscopic Skull Base Surgery, Department of Head and Neck Surgery & Communication Sciences, Duke University, Durham, NC, USA

Gady Har-El Department of Otolaryngology-Head and Neck Surgery, Lenox Hill/Northwell Health and Donald and Barbara Zucker School of Medicine at Hofstra/Northwell, New York, NY, USA

Elisabeth Hultcrantz Department of Biomedical and Clinical Sciences, Division of Sensory Organs and Communication, Linköping University, Linköping, Sweden

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

Giannicola Iannella Department of Head-Neck Surgery, Otolaryngology, Head-Neck and Oral Surgery Unit, Morgagni Pierantoni Hospital, Forlì, Italy

Head and Neck Department, ENT Unit, Morgagni-Pierantoni Hospital, AUSL of Romagna, Forlì, Italy

Joseph B. Jacobs Professor Emeritus, New York University School of Medicine, New York, NY, USA

David W. Jang Division of Rhinology and Endoscopic Skull Base Surgery, Department of Head and Neck Surgery & Communication Sciences, Duke University, Durham, NC, USA

Seth J. Kanowitz Advocare ENT Specialists of Morristown, Morristown, NJ, USA

David W. Kennedy Department of Otolaryngology-HNS, Sidney Kimmel School of Medicine, Thomas Jefferson University, Philadelphia, PA, USA

Suat Kilic, MD Rhinology, Sinus and Skull Base Surgery, Cleveland Clinic Foundation, Cleveland, OH, USA

Onur Koç Hacettepe University, Ankara, Turkey

Stilianos E. Kountakis Department of Otolaryngology–Head and Neck Surgery, Medical College of Georgia–Augusta University, Augusta, GA, USA

Donald C. Lanza Sinus & Nasal Institute of Florida, P.A. St. Anthony's Outpatient Center, St. Petersburg, FL, USA

Georges Lawson Université Catholique de Louvain, Ottignies-Louvain-la-Neuve, Belgium

Kristopher Lay Alabama Nasal & Sinus Center, St. Vincent's Health and Wellness, Birmingham, AL, USA

Anna Lazutkin Division of Rhinology and Endoscopic Skull Base Surgery, Department of Head and Neck Surgery & Communication Sciences, Duke University, Durham, NC, USA

Department of Otolaryngology / Head & Neck Surgery, Hebrew University School of Medicine, Hadassah Medical Center, Jerusalem, Israel

Richard A. Lebowitz NYU Otolaryngology Associates, New York, NY, USA

Thomas T. Le Department of Otorhinolaryngology, University of Maryland Medical System, Baltimore, MD, USA

Seth M. Lieberman NYU Otolaryngology Associates, New York, NY, USA

Francis T. K. Ling Ent Clinic, Windsor, ON, Canada

Erin Lopez Department of Otolaryngology-Head and Neck Surgery, The University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Department of Otolaryngology-Head and Neck Surgery, G0412 Neurosciences Hospital, CB #7070, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Tasher Losenegger Department of Otorhinolaryngology, Rush University Medical Center, Chicago, IL, USA

Chadi A. Makary Department of Otolaryngology-Head and Neck Surgery, West Virginia University, Morgantown, WV, USA

Steven Mariën ENT & Head and Neck Surgery, Antwerp University Hospital, Antwerp, Belgium

Nose, Throat and Ear Diseases, AZ Monica, Antwerp, Belgium

Bradley F. Marple Department of Otolaryngology-Head and Neck Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Fasil Mathews Department of Otolaryngology – Head and Neck Surgery, State University of New York at Downstate Medical Center, Brooklyn, NY, USA

Giuseppe Meccariello Department of Head-Neck Surgery, Otolaryngology, Head-Neck and Oral Surgery Unit, Morgagni Pierantoni Hospital, Forlì, Italy

Tanya K. Meyer Department of Otorhinolaryngology, University of Maryland Medical System, Baltimore, MD, USA

Amir Minovi ENT Clinic, St. Elisabeth Hospital, Cologne, Germany

Eric J. Nisenbaum Department of Otolaryngology, University of Miami – Leonard Miller School of Medicine, Miami, FL, USA

T. Metin Önerci Department of Otorhinolaryngology–Head and Neck Surgery, Hacettepe University Faculty of Medicine, Ankara, Türkiye

International Rhinology Society, Rhinology and Allergy, Sleep, Facial Plastic Surgery Committees of International Federation of Oto-Rhino-Laryngological Societies, Ankara, Türkiye

Norman Orabi Department of Otolaryngology-Head & Neck Surgery, West Virginia University, Morgantown, WV, USA

Kürşat Murat Özcan Department of Otorhinolaryngology, Ministry of Health Ankara Bilkent City Hospital, Ankara, Turkey

Edward B. Pang Department of Medicine, Royal Glasgow Infirmary, Glasgow, UK

Kathleen A. Pang Department of Medicine, Ministry of Health Singapore, Singapore, Singapore

Department of Medicine, Ministry of Health Singapore, Singapore, Singapore

Kenny P. Pang Otorhinolaryngology, Asia Sleep Centre, Paragon Medical Centre, Singapore, Singapore

Chirag Patel Department of Otolaryngology – Head & Neck Surgery, Loyola University Health System, Maywood, IL, USA

Department of Neurological Surgery, Loyola University Health System, Maywood, IL, USA

Wolfgang Pirsig Department of Otorhinolaryngology, University Hospital Ulm, Ulm, Germany

Hassan H. Ramadan Department of Otolaryngology-Head & Neck Surgery, West Virginia University, Morgantown, WV, USA

Madeline J. L. Ravesloot Department of Otorhinolaryngology Head and Neck Surgery, OLVG, Amsterdam, The Netherlands

Marc Remacle Université Catholique de Louvain, Ottignies-Louvain-la-Neuve, Belgium

Camilo Reyes Department of Otolaryngology—Head and Neck Surgery, Medical College of Georgia—Augusta University, Augusta, GA, USA

Barak Ringel Department of Otorhinolaryngology, Head and Neck Surgery, Mass Eye and Ear, Boston, MA, USA

Daniel Rodenstein Université catholique de Louvain, Ottignies-Louvain-la-Neuve, Belgium

Philippe Rombaux Department of Otorhinolaryngology, Clinique Universitaires Saint-Luc, Brussels, Belgium

Institute of Neuroscience, Université catholique de Louvain, Brussels, Belgium

Banu Saglam-Aydinatay Private Practice, Ankara, Turkey

Zoukaa B. Sargi Department of Otolaryngology, University of Miami – Leonard Miller School of Medicine, Miami, FL, USA

Paul Schalch Department of Otolaryngology – Head and Neck Surgery, University of California San Diego, San Diego, CA, USA

Bert Schmelzer Ziekenhuis Netwerk Antwerpen (ZNA), Section of Otorhinolaryngology, Head and Neck Surgery, Antwerp, Belgium

Brent A. Senior Harold C Pillsbury, III Distinguished Professor of Otolaryngology, Chief, Division of Rhinology, Allergy, and Endoscopic Skull Base Surgery, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Noah Shaikh Department of Otolaryngology-Head and Neck Surgery, West Virginia University, Morgantown, WV, USA

Michael J. Sillers Alabama Nasal & Sinus Center, St. Vincent's Health and Wellness, Birmingham, AL, USA

Ioannis G. Skoulas Venizelion Hospital Heraklion, Heraklion, Crete, Greece

Timothy L. Smith Department of Otolaryngology/Head and Neck Surgery, Oregon Health & Science University, Portland, OR, USA

James A. Stankiewicz Department of Otolaryngology – Head & Neck Surgery, Loyola University Health System, Maywood, IL, USA

Luigi Marco Stringa Department of Otolaryngology, Head and Neck Surgery, University of Ferrara, Ferrara, Italy

Ahmet Emre Süslü Department of Otorhinolaryngology Head and Neck Surgery, Hacettepe University Faculty of Medicine, Ankara, Turkey

Tulin Taner Department of Orthodontics, Faculty of Dentistry, Hacettepe University, Ankara, Turkey

B. Tucker Woodson Professor and Chief Division of Sleep Medicine and Surgery, Department of Otolaryngology Medical College, Milwaukee, WI, USA

Hakan H. Tüz Hacettepe University, Ankara, Turkey

Jonathan Tyes School of Medicine, University of Louisville, Louisville, Louisville, USA

Claudio Vicini Department of Head-Neck Surgery, Otolaryngology, Head-Neck and Oral Surgery Unit, Morgagni Pierantoni Hospital, Forlì, Italy

Head and Neck Department, ENT Unit, Morgagni-Pierantoni Hospital, AUSL of Romagna, Forlì, Italy

Department of Otolaryngology, Head and Neck Surgery, University of Ferrara, Ferrara, Italy

Mark C. Weissler University of North Carolina Chapel Hill, Chapel Hill, NC, USA

Margaret E. Wieser Department of Otolaryngology-Head and Neck Surgery, University of Kentucky, Lexington, KY, USA

Andrew A. Winkler Department of Otorhinolaryngology, University of Maryland Medical System, Baltimore, MD, USA

Troy D. Woodard, MD Rhinology, Sinus and Skull Base Surgery, Cleveland Clinic Foundation, Cleveland, OH, USA

Bradford A. Woodworth Department of Otolaryngology, University of Alabama at Birmingham, Birmingham, AL, USA

Grace Wu Facial Plastic Surgery, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, USA

Adam M. Zanation Department of Otolaryngology-Head and Neck Surgery, G0412 Neurosciences Hospital, CB #7070, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Part I

Sinus

1 Radiologic Anatomy of the Paranasal Sinuses

Ramon E. Figueroa

Core Messages

- The complex interaction of multiple factors over time results in an endless combination of sinus anatomic variations.
- An intimate knowledge of sinus anatomy and a clear understanding of its physiology and anatomic variants are required for safe and effective sinus surgery.
- Rhinologists should evaluate each side of the face as a completely independent anatomic, functional and surgical entity.
- The frontal sinus drainage pathway is the most complex of all sinus outflow tracts.
- The agger nasi cells and the uncinate process dictate the floor and the pattern of drainage of the frontal recess.
- Familiarity with anatomic variants in the frontal recess is required for safe anterior skull base and frontal recess surgery.
- The olfactory fossa is frequently the lowermost point in the floor of the anterior cranial fossa.
- The ostiomeatal complex is the common pathway of drainage of the anterior paranasal sinuses.
- The ethmoid infundibulum is the key element to understand the anatomy and physiology of the ostiomeatal complex.
- The sphenoethmoid recess is the common pathway for mucociliary drainage from posterior ethmoid air cells and the sphenoid sinus.
- Onodi cells frequently have associated dehiscence of the optic nerves and are a surgical danger zone as a potential site for iatrogenic endoscopic optic nerve injury or intracranial penetration.

R. E. Figueroa (✉)
Department of Radiology, Medical College of Georgia – Augusta University, Augusta, GA, USA
e-mail: rfigueroaortiz@augusta.edu

1.1 Introduction

The anatomy of the paranasal sinuses is complex and variable, changing from patient to patient, and even from side to side in the same patient. This complexity results from the variable patterns of sinus ventilation and drainage dictated by independent sinus development. Sinus ventilation and drainage determines intrasinus mucociliary health, which also determines the efficiency of sinus growth and pneumatization. The final individual sinus configuration is additionally influenced by the evolving growth of neighboring sinuses, competing for space as they pneumatize the facial bones and skull base, also in competition with erupting teeth in the maxilla and the ever-constant intracranial pressure gradients along the skull base. The complex interaction of all these factors over time dictates an endless combination of anatomic variations that force the rhinologist to evaluate each side of the face as a completely independent anatomic, functional and surgical entity.

Recent significant advances in computed tomography (CT), especially the introduction of multidetector helical scanning and the routine availability of computer workstations, have made demonstration of this complex anatomy easier and more useful to rhinologic surgical planning. This improvement in imaging clarity and multiplanar demonstration of sinus complex anatomy is now of even more clinical relevance in view of the extensive developments in powered instruments, better endoscopic devices and surgical navigation with CT cross-registration.

1.2 Functional Concepts

The sinonasal embryologic development during the first trimester is characterized by the emergence of more than six ethmoturbinals, which progressively coalesce and differentiate into the final anatomy of the lateral nasal wall [9].

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2025
S. E. Kountakis, T. M. Önerci (eds.), *Rhinologic and Sleep Apnea Surgical Techniques*,
https://doi.org/10.1007/978-3-031-27136-6_1

The ethmoturbinals give rise to the following structures:

- The most superior remnant of the first ethmoturbinal becomes the agger nasi mound.
- The remnant of the descending portion of the first ethmoturbinal becomes the uncinate process.
- The basal lamella of the second ethmoturbinal pneumatizes and gives rise to the bulla ethmoidalis.
- The basal lamella of the third ethmoturbinal becomes the basal lamella of the middle turbinate.

The nasal mucosa invaginates at specific points in the lateral nasal wall forming nasal pits that develop into the anlages of maxillary, frontal sinuses and ethmoid cells [2]. The mesenchyme resorbs around the invagination of the nasal pits, allowing progressive development of the sinus cavity. The embryologic point at which the initial invagination occurs becomes the future sinus ostium. Cilia develop and orient toward this ostium, allowing mucus to flow toward and through the ostium. The efficiency of the mucociliary drainage is then dictated and impacted by the patency, tortuosity and/or frank narrowing of the resulting drainage pathways, which are progressively modified by the sequential ongoing pneumatization process occurring during the patient's life. Typically, the ethmoid cells and the maxillary antra are pneumatized at birth, with the maxillary antra progressively expanding into mature sinuses as the maxilla matures and the teeth erupt. The frontal sinus develops and expands in late childhood to early adolescence, and continues to grow into adulthood. The rate of sinus growth is modified by the efficiency of ventilation and mucociliary drainage dictated by the patency of the sinus ostium and the corresponding drainage pathways. The frontal sinus drainage pathway is the most complex of all sinus outflow tracts, impacted by its anatomic relationships with the agger nasi, anterior ethmoid cells and pattern of vertical insertion of the uncinate process [3, 4]. The frontal sinus mucociliary output joins the outflow from the anterior ethmoid and maxillary sinuses at the ostiomeatal complex, with the mucociliary transport continuing posteriorly over the attachment of the inferior turbinate, through the choanna and toward the nasopharynx anterior to the torus tubarius. Similarly, the mucociliary transport output of the posterior ethmoid and sphenoid sinuses emerges into the sphenoethmoid recess at the level of the superior meatus to be transported downwards toward the nasopharynx posterior to the torus tubarius.

1.3 Sinus Imaging Evaluation

The evaluation of the paranasal sinuses for functional endoscopic sinus surgery is traditionally performed with continuous coronal and axial 3-mm CT slices to provide orthogonal sinus anatomy planes [6, 7]. Recent CT scanner advances with the introduction of multidetector helical designs and faster computers with larger processing capacities now allow single plane thin-section high-resolution databases to be acquired and postprocessed to depict the sinus anatomy in any planar projection, with high definition of the underlying anatomy. This multiplanar capability has mostly impacted the evaluation of all sinus drainage pathways, since perpendicular reconstructions of the frontal recess, ostiomeatal complex and sphenoethmoid recess can now be easily obtained from a single-plane image acquisition.

Typical high-resolution multidetector scanning is performed in the axial plane (Fig. 1.1a) following the long axis of the hard palate, using low milliampere technique, a small field of view (18–20 cm) and 1.25 mm collimation, with data back-processed in 0.65 mm thickness in a bone algorithm and displayed in mucosal (window of 2000, level of −200) and bone (3500/800) detail. Most centers use this pattern of data acquisition for three-dimensional computer-assisted surgical navigation. Interactive processing and evaluation of the data are then performed on the CT workstation to define a coronal plane perpendicular to the hard palate for the ostiomeatal complex (Fig. 1.1b) and a sagittal plane perpendicular to the hard palate for the frontal recess (Fig. 1.1c). The axial plane perpendicular to the rostrum of the sphenoid sinus allows for adequate evaluation of the sphenoethmoid recess.

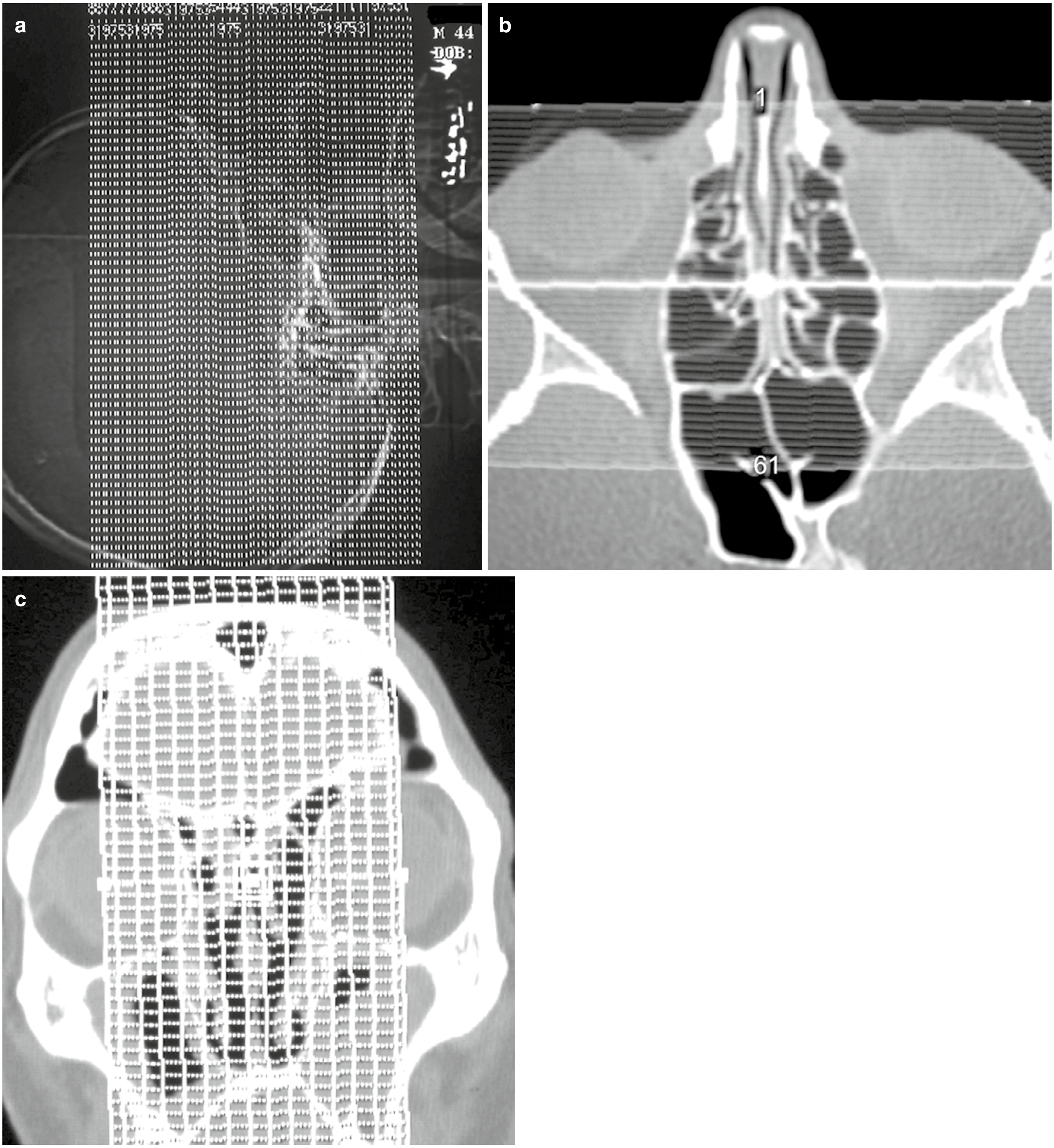

Fig. 1.1 High-resolution sinus navigation CT protocol. (**a**) Lateral scout view showing the typical prescription of axial thin-section slices. (**b**) An axial image at the level of the nasal cavity helps prescribe the coronal reformatted images. (**c**) The sagittal reformatted images are more accurately prescribed from the coronal reformatted images

1.4 Frontal Sinus Drainage Pathway

The frontal sinus grows and expands within the diploic space of the frontal bone from the frontal sinus ostium medial and superior to the orbital plates, enclosed anteriorly by the cortical bone of the anterior frontal sinus wall and posteriorly by the cortical bone of the skull base and the posterior frontal sinus wall (which is also the anterior wall of the anterior cranial fossa). Each frontal sinus grows independently, with its rate of growth, final volume and configuration dictated by its ventilation, drainage and the corresponding growth (or lack of it) of the competing surrounding sinuses and skull base.

1.4.1 Frontal Sinus Ostium

The frontal sinus narrows down inferiorly and medially into a funnel-shaped transition point, which is defined as the frontal sinus ostium (Fig. 1.2a–c), extending between the anterior and posterior frontal sinus walls at the skull base level. This point is typically demarcated along its anterior wall by the variably shaped bone ridge of the naso-frontal buttress, frequently called the "nasal beak" (Fig. 1.2d). The frontal sinus ostium is oriented nearly perpendicular to the posterior wall of the sinus at the level of the anterior skull base [3].

1.4.2 Anterior Ethmoid Artery

The anterior ethmoid artery is a terminal branch of the ophthalmic artery that crosses the lamina papyracea along the posterior wall of the frontal recess to supply the dura of the olfactory fossa and the anterior falx cerebri. It is a constant

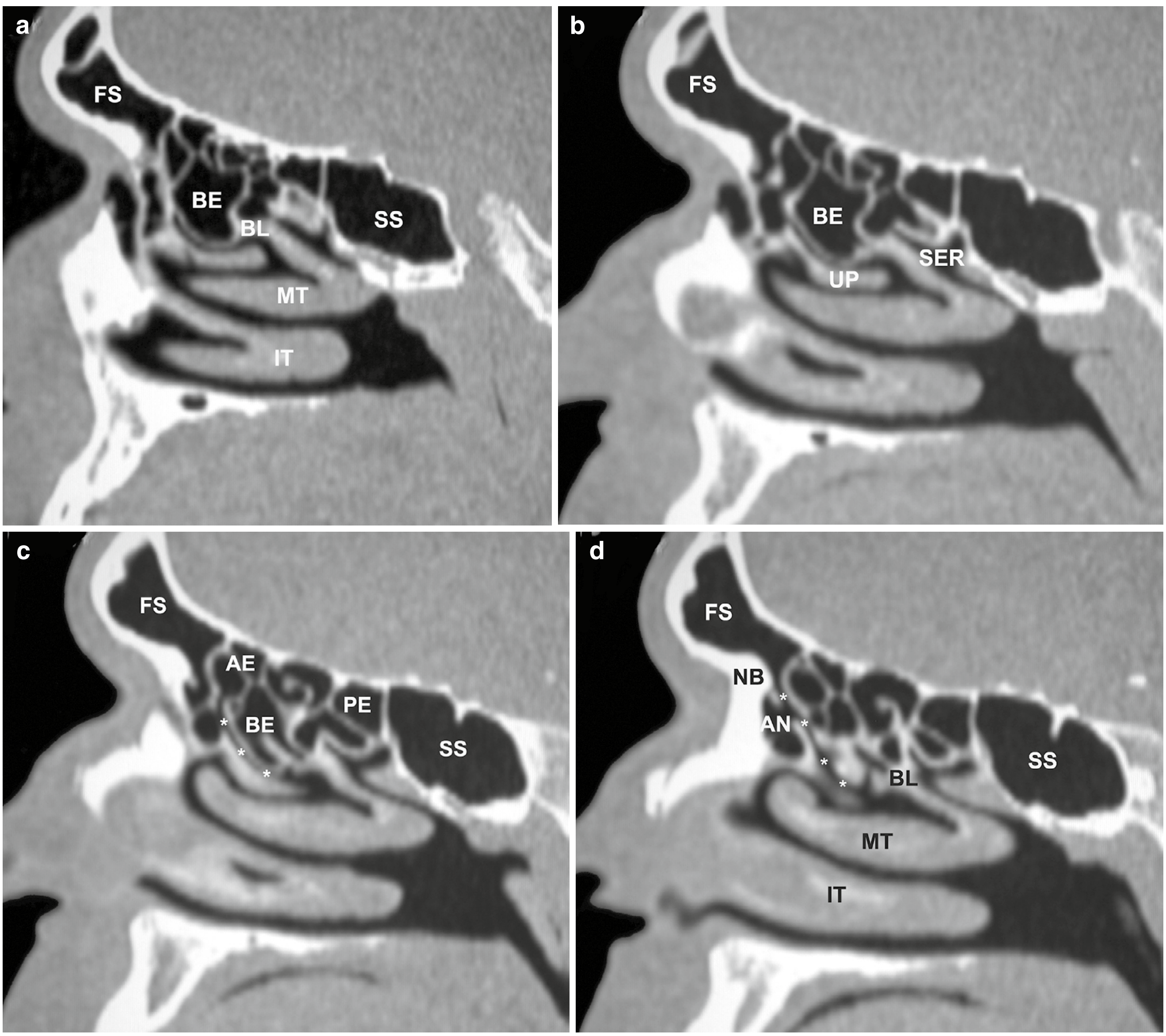

Fig. 1.2 The frontal sinus ostium: sagittal sequential reformatted images from midline to lateral showing the many important anatomic landmarks. Sagittal images (Figures **a**, **b**, **c**, **d**) at the level of the frontal sinus (*FS*) illustrate the frontal sinus ostium. *Asterisks* ethmoid infundibulum, *AE* anterior ethmoid, *AN* agger nasi cells, *BE* bulla ethmoidalis, *BL* basal lamella of the middle turbinate (*MT*), *IT* inferior turbinate, *NB* nasal beak, *PE* posterior ethmoid, *UP* uncinate process, *SER* sphenoethmoid recess, *SS* sphenoid sinus

vascular landmark of the posterior wall of the frontal recess, crossing through the anterior ethmoid canal, which can be frequently dehiscent, posing a risk of vascular injury when exploration of the frontal recess is surgically necessary (Fig. 1.3b).

1.4.3 Frontal Recess, Agger Nasi and Uncinate Process

The Anatomic Terminology Group defined the frontal recess as "the most anterior and superior part of the anterior ethmoid complex from where the frontal bone becomes pneumatized, resulting in a frontal sinus" [8, 9]. The frontal recess frequently looks like an inverted funnel (Fig. 1.3a) on sagittal images, opening superiorly toward the frontal sinus ostium, with its anatomic boundary dictated by the walls of surrounding structures.

The boundaries of the frontal recess are as follows:

- The lateral wall of the frontal recess is defined by the lamina papyracea of the orbit.
- The medial wall is defined by the vertical attachment of the middle turbinate (its most anterior and superior part).
- Its posterior wall is variable, depending on the basal lamella of the bulla ethmoidalis reaching (or not) the skull base, or if it is dehiscent allowing communication with the suprabullar recess, or if it is hyperpneumatized anteriorly, producing a secondary narrowing of the frontal recess from forward deformity of its posterior wall [2].

The agger nasi cells and the uncinate process dictate the floor and the pattern of drainage of the frontal recess. The frontal recess can be narrowed from anterior-inferior direction by hyperpneumatized agger nasi cells. Furthermore, the frontal recess inferior drainage is dictated by the insertion of the vertical attachment of the uncinate process, a sagittally oriented hooklike bony leaflet (Fig. 1.4a). Whenever the uncinate process attaches to the skull base or the superior-anterior portion of the middle turbinate, the frontal recess will drain directly into the superior end of the ethmoid infundibulum (Fig. 1.4b). If the uncinate process attaches laterally into the lamina papyracea of the orbit, the frontal recess will open directly into the superior aspect of the middle meatus and the ethmoid infundibulum will end blindly into the recessus terminalis.

1.4.4 Ethmoid Infundibulum

The ethmoid infundibulum is a true three-dimensional space and is defined (Fig. 1.5a):

- Laterally by the lamina papyracea.
- Anteromedially by the uncinate process.
- Posteriorly by the bulla ethmoidalis.

It opens medially into the middle meatus across the hiatus semilunaris inferioris, a cleft-like opening between the free posterior margin of the uncinate process and the corresponding anterior face of the bulla ethmoidalis (Fig. 1.5b). This is the functional common pathway of mucociliary drainage for the anterior ethmoid, agger nasi and maxillary sinus mucus. The frontal sinus mucus also drains in this direction when the frontal recess opens to the top of the ethmoid infundibulum.

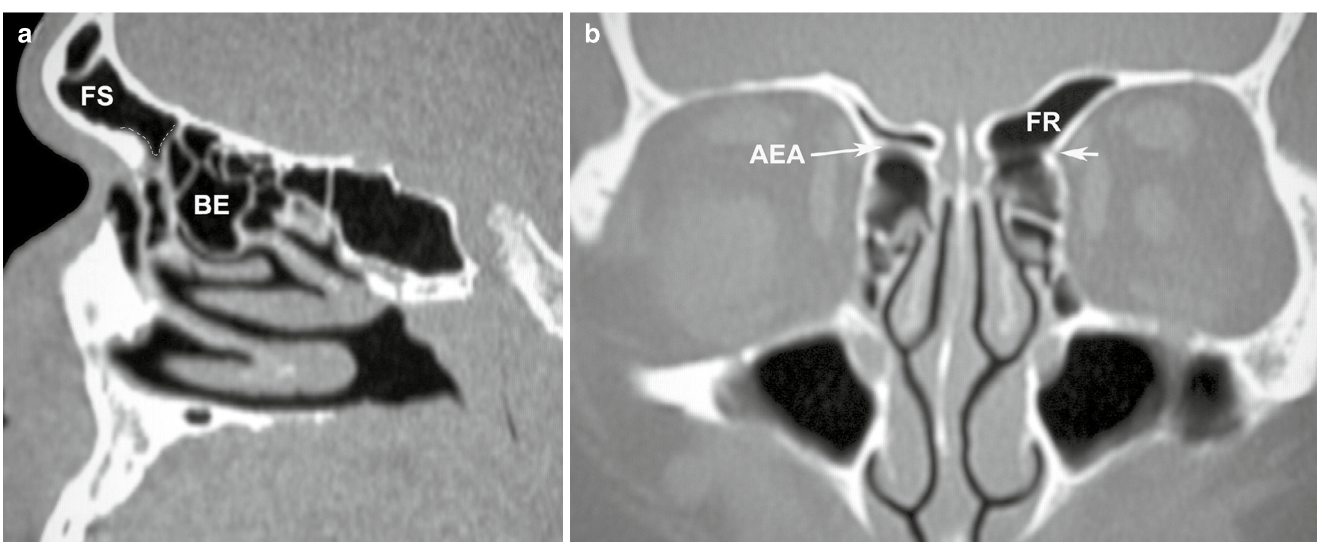

Fig. 1.3 The frontal recess. (**a**) Sagittal reformatted image at the frontal recess showing the frontal sinus ostium as a funnel shaped outflow tract (*dashed line*). (**b**) Coronal image showing the right anterior ethmoid artery (*AEA*) coursing through its bony canal (*long arrow*). The left anterior ethmoid artery is dehiscent (*short arrow*) just below the frontal recess

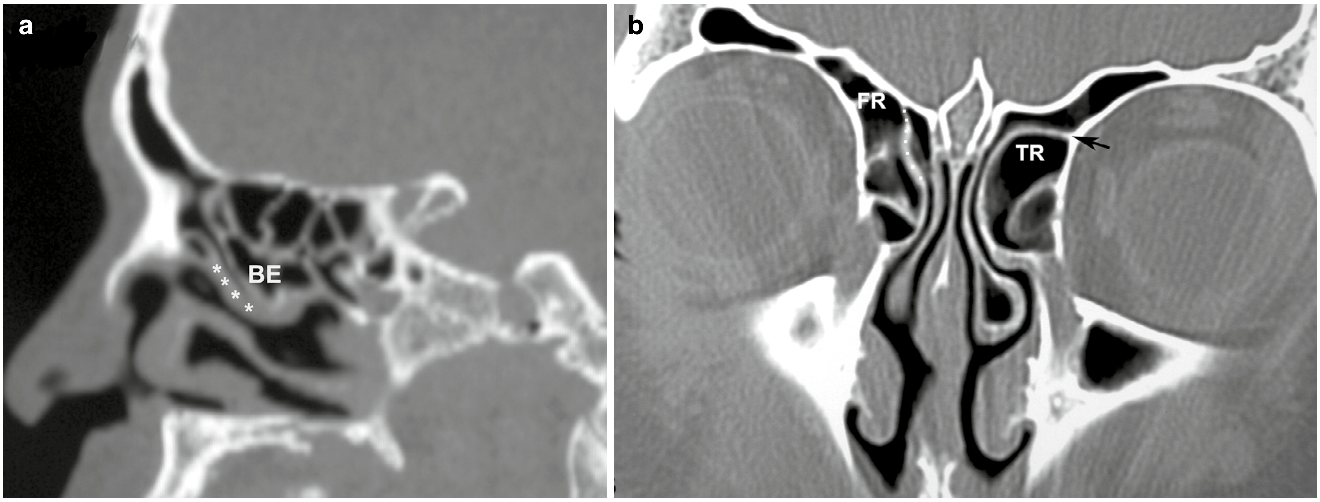

Fig. 1.4 The uncinate process. In the sagittal image (**a**) the uncinate process (*asterisks*) is shown as a curved bony projection that extends toward the frontal recess. It defines the anterior margin of the ethmoid infundibulum. The bulla ethmoidalis (*BE*) defines the posterior wall of the ethmoid infundibulum. In the coronal image (**b**) the left uncinate process attaches to the lamina papyracea (*arrow*), with the frontal recess (*FR*) opening directly to the middle meatus, and the left ethmoid infundibulum ending in a blind end or "terminal recess" (*TR*). The right uncinate process attaches to the skull base (*dotted line*), with the right frontal recess emptying into the right ethmoidal infundibulum

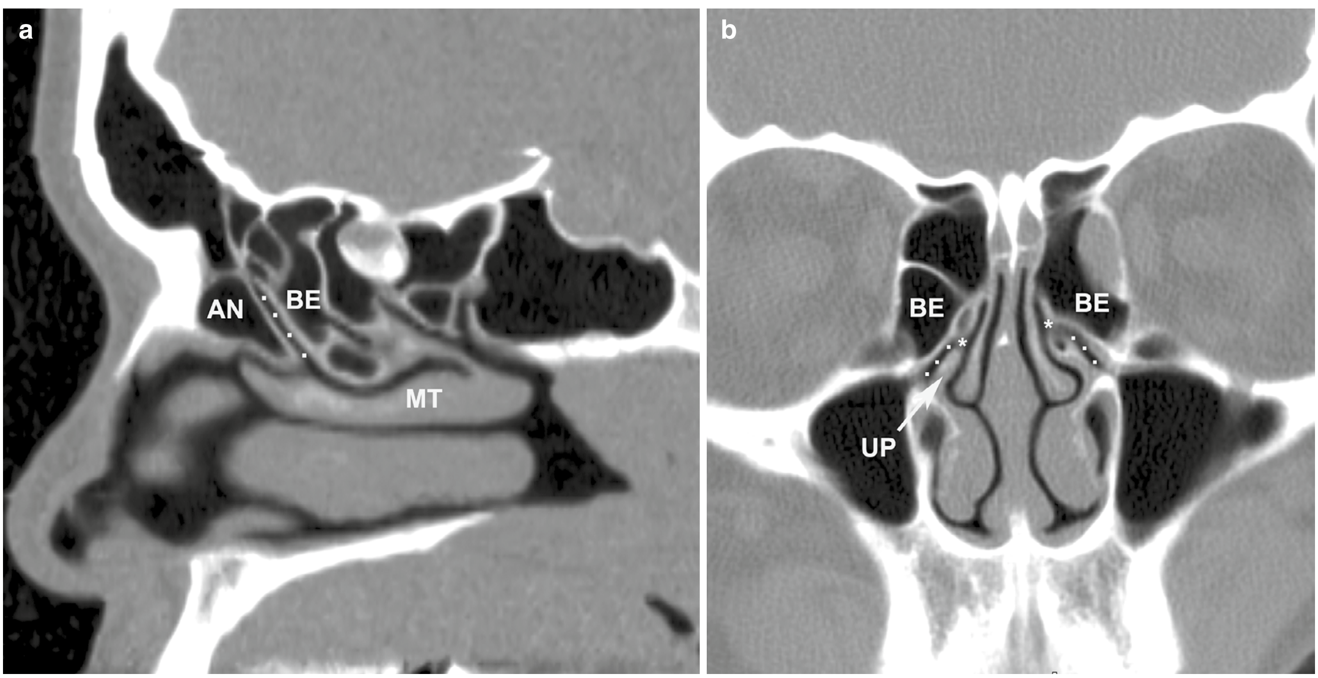

Fig. 1.5 The ostiomeatal complex. Notice on the sagittal image (**a**) the cleft-like ethmoid infundibulum (*dotted line*), bordered anteriorly by a pneumatized agger nasi cell (*AN*) and posteriorly by the bulla ethmoidalis (*BE*). The middle turbinate (*MT*) is seen below. In the coronal image, (**b**) the ethmoid infundibulum (*dotted line*) lies between the uncinate process (*UP*) and the bulla ethmoidalis (*BE*), opening into the middle meatus across the hiatus semilunaris inferior (*asterisks*). Notice the deep olfactory fossa (Keros type III)

1.4.5 Anatomic Variants of the Frontal Recess

Several important anatomic variants impact on the anatomy of the frontal recess and the anterior skull base. Familiarity with these anatomic variants is required for safe anterior skull base and frontal recess surgical considerations.

1.4.5.1 Frontal Cells

The frontal cells are uncommon anatomic variants of anterior ethmoid pneumatization that impinge upon the frontal recess and typically extend within the lumen of the frontal sinus ostium above the level of the agger nasi cells (Fig. 1.6).

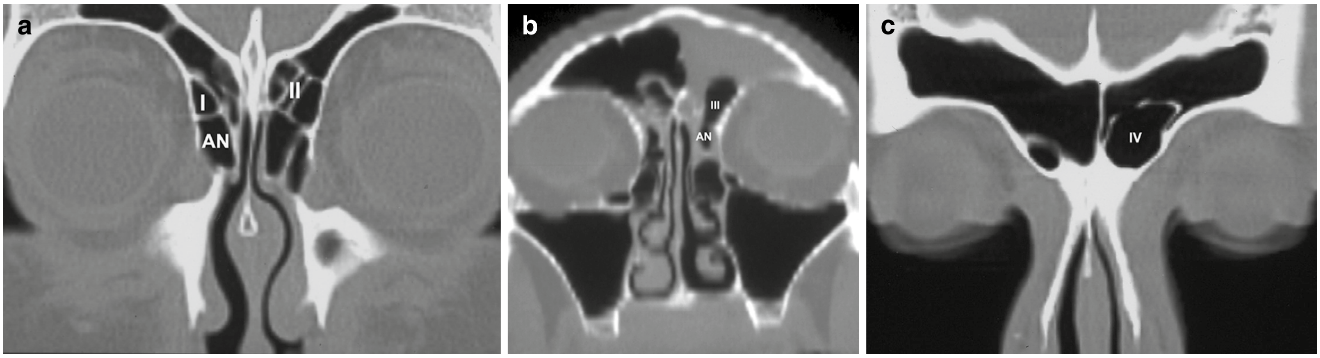

Fig. 1.6 Frontal cells. Frontal cells are rare air cells above the agger nasi (*AN*) that impinge upon the frontal recess and frontal sinus. Type *I* is a single cell above the agger nasi, while type *II* is a tier arrangement above the agger nasi (**a**). Type *III* is a single large frontal cell projecting into the frontal sinus lumen (**b**). Type IV is a large cell completely contained in the frontal sinus ("sinus within a sinus") (**c**)

The different types of frontal cells as described by Bent are as follows [1, 9]:

- Type I frontal cells are described as a single frontal recess cell above the agger nasi cell (Fig. 1.6a).
- Type II frontal cells are a tier of cells above the agger nasi cell, projecting within the frontal recess.
- A type III frontal cell is defined as a single massive cell arising above the agger nasi, pneumatizing cephalad into the frontal sinus (Fig. 1.6b).
- A type IV frontal cell is a single isolated cell within the frontal sinus acting as a "sinus within a sinus," frequently difficult to visualize owing to its thin walls (Fig. 1.6c).

All frontal cells can be clinically significant if they become primarily infected or if they stenose the frontal sinus ostium, leading to mucus recirculation and secondary frontal sinusitis.

1.4.5.2 Supraorbital Ethmoid (SOE) Cells

This is when the anterior ethmoid sinus pneumatizes the orbital plate of the frontal bone posterior to the frontal recess and lateral to the frontal sinus (Fig. 1.7a, b, c), frequently developing from the suprabullar recess [2]. The degree of pneumatization of the supraorbital ethmoid cells can reach the anterior margin of the orbital plate and mimic a frontal sinus. We can best trace the supraorbital ethmoid cell toward the anterior ethmoid sinus on axial CT images, which allows us to recognize this variant better.

1.4.5.3 Depth of Olfactory Fossa

The orbital plate of the frontal bone slopes downwards medially to constitute the roof of the ethmoid labyrinth (foveola ethmoidalis), ending medially at the lateral border of the olfactory fossa (Fig. 1.8). This configuration makes the olfactory fossa the lowermost point in the floor of the anterior cranial fossa, frequently projecting between the pneumatized air cells of both ethmoid labyrinths [9]. The depth of the olfactory fossa into the nasal cavity is dictated by the height of the lateral lamella of the cribriform plate, a very thin sagittally oriented bone, continuous with the vertical attachment of the middle turbinate, defining the lateral wall of the olfactory fossa.

Keros [5] described the anatomic variations of the ethmoid roof and the olfactory fossa, classifying it in three surgically important types:

1. Type I has a short lateral lamella, resulting in a shallow olfactory fossa of only 1–3 mm in depth in relation to the medial end of the ethmoid roof.
2. Type II has a longer lateral lamella, resulting in an olfactory fossa depth of 4–7 mm.
3. Type III has a much longer lateral lamella (8–16 mm), with the cribriform plate projecting deep within the nasal cavity well below the roof of the ethmoid labyrinth.

The type III configuration represents a high-risk area for lateral lamella iatrogenic surgical perforation in ethmoid endoscopic surgical procedures. Occasionally there may be asymmetric depth of the olfactory fossa from side to side, which must be recognized and considered prior to surgery.

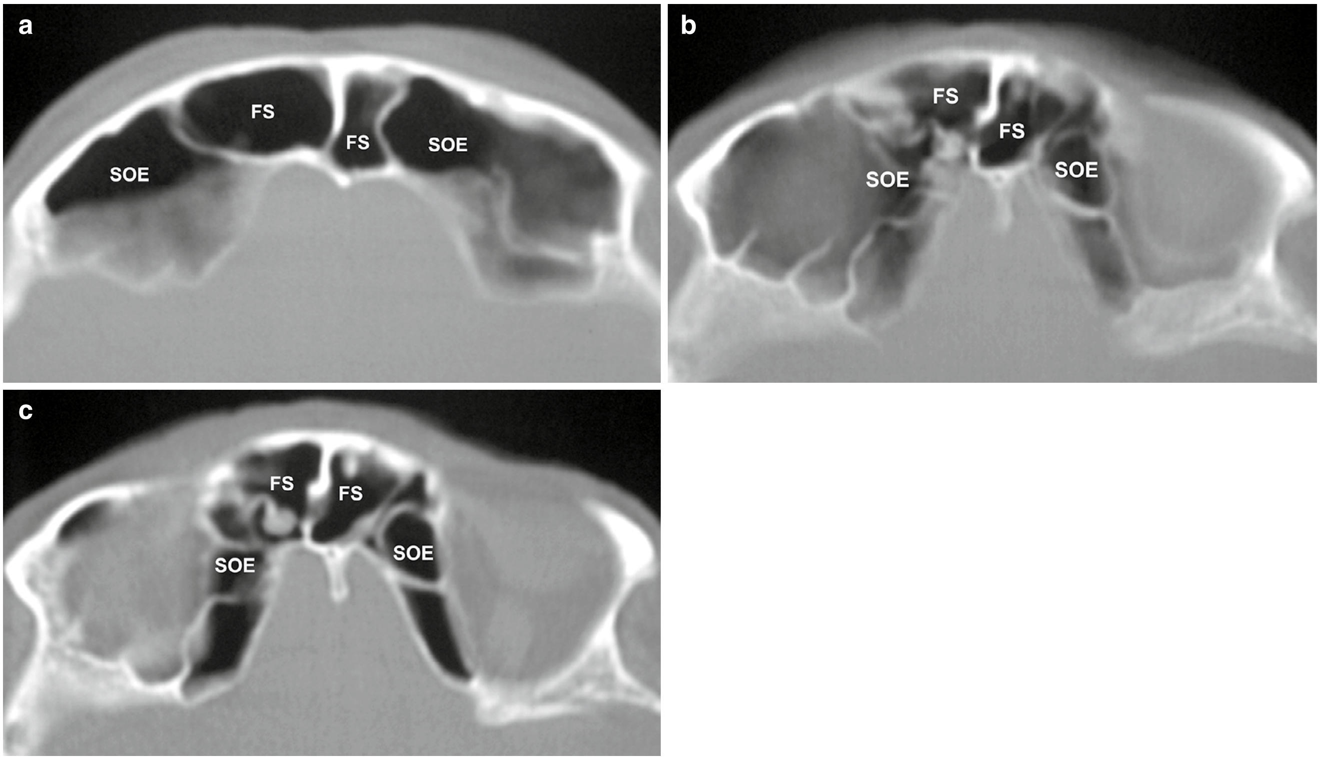

Fig. 1.7 (**a**, **b**, **c**) Supraorbital ethmoid cells. In the sequential axial images, the supraorbital ethmoid cells (*SOE*) expand and pneumatize anteriorly the orbital plate of the frontal bone, not to be confused with the frontal sinus (*FS*)

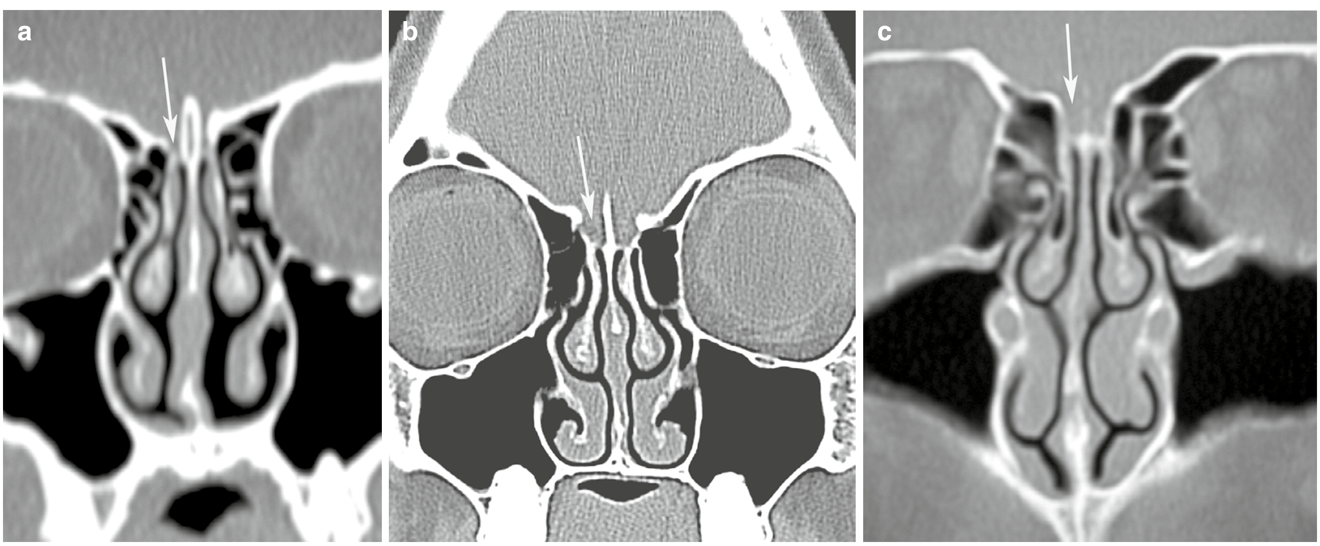

Fig. 1.8 Depth of the olfactory fossa. The length of the lateral lamella of the cribriform plate determines the depth of the olfactory fossa (*arrows*), categorized by Keros in type I (**a** 1–3-mm deep), type II (**b** 4–7-mm deep) and type III (**c** 8–16-mm deep)

1.5 Ostiomeatal Complex

The ostiomeatal complex is the common pathway of drainage of the anterior paranasal sinuses, acting as the functional unit that controls and modulates the mucociliary drainage from the frontal sinus, anterior ethmoid sinus and maxillary sinus.

The ostiomeatal complex comprises a combination of structures:

- Uncinate process.
- Ethmoid bulla.
- Middle turbinate.
- Spaces between these structures (ethmoid infundibulum, hiatus semilunaris and middle meatus) (Fig. 1.5).

The efficiency of drainage is dictated by the patency or closure of these spaces in response to the nasal cycle of alternating phases of mucosal engorgement and mucosal thinning, typically on cycles of 4–6 h. Whenever the ostiomeatal complex spaces are further narrowed by anatomic variants, mucosal polyps, inflamed mucosa, scars or synechiae, the resulting decreased drainage capacity of the system will result in backpressure accumulation of mucous secretions within the corresponding sinus spaces, increasing the likelihood of secondary bacterial colonization of the previously sterile sinus secretions by backflow of nasal cavity bacteria into the obstructed sinus spaces.

1.5.1 Structures and Spaces

The ethmoid infundibulum is the key element to understand the anatomy and physiology of the ostiomeatal complex (Fig. 1.5a). The ethmoid infundibulum is a sickle-shaped sagittally oriented three-dimensional space extending from the agger nasi/frontal recess region toward the middle meatus, running downwards and posteriorly between the lamina papyracea of the ipsilateral orbit laterally and the uncinate process medially. This resulting V-shaped drainage channel collects the mucociliary output of the frontal sinus, agger nasi cells, anterior ethmoid cells and maxillary sinus. The maxillary sinus mucous secretions are transported by mucociliary clearance toward its natural ostium, located along the superior aspect of the maxillary sinus medial wall, opening into the junction of the middle and posterior third of the ethmoid infundibulum, which in turn opens medially into the middle meatus to direct the mucociliary transport secretions toward the choanna and nasopharynx.

The space connecting the ethmoid infundibulum and the middle meatus is the hiatus semilunaris inferioris, a two-dimensional cleft between the free edge of the uncinate process and the leading anterior ethmoid air cell in the middle meatus, the ethmoid bulla (Fig. 1.5b).

The uncinate process projects from the maxilla, easily recognized as a bony leaflet oriented upwards from the base of the inferior turbinate and the posterior margin of the nasolacrimal duct bony buttress. Its free edge defines the hiatus semilunaris inferioris and constitutes the medial wall of the ethmoid infundibulum.

The ethmoid bulla is the dominant ethmoid air cell projecting into the middle meatus, arising medially from the lamina papyracea of the orbit. Its attachment or bulla lamella can insert upwards into the skull base and the undersurface of the basal lamella of the middle turbinate, or into the lamina papyracea laterally. When it attaches to the lamina papyracea, the ethmoid bulla will create a narrow space between its roof and the basal lamella of the middle turbinate, recognized as the sinus lateralis, which can on occasion extend superiorly toward the frontal recess above the roof of the ethmoid bulla. The opening of the sinus lateralis toward the middle meatus is known as the hiatus semilunaris superioris.

The middle turbinate is a process of the ethmoid bone that defines the functional space of the middle meatus underneath it. Its basal lamella is attached vertically in the sagittal plane into the lateral lamella of the cribriform plate (Fig. 1.9). It continues posteriorly in a coronal orientation along the lamina papyracea and ends in an axial plane along the lateral nasal wall toward the choanna. This three-planar pattern of attachment is of paramount importance for the stability of the middle turbinate. This is most obvious after endoscopic surgical procedures, since surgical fracture of any of these planar attachments increases the likelihood of turbinate lateralization and secondary ostiomeatal complex postsurgical scarring and obstruction. In addition, the basal lamella of the middle turbinate represents the anatomic, embryologic and functional boundary between the anterior and posterior ethmoid sinuses. Any sinus spaces anterior to the basal lamella of the middle turbinate will drain toward the ostiomeatal complex, while any sinus spaces posterior to this structure will drain toward the sphenoethmoid recess.

1.5.2 Anatomic Variants of the Ostiomeatal Complex

- *Paradoxical middle turbinate*: inverted configuration of the middle turbinate, which curves toward the lateral nasal wall at the level of the ostiomeatal complex. It decreases the caliber of the middle meatus and may impair mucociliary drainage (Fig. 1.10a).
- *Concha bullosa*: pneumatization of the middle turbinate from its vertical attachment to its bulbous portion. By decreasing middle meatal caliber, it may become an obstructing lesion on the active phase of the nasal cycle. It may pneumatize from the anterior or the posterior ethmoid air cells (Fig. 1.10b).
- *Pneumatized uncinate process*: may decrease the hiatus semilunaris caliber (Fig. 1.10c).
- *Posterior fontanelle*: occasional defect in the lateral nasal wall behind the ethmoid infundibulum that freely communicates the maxillary sinus and the middle meatus (Fig. 1.10d). No mucociliary transit occurs through this space. Its presence must be recognized to avoid confusing it with the natural ostium of the maxillary sinus, which can result in failed middle meatal antrostomy.

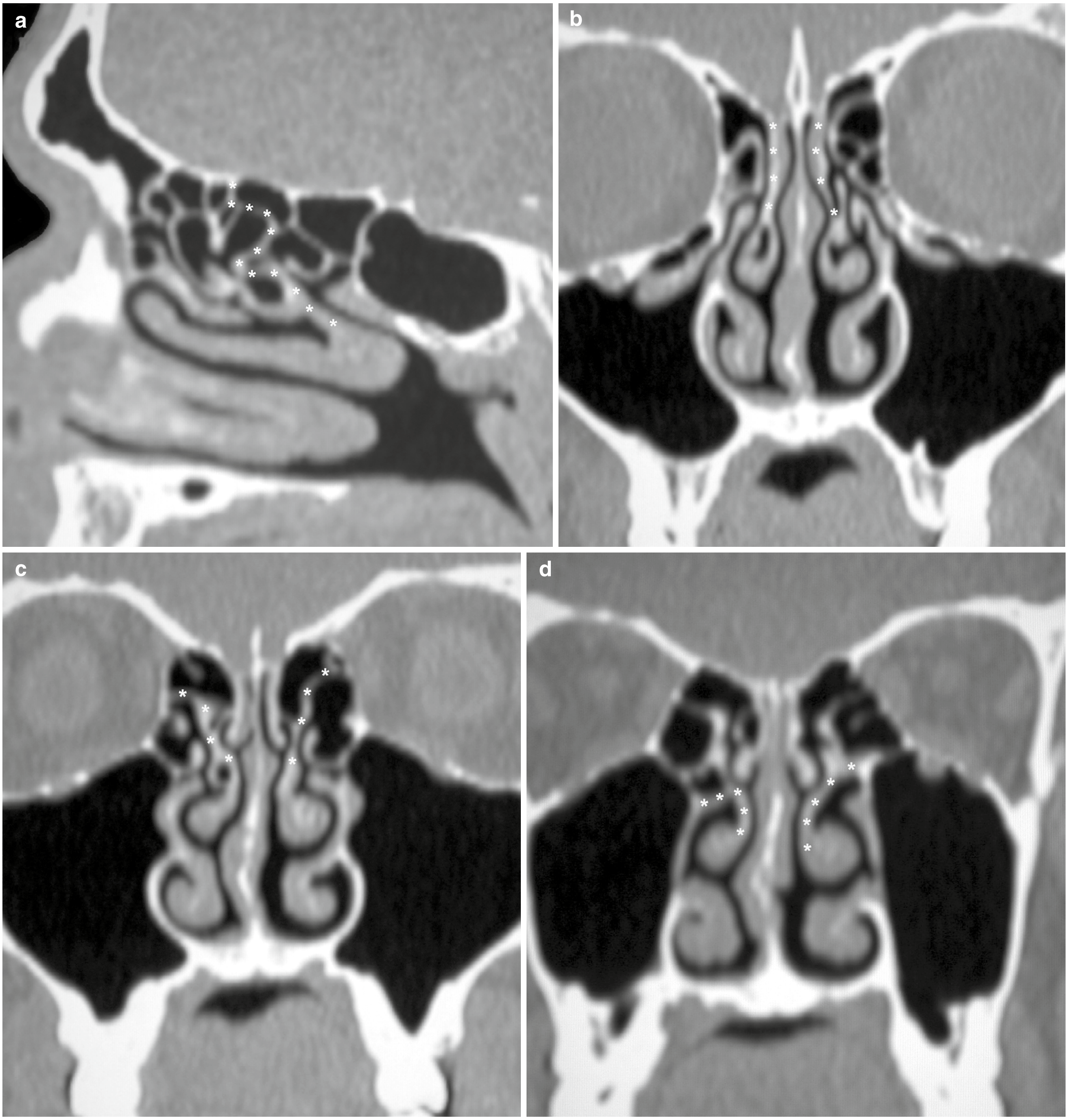

Fig. 1.9 Middle turbinate anatomy. The sagittal image (**a**) shows the complex deformity of the basal lamella of the middle turbinate (*asterisks*) deflected by the asymmetric competing growth of the anterior and posterior ethmoid cells. Sequential coronal images show the basal lamella of the middle turbinate in the sagittal plane (**b**) at the olfactory fossa, the coronal plane (**c**) at the lamina papyracea and the axial plane (**d**) at the posterior nasal cavity

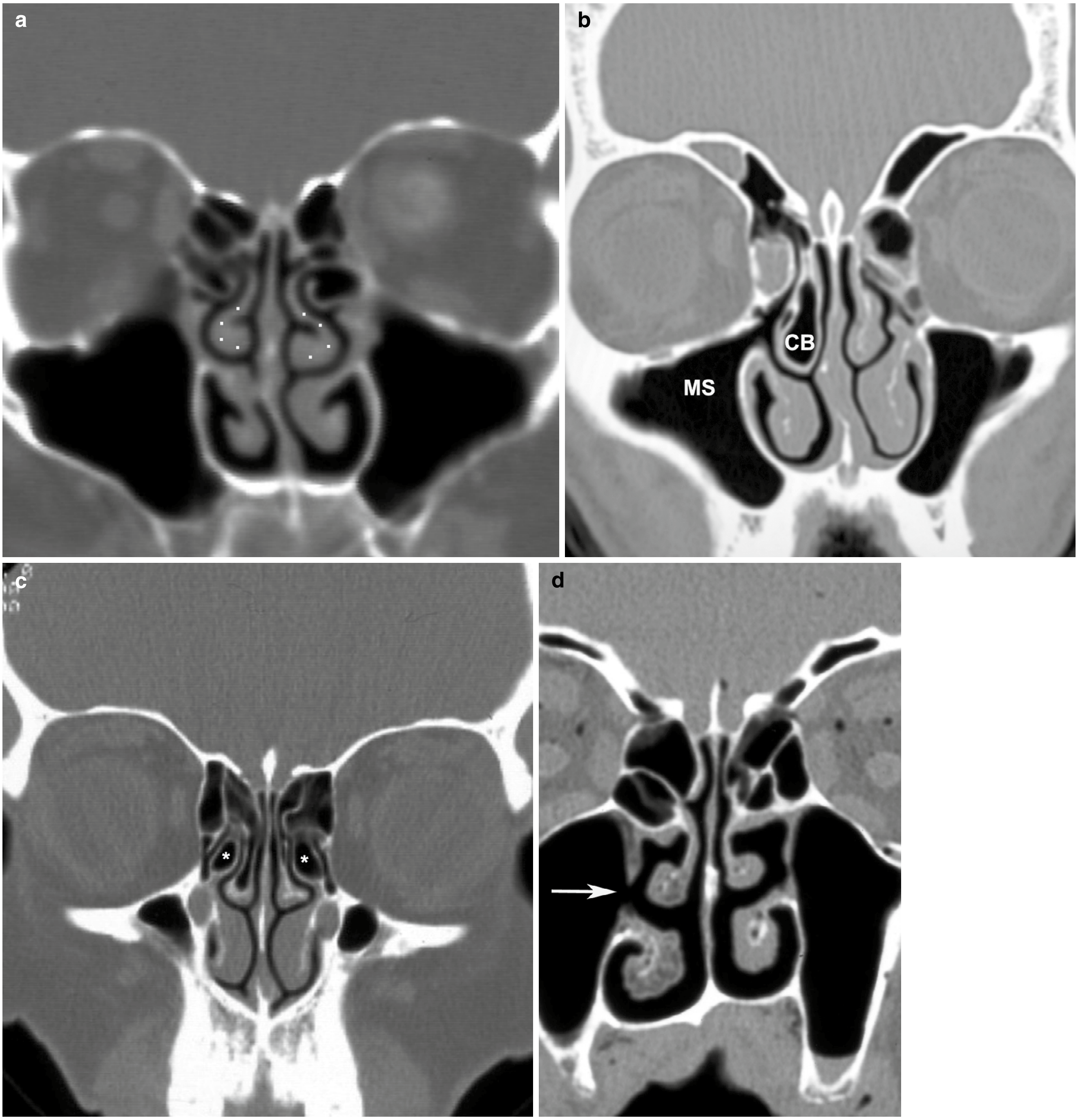

Fig. 1.10 Anatomic variants of the ostiomeatal complex. (**a**) Bilateral paradoxical turn of the middle turbinates (*dots*). (**b**) A typical pneumatized middle turbinate or concha bullosa (*CB*). Notice the uncinectomy at the natural ostium of the right maxillary sinus (*MS*). (**c**) Bilateral pneumatized uncinate processes (*asterisks*). (**d**) A wide right maxillary sinus posterior fontanelle (*arrow*), which may mimic a maxillary sinus ostium by endoscopy. *CB* concha bullosa, *MS* maxillary sinus