Endonasal Endoscopic Surgery of Skull Base Tumors: An Interdisciplinary Approach

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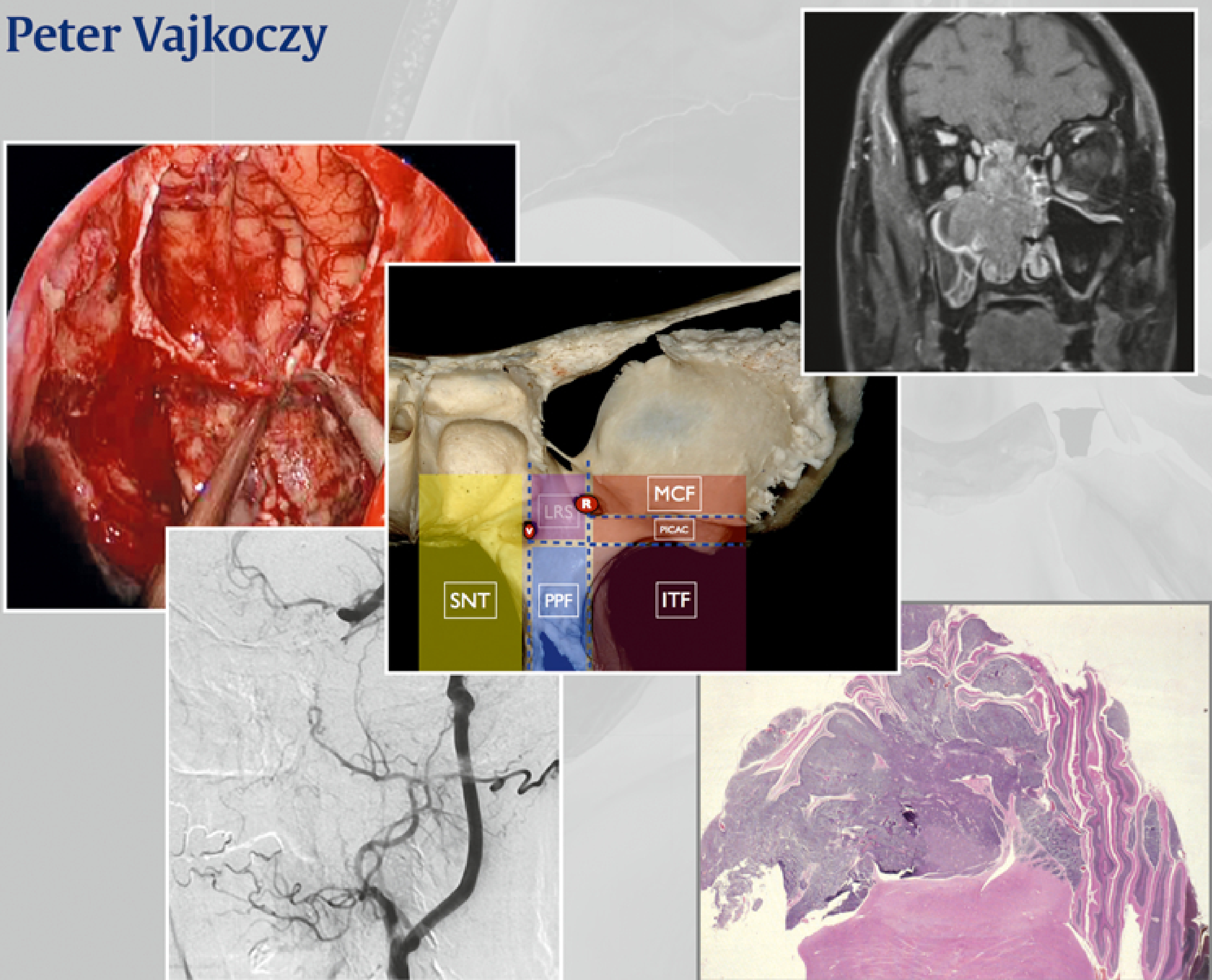

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In Memoriam

We dedicate this book to Professor Wolfgang Draf (1940–2011).

As the main surgical teacher of Ulrike Bockmühl, and as a close friend of Ricardo Carrau, Amin Kassam, and Peter Vajkoczy, he was the initiator and father of this book. But, unfortunately, he departed from us before we could finish it.

Wolfgang was an eclectic clinician and surgeon with interest in all the subspecialties of our discipline (otology, facial plastic surgery, head and neck oncology, rhinology, and skull base surgery). However, his heart would beat faster for rhinology and skull base surgery. His innovative and revolutionary contributions will mark forever the history of these two fields and his name will be passed on to future generations. He was among the first otolaryngologists to study and expand the indications of endoscopy as a diagnostic tool in paranasal sinus diseases. Additionally, he enthusiastically pioneered the use of the operative microscope in the field of sinonasal and skull base surgery for transnasal as well as external procedures. In the tireless effort of refining endonasal approaches to the sinuses, he realized that the microscope had limitations that could be overcome by the combined use of a microscope and endoscope, for which he coined the term "microendoscopic approach."

Among Wolfgang's numerous scientific contributions, the systematization of endonasal approaches to the frontal sinus, known as Draf type I to III drainages, which stands as a milestone in the history of modern rhinosurgery, deserves a special mention. His interest for frontal sinus surgery was a guiding theme in his professional life. He continued to refine his philosophy of management, remaining open to cooperation with other surgeons. He was also a pioneer in understanding the potential role of microendoscopic techniques in the transnasal resection of benign and malignant tumors. He strongly believed in the power of cooperation between different disciplines; therefore, he promoted the creation of multidisciplinary teams to take profit from the professional and surgical expertise of specialists in different areas.

Wolfgang authored many papers, books, and book chapters, as well as hundreds of invited lectures at meetings and courses worldwide and his contributions to the scientific sessions were marked by clarity, intuition, and balance. He was always open to new ideas ("never be dogmatic" was one of his preferred mottos) and he infected people with his unequaled humanity and enthusiasm. We will always miss his invaluable teachings, his sharp and balanced comments, and his witty and friendly company.

In commemoration of this honorable personality we completed this book.

The Editors

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Foreword

Some years ago, I received a letter from Professor Draf inviting me to write a foreword for this book. I felt honored for such proposal, coming from such a renowned teacher. I consider myself privileged to have lived these years inside a true evolutionary process, i.e. the endoscopic endonasal approach to skull base tumors. There are no secrets to explain the success of these techniques; one must only consider four major explanations:

The first is the widespread recruitment and active involvement of young surgeons. Their energy and enthusiasm have turned a mere "attempt to change" into a continuous and high pace development.

The second is the commitment to surgical competency rather than to titles, ranks, or interspecialty turf battles, academic or not.

The third is the partnership and exchange of ideas and concerns with pharmaceutical companies and instrument manufacturers. Day after day this relationship has helped satisfy the surgeon's quest for performance improvement.

The fourth and last reason, but by no means the least important, is the cooperation among different specialists. I cannot imagine the progress of our school in Naples without giving proper credit to the professionals of contiguous disciplines, which have contributed significantly to improve our outcomes. One should consider and ponder that we would have never understood the relevant anatomy without the contributions of Manfred Tschabitscher and his peers; that we could not be abreast of evolving diagnostic and therapeutic possibilities of contemporary neuroradiology without close contact with colleagues that deal and develop these techniques, namely neuroradiologists, interventional radiologists, and endovascular neurosurgeons; that we have a better understanding of the relationships of a surgical corridor and its target with the surrounding vasculature and neural structures due to Amin Kassam's obsession with acquiring a thorough anatomical knowledge and following meticulous pre- and intraoperative preparation; that we could not have understood the design of a transnasal approach or learn to respect nasal function without the tremendous experience and didactic perspectives of otolaryngologists such as Paolo Castelnuovo and other distinguished endoscopic surgeons; that we could not achieve an intraoperative systemic balance of the patients without the help of our operating room partners, the neuroanesthesiologists; that we depend on the collaboration with the pathologists to gain insight into our surgical specimens; and, that many times we owe our successes and ability to overcome the pitfalls of our surgeries to the interspecialty cooperation with endocrinologists.

Professor Draf has passed away, but his lessons stay; his legacy is immense and displays his extraordinary ability to share knowledge, his enthusiastic support for the scientific community and his will to participate in the process, his joy of learning, and the realization that one learns from teaching. Many times, hearing his name still sounds like music to me, like the music he loved.

The kind invitation from Professor Draf was repeated by Ulrike Bockmühl on the occasion of the 5th World Congress for Endoscopic Surgery of the Brain, Skull Base and Spine, held in Vienna in 2012, under the superb leadership of Professor Stammberger, and has been ultimately renewed by Ricardo Carrau. Ric represents the link between the otolaryngology and neurosurgical worlds, a master role model and a pioneer, a man and a "pro" per vocation, with an extraordinary sense of proportion, talented in adjusting everyday's balance, trying to find always the right distance; he figures as a paramount figure in the development and progress of skull base surgery.

This surgical opera collects the contributions from many big actors. In this current and wonderful season, it comprises the bright movement of humans and ideas around the world; thus promoting cross-fertilization among different specialties and in turn impacting all of us, from the individual to entire populations. I have experienced this change; I have crossed paths and connected with extraordinary men and women and with unique people that have changed my life. Ed Laws has offered his special values of science and humanism, and Dr A. Michael Apuzzo his sharp and broad mind. I owe many others, from around the world, who by visiting my service have exposed my residents, coworkers, professional partners, and myself to multiple and new stimuli; thus creating a virtuous mechanism, a method to move frontiers forward under the realities of a team approach.

I feel proud, as a neurosurgeon, to have the task of writing this foreword. In the endonasal team approach to the skull base many figures are complementary; however, I found myself thrown into the “parterre de roi” while still considering myself as just a soldier. As a soldier, I am proclaiming the multidisciplinary teams’ knowledge, competence, and respect for each other. All those who contribute to the progress are welcome, whether the contribution is strictly technological, surgical, biological, molecular, or other. Our common goal is to create a better future for the patients, and for the young generations of surgeons and physicians, those with the will to grow professionally and to better understand the disease processes. Together with constant improvement of our knowledge, techniques, and technologies we must be ready to accept novel forms of medicine, surgery, and engineering, targeted deeper toward the submolecular structures.

Nonetheless, one of the most significant innovations by those who have contributed to this book is the acceptance of the work and interventions by other specialists without feeling threatened or bothered in any way. On the contrary, they are and feel rather lucky to be able to grow and to exchange knowledge and know-how, and to live in the middle and be the caretakers of this evolution involving diseases and techniques, and impacting generations of patients and surgeons.

Paolo Cappabianca

Preface

"In times of change learners inherit the earth; while the learned find themselves beautifully equipped to deal with a world that no longer exists."

—Eric Hoffer

During the past 20 years neurosurgery and otolaryngology–head and neck surgery have evolved exponentially, bringing no less of a dramatic transformation to the treatment of skull base pathologies. In turn, the cross-pollination of multiple specialties with interest in the skull base has amplified the effect and spread of many alternative paradigms; thus, breeding a transmutation in both neurosurgery and otolaryngology–head and neck surgery. We have witnessed the introduction of subcranial approaches and pedicled flaps, and the evolution toward novel minimal access approaches such as endonasal endoscopic approaches and mini craniotomies. In conjunction with advancements in the fields of diagnostic and interventional radiology, radiation, and medical oncology, as well as technological innovations, we have improved our surgical armamentarium; henceforth, we have improved the surgical outcomes and quality of life of our patients.

The magnitude and speed of change are astounding; therefore, presenting a great challenge in keeping abreast of this ever-expanding and exciting bounty of information. Further progress can be expected as a result of ongoing experience and contemporary training by leading centers. This never-ending effort toward perfecting our care provides momentum and guidance in the search for new ideas. We remain both learned and enthusiastic learners and look forward to being humbled by new and advanced techniques that will turn our previous attempts into seemingly primitive tools.

Even in this era of digital information we rely on traditional time-proven methods to continue our medical education. A book still provides an experience and service that is different to that acquired online or with other digital media. However, books focused on the skull base are, by the very rare nature of the specialty, sparse; and that is especially true if we address those dealing with endoscopic endonasal techniques. These circumstances triggered the inception of our journey to edit a multidisciplinary book revolving around current endoscopic endonasal skull base surgery.

We have made a concerted effort to address the fundamentals of skull base anatomy and pathology that in conjunction with current diagnostic and interventional imaging techniques will serve to provide the reader with a deep understanding of these topics. Novel endoscopic endonasal surgeries are just a complement of pre-existent techniques and part of the continuous evolution of the specialty. As they mature, they will become the foundation of newer ones. Therefore, we offer a chapter where skull base pathologies are addressed from a 360° panoramic view, putting the endonasal approaches into the context of a complete skull base practice. A discussion of the general principles and management of the sinonasal corridor, addressing various perioperative concerns, follows this pivotal overview. At the core, various skull base surgery groups have favored us by presenting their experience, philosophy of treatment, technique, results, and clinical pearls. We are grateful for the altruistic spirit of all our contributors and feel extremely lucky that we were able to attract some of the most experienced skull base surgery groups from Europe and North America. Oskar Hirsch and Walter Dandy would be spellbound by the evolution of endonasal skull base surgery and the ensuing exchange of ideas more than 100 years after their independent introduction of transsphenoidal pituitary surgery.

We offer this comprehensive book on the management of skull base pathologies with the hope that it will serve as a study guide and reference work for "learners" in both neurosurgery and head and neck surgery. Notwithstanding, reader beware that although all the information offered was current at the time of writing, we do not claim to provide eternal certainties. Being "learned" is but a flitting moment.

The Editors

Acknowledgments

Although it is not possible to list all the formidable individuals who contributed to this project, we would like to express our gratitude to everyone involved in the creation of this book. Special recognition must be given to those who made this book possible:

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Chapter 1

History of Endonasal Tumor Surgery

1 History of Endonasal Tumor Surgery

Wolfgang Draf†, Philip Michael, Amir Minovi

1.1 Introduction

Endonasal tumor surgery developed from the interactions of the field of rhinology and the field of skull base surgery. Rhinology initially arose as a specialty centered on the management of infectious diseases of the nose and paranasal sinuses. Skull base surgery arose from the combined efforts of otolaryngologists–head and neck surgeons, craniofacial surgeons, and neurosurgeons devoted to the treatment of congenital, traumatic, neoplastic, and other various pathologies affecting this complex area. Importantly, skull base surgeons established the principles of management and surgery of the neurovascular anatomy that are critical to achieve optimal outcomes. Major advances in rhinology such as the introduction of microscopic and endoscopic visualization tools and techniques, and developments in radiology including computer-assisted tomography, magnetic resonance imaging, and interventional radiology, facilitated the benefits of endonasal tumor surgery. More recently these developments have been complemented through the use of powered instrumentation and intraoperative image guidance that have helped to optimize the results of endonasal surgery.

In this chapter, we hope to provide a brief summary highlighting major contributions from related specialties and significant developments that have led to improvements in endonasal skull base surgery (▶ Fig. 1.1) and have allowed it to become a fascinating and rapidly evolving concept.

1.2 The Origins of Sinus Surgery

Egyptian papyrus writings discuss rhinological techniques that were used by Egyptian surgeons to remove brain tissue transnasally as part of the mummification procedure.[1,2] In the second decade AD, Galen of Pergamum presented detailed anatomical studies of the nose describing the lamina papyracea and nasolacrimal duct.[3] It was later, during the Renaissance period, when Leonardo da Vinci (1452–1519) described different paranasal sinuses, including the maxillary sinus, and produced illustrations of the nasal conchae and the paranasal sinuses drawn from observations of anatomical specimens. Subsequently, Andreas Vesalius (1514–1564) differentiated between maxillary, frontal, and sphenoid sinuses, and Giovanni Filippo Ingrassia (1510–1580) delineated the anterior ethmoid cells. Furthermore, Nathaniel Highmore (1651) provided a detailed description

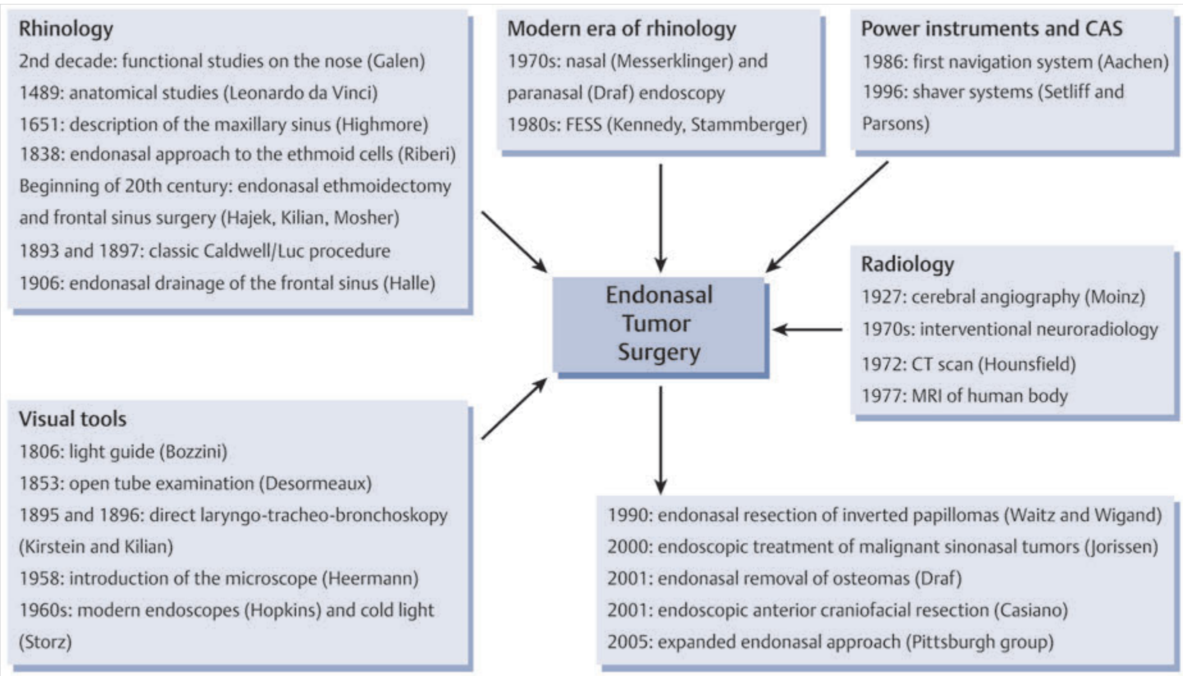

Fig. 1.1 Major steps from different disciplines in the evolution of endonasal tumor surgery. CAS, computer-aided surgery; CT, computed tomography; FESS, functional endoscopic sinus surgery; MRI, magnetic resonance imaging.

of the maxillary sinus, which subsequently conveyed his name: “Highmore’s antrum.”[4]

In 1660, C. V. Schneider (Wittenberg, Germany) concluded that the nasal mucus is not produced by the brain, but rather by the mucosa lining the paranasal sinuses.[5] Consequently, multiple approaches to the maxillary sinus were described to access these secretions. Molinetti (1675) published the description of an approach to the anterior maxillary sinus wall via an incision in the cheek[6] and Cowper and Drake reported the treatment of maxillary sinus suppuration through an opening of the alveolus.[3] Subsequently, Jourdain (1761) and Hartmann (1883) opened and irrigated the maxillary sinus through its natural ostium in the middle nasal meatus while Lichtwitz (1890, Bordeaux) performed the first irrigation of the maxillary sinus via puncture of the inferior meatus. Lamorier (1743) and Desault (1789) mentioned the canine fossa approach, which was also practiced by Küster (Marburg, Germany) a century later. However, unlike Lamorier, who suggested an opening through the tuber maxillae, Küster used a more anterior approach through the canine fossa utilizing a local cheek flap to line the opening creating a fistula, which was then used for further irrigation. Thereafter, Caldwell (1893) and Luc (1897) independently described a more radical surgery that included opening the anterior maxillary sinus wall in combination with an inferior meatal antrostomy. This classic Caldwell–Luc procedure remained the gold standard option in the treatment of maxillary sinusitis for many decades.

In 1905 Denker proposed enlarging the maxillary sinus approach by resecting the piriform crest. Of interest, Denker recommended the preservation of healthy mucosa as much as the procedure allowed. Although the pathophysiology of mucosa regeneration was not fully understood, a functional surgical strategy was advocated.[3]

Riberi (1838) first described an endonasal approach to the ethmoid cells in a case involving the management of the frontal sinus by resecting the lamina papyracea using a chisel. Subsequently, the endonasal ethmoidectomy technique was further refined by Gruenwald (1893), Hajek (1899), Killian (1900), and Uffenorde (1907).

In English publications, Mosher was regarded as the founder of endonasal ethmoid sinus surgery, describing a more detailed and structured surgical technique.[3] In 1912, Mosher suggested that the natural “ostium” of the frontal sinus could be reached more easily through an endonasal approach. At the beginning of this new period in rhinology, few surgeons were able to perform a successful ethmoidectomy and simple drainage of the frontal sinus, but Halle successfully performed endonasal drainage of the frontal sinus in 1906. In this pre-antibiotic and pre-endoscopic era, endonasal surgery of the paranasal sinuses was a life-threatening procedure with a high incidence of catastrophic complications including meningitis, brain abscesses, and encephalitis. Consequently, despite some early successes of endonasal surgery, Mosher declared that intranasal ethmoidectomy had been “proven to be one of the easiest ways to kill a patient.” Furthermore, anesthesia techniques were inadequate to provide a bloodless operative field.[3] It was for these reasons that for many decades most rhinologists advocated an external approach to paranasal sinus surgery. From 1920 to almost 1980, endonasal surgery was generally abandoned worldwide and remained relegated to a handful of centers.

1.3 Development of Visual Tools in Sinus Surgery

Endonasal sinus surgery was revolutionized and entered a new era with the introduction of the operating microscope and subsequently the rod-lens endoscope. In the middle of the 20th century, Heermann (1958) introduced the microscope in endonasal sinus surgery.[7] A decade before, the microscope was mainly used to aid surgery of the middle ear, as it provided excellent visualization of the surgical field. This development, together with the introduction of the self-retracting speculum, facilitated bimanual surgical techniques, which enabled the surgeon to apply suction with one hand and dissect in a relatively bloodless surgical field with the other hand.

However, it was the advent of rod-lens endoscopes that renewed interest in endonasal surgery. The roots of endoscopy can be traced to the 18th century, starting with the development of visual tools for examination of organs that were deeply located. Philipp Bozzini is regarded as one of the founding fathers of endoscopy. His “Lichtleiter” (light guide) consisted of a housing in which a candle was placed.[8] In 1853, for the examination of the genitourinary passages Antonin Jean Desormeaux[9] described an open tube, which contained condenser lenses to gain a higher light intensity. Subsequently this open tube endoscopy technique was used for direct laryngo-tracheo-bronchoscopy, first described by Kirstein in 1895 and then by Killian in 1896.[10]

In 1877, Max Nitze achieved another breakthrough when he developed the first cystoscope.[11] Following Edison’s invention of the filament globe in 1879, Nitze and his team were able to miniaturize it to a size that was small enough to fit into the tip of a cystoscope. However, Nitze’s lens system had many limitations including poor image quality and rigidity.

To overcome these deficiencies, Harold Horace Hopkins (▶ Fig. 1.1), a British physicist, began to use glass fibers for image transmission[12]; these transported the optical image with lower degradation of quality over a greater distance, thus revolutionizing endoscopic technology.[13] However, Hopkins’ innovation was ignored by industry and he was unable to continue his research. Despite this obstacle, in 1960, J. G. Gow, a British urologist, encouraged Hopkins to develop a cystoscope with improved image quality. Hopkins replaced the previous lens and air-interspace optical relays with glass rods. This development led to improved light transmission, which resulted in brighter and more detailed images. Furthermore, the viewing angle could be increased giving the examiner significantly better orientation. Using this technology, Hopkins was able to construct telescopes measuring 2 to 3 mm in diameter, which also revolutionized pediatric endoscopy. In early 1960s, Hopkins' endoscopic system was mostly ignored until Karl Storz, the head of Karl Storz Company, recognized the high potential of Hopkins' telescopes. In 1964 a very fruitful collaboration between Hopkins and Storz began. The value of these telescopes was further increased with the development of "cold light," provided by an external halogen light that transported the light through the entire length of the telescope.[13]

1.4 Diagnostic and Radiological Tools

Modern endonasal skull base surgery could not have been initiated without the parallel development of novel diagnostic tools including computed tomography (CT), magnetic resonance imaging (MRI), and angiography. In 1972, Godfrey N. Hounsfield, developed the CT scan in the UK, heralding a new era in diagnostic imaging.[14] Improvements in resolution of newer and faster CT scanners made this imaging technique increasingly popular and economical. At the beginning of the 1980s, W. Draf suggested the use of routine preoperative CT scans prior to embarking upon endoscopic sinus surgery.[15] This concept, which was initially heavily mistrusted and declined, is nowadays regarded as a matter of course. Development of a systematic preoperative CT evaluation for the treatment of chronic sinusitis ensued shortly afterwards.[16] Furthermore, CT was also advocated for the preoperative evaluation and treatment planning of sinonasal tumors.[17] Parallel to the development of CT, the diagnostic use of MRI started in the 1970s.[18] The first publication of MRI of the human body appeared in 1977. Subsequently, in the mid-1980s, the first reports of MRI of sinonasal tumors were published,[19,20] and in the following two decades MRI rapidly became the routine method of preoperative imaging of sinonasal tumors in addition to CT scans.[21]

Developments in angiography and interventional techniques, including embolization, greatly facilitated the endonasal management of highly vascularized tumors such as angiofibromas. In 1927, Egas Moniz, a neurologist from Portugal, reported opacification of the carotid artery by using a contrast medium; a technique that he called cerebral angiography.[22] Another major development was that of Seldinger, a Swedish radiologist, who introduced the percutaneous technique for cardiac catheterization in 1953. Further advances established interventional neuroradiology as a subspecialty of radiology and led to the development of endovascular neurosurgery. Consequently, the application of interventional neuroradiology and endovascular neurosurgery embolization of highly vascularized tumors has significantly broadened the options of endonasal tumor surgery.[23]

1.5 Powered Instrumentation and Navigation in Sinus Surgery

Orthopedic surgeons used soft-tissue shavers or microdebriders during knee arthroscopy for many years before they were introduced into endonasal surgery. Dr J. C. Urban held the patent for the original instrument that was named as a "vacuum rotatory dissector." In 1996, Setliff and Parsons introduced the use of soft-tissue shavers in endoscopic sinus surgery.[24] They rapidly became one of the most commonly used powered instruments in endonasal surgery. Additionally, bone-cutting drills have been especially beneficial in endonasal skull base surgery when there is a need for extended removal of the underlying bony structures.[25]

Image-guidance systems were first used in the field of neurosurgery[26] but were subsequently found to be beneficial in endoscopic sinus surgery. In 1985, RWTH Aachen University, Aachen, Germany, designed a prototype specific for rhinology. Schloendorff proposed the term "computer-aided surgery" (CAS), which was introduced in 1986.[26] Introduction of the first CAS system in otorhinolaryngology provided real-time information regarding the location of surgical instruments. Thus, CAS aided the localization of tumors and allowed radiological confirmation of nearby hazardous areas such as the orbit and brain. CAS systems are continuously being improved by the incorporation of new technologies such as real-time updated perioperative CT[27] and they are now regarded as useful tools during endonasal tumor surgery.[28] However, it has been highlighted that CAS systems should remain an adjunct to surgical procedures rather than a replacement for surgical technique and experience.[29]

1.6 Functional Endonasal Sinus Surgery

In the period from the 1950s to the 1970s, the development of new optical aids including the operating microscope and rod-lens endoscopes revolutionized the surgical management of rhinosinusitis. Improvements in the understanding of the pathophysiology of paranasal sinus inflammatory disease played an important role in the rebirth of endonasal sinus surgery.

Endoscopes with a smaller diameter, higher illumination, and improved resolution motivated surgeons such as Messerklinger to switch from a microscope to the endoscope for functional studies of nasal and paranasal sinus mucosa (function).[30] On the basis of Messerklinger's studies regarding the pathogenesis of chronic rhinosinusitis, his student Heinz Stammberger introduced a conservative method of sinus surgery. David Kennedy, in the United States, adopted this technique and their combined efforts propelled functional endoscopic sinus surgery to a global scale.[31,32] They declared that the main goal of this surgery was to "maintain mucociliary function where possible."[33]

Complementing the findings of Messerklinger, who investigated the anatomy and pathophysiology of the nose and its relationship to chronic sinusitis, Wolfgang Draf examined the different sinuses systematically and directly,[34] becoming the first person to perform endoscopy of the frontal and the sphenoid sinus. His primary goal was to formulate more robust indications for sinus surgery, thereby avoiding unnecessary radical procedures; especially taking into consideration that imaging techniques at that time were limited and offered only plain radiograms and only occasionally conventional tomography. Subsequently, and emulating Messerklinger, Draf began to utilize endonasal techniques to manage inflammatory sinonasal disorders using the operating microscope in combination with rigid endoscopy and powered instrumentation. Between 1980 and 1984, the Fulda School developed a system of endonasal drainage procedures directed at the frontal and sphenoid sinuses.[35]

1.7 The Development of Endonasal Oncologic and Skull Base Surgery

After the new era of endonasal sinus surgery was established, a few surgeons adopted an exclusively endonasal approach for the removal of benign tumors. In 1990, Waitz and Wigand were the first to present such an exclusive endonasal endoscopic approach for the resection of inverted papillomas in a large series of patients.[36] Later, others reported the endonasal resection of other benign tumors such as osteomas.[37] The increased recognition of endonasal tumor surgery did not come without controversy, debate, and mistrust. Many surgeons argued that a purely endonasal approach may compromise the ability to remove tumor in its entirety resulting in potentially higher recurrence rates.[38] Others advocated that a complete, en bloc tumor resection was essential. Nevertheless, further developments of endonasal surgery over the last two decades have led to the wide acceptance of the concept that the endonasal approach for benign tumors is adequate in most cases.

Several authors have reported large series highlighting the possibilities, and also the limitations, of endonasal tumor surgery.[21,39] In particular, endoscopes afford an improved assessment of deeper structures and provide the capability to "look around the corner." Subsequent to the acceptance of the endonasal technique for the excision of benign lesions, a few authors presented their experience with endonasal resection of malignant tumors.[40] Casiano described endoscopic anterior craniofacial resection for the management of esthesioneuroblastoma[41] and the Fulda group reported a large series of selected malignant tumors managed through an endonasal approach.[25]

Several authors have demonstrated that in selected cases endonasal tumor surgery using en bloc or piecemeal resection and controlled by intraoperative histologic analysis (i.e., frozen sections)[42,43,44] produces equal or superior results in comparison with the traditional external procedures such as lateral rhinotomy, midfacial degloving, and subcranial operations. However, this does not mean that traditional surgical techniques are obsolete, as surgeons advocate their use in patients with large tumors.

Whereas the initial developments in nasal endoscopy were directed at the nose and paranasal sinuses, the advent of the aforementioned technological advancements in imaging coupled with procedure-specific surgical instrumentation has broadened the anatomical access afforded via the transnasal route. Interdisciplinary groups of endoscopic skull base surgery have been based upon the earlier initiatives of Sethi et al (1995) in Singapore[45] and Jho et al (1997) in Pittsburgh[46] with the endonasal approach to pituitary surgery now being commonplace. Subsequently, through the use of thorough surgical planning and training, the Pittsburgh group further developed the so-called expanded endonasal approaches. These approaches enable access to the entire ventral skull base with a minimally invasive approach associated with oncological outcomes that are comparable with conventional techniques.[47]

The first Interdisciplinary Congress of Endoscopic Surgery of the Skull Base, Brain and Spine took place in Pittsburgh in 2005 as a result of the efforts of Ricardo Carrau (otolaryngologist–head and neck surgeon), Amin Kassam (neurosurgeon), and Carl Snyderman (otolaryngologist–head and neck surgeon). This meeting brought together the Pittsburgh group with many other pioneers of endonasal endoscopic surgery from already advanced interdisciplinary groups from all over the world, for example: Paolo Castelnuovo (otolaryngologist–head and neck surgeon) from Varese, Italy, and Piero Nicolai (otolaryngologist–head and neck surgeon) from Brescia, Italy, and their neurosurgical partner Davide Locatelli (neurosurgeon); Wolfgang Draf and his neurosurgeon Robert Behr, Fulda, Germany; Georgio Frank (neurosurgeon) and Ernesto Pasquini (otolaryngologist–head and neck surgeon), Bologna, Italy; Paolo Cappabianca (neurosurgeon), Naples, Italy; Alexandre Felippu, Aldo Stamm, and Velutini (otolaryngologists and neurosurgeon from São Paulo, Brazil); Heinz Stammberger (otolaryngologist–head and neck surgeon) and Michael Mokry (neurosurgeon) from Graz, Austria; Vijay Anand (otolaryngologist) and Theodore Schwartz (neurosurgeon) from New York, United States; Alfredo Herrera (otolaryngologist–head and neck surgeon), Bogota, Colombia; and many others. It was a highly stimulating event and it was decided to continue this exchange in different cities around the world.

1.8 Conclusions

As described above, the evolution of endonasal tumor surgery was achieved through a variety of new inventions and contributions from related specialties. In particular, close interdisciplinary collaboration(s) between otolaryngologists–head and neck surgeons, neurosurgeons, and neuroradiologists during the last four decades has significantly contributed to the progress in this field.

More recent developments in techniques and equipment have increased the breadth of anatomical access afforded by minimally invasive, endonasal routes to areas previously restricted to conventional, external, neurosurgical approaches. Consequently, endonasal tumor surgery remains a fascinating field and further advancement of its techniques with fewer complications, together with a higher quality of life, is expected.

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Chapter 2

Anatomy of Anterior, Central, and Posterior Skull Base

2

2 Anatomy of Anterior, Central, and Posterior Skull Base

2.1 The Osseous Anatomy of the Skull Base and Related Regions

Andreas Prescher

2.1.1 Introduction and General Aspects

The human skull base is a very complicated anatomical structure, which has intensive topographical relations to important neurovascular structures and sense organs. Therefore, the skull base demands a specialized and very detailed anatomical knowledge to achieve a successful surgery. Furthermore, the skull base involves different medical disciplines such as neurosurgery, ear, nose, and throat surgery, maxillofacial surgery, ophthalmology, neuropathology, and neuroradiology. Anatomy, embryology, and developmental sciences, as well as comparative anatomy, are also involved. In particular, the radiological and neuroradiological exploration of the skull base demands a very distinct knowledge of the topography, the variations, the abnormalities, and the pathology. Because of this exhaustive complexity of the structure "skull base" the International Skull Base Study Group was founded in 1979 in Montpellier by Hermann Dietz, Wolfgang Draf, Claude Gros, Jan Helms, Pierre Rabischong, Madjid Samii, and Kurt Schürmann.

In presenting an anatomical survey of the anatomy of the human skull base, the first step is to consider the osseous structures, which are fundamental. In the second step the muscles, vessels, and nerves are important and must be added to the osseous structures. In the last step the surgical and endoscopic anatomy will complete the whole survey and present the essential landmarks, the topography, and practical important facts. The overview of skull base anatomy in this book follows this concept. The important developmental history (ontogeny as well as phylogeny) of the skull base, which is the key to the different variations and malformations, is not addressed in this section, and only some hints to essential abnormalities are given. On the other hand, the paranasal sinuses are described in detail, because their conditions are relevant for the anatomy of endoscopic approaches.

The human skull base is a terracelike base plate for the cerebrum, cerebellum, and brain stem, and it can be divided into the anterior, middle, and posterior cranial fossa (▶ Fig. 2.1). In each fossa typical parts of the central nervous system are localized. In addition, each fossa can be subdivided for systematic description into two lateral parts and a medial one. The anterior cranial fossa consists of three osseous components: the frontal bone, the ethmoidal bone, and the sphenoid bone. Dorsally the anterior fossa is bordered by the margins of the lesser sphenoid wings, which are medially ending as anterior clinoid processes and the anterior margin of the prechiasmatic sulcus. The medial cranial fossa has only two components: the sphenoid bone and the temporal bones. This important fossa is bordered dorsally by the superior angle of the petrous pyramid in its lateral parts, whereas the dorsum sellae constitutes the dorsal border of the medial part. The posterior fossa is composed of the temporal bones and the occipital bone, with its basilar part, its lateral parts, and the inferior part of the squama ossis occipitalis.

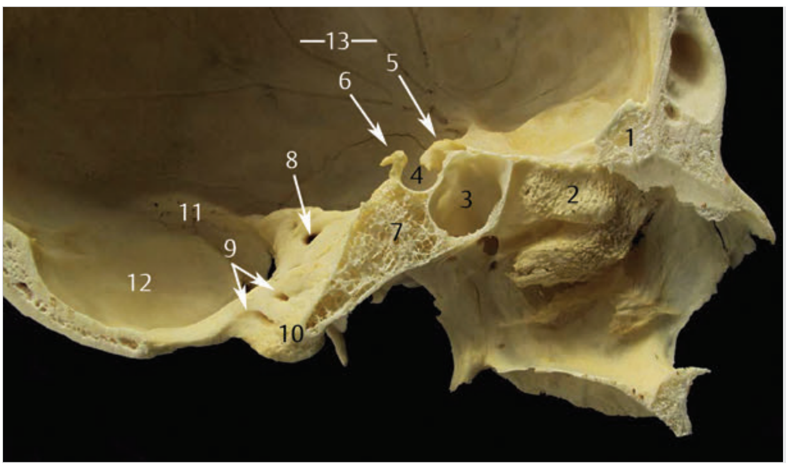

Fig. 2.1 Median sagittal section of the skull base presenting the terracelike architecture with the anterior, middle, and posterior cranial fossa.
1, Crista galli; **2**, concha nasalis superior; **3**, sphenoid sinus; **4**, sella turcica; **5**, processus clinoideus anterior; **6**, dorsum sellae with processus clinoideus posterior; **7**, clivus; **8**, porus acusticus internus; **9**, bipartite canalis hypoglossi; **10**, condylus occipitalis; **11**, sulcus sinus transversi and sigmoidei; **12**, fossa cerebellaris; **13**, sulci arteriosi of the middle meningeal artery.

2.1.2 Anterior Cranial Fossa

Medial Area

In the medial part, the olfactory fossa is visible; this consists of the fragile lamina cribrosa and the crista galli as midline structures. The height of the crista galli decreases from anterior to posterior. Different morphologic types of the crista galli, as well as of the cribriform plate, have been described.[1] In front of the crista galli the foramen cecum can be seen, which is normally obliterated in the adult. Posteriorly this foramen is bordered by the alar processes of the ethmoid, and anteriorly it is formed by the frontal bone. During development, an extension of the superior sagittal sinus passes through the foramen cecum and joins the venous system of the nasal cavity. Only in rare cases do this duct and its venous connection persist into adulthood. In contrast to this widely accepted concept, other authors[2] state that only connective tissue can be found within the foramen cecum, even in young children or fetuses. In front of the foramen cecum the crista frontalis is localized as an osseous ridge, which is often divided by the sulcus for the superior sagittal sinus. Both structures, the crista galli and the crista frontalis, are important for the insertion of the falx cerebri.

The cribriform plate presents a lot of little foramina olfactoria: 43 on the right side and 44 on the left side.[1] Furthermore, it is important that the foramina olfactoria often present larger foramina, often adjacent to the crista galli. At the bottom of these larger foramina, smaller foramina can be recognized. Therefore Sieglbauer[3] described the lamina cribrosa as a multilayered sieve. In the anterior part a distinct foramen for the passage of the anterior ethmoidal artery, accompanied by the anterior ethmoidal nerve and vein, can be described: the foramen cribro-ethmoidale.

The lateral border of the olfactory groove is formed by the thin lamella lateralis (see next). This lamella lateralis usually presents also a small foramen or cleft in its anterior or medial part, where the orbitocranial canal, containing the anterior ethmoidal artery, vein, and nerve, enters the endocranium. In the posterolateral corner of the olfactory fossa, between the cribriform plate, the sphenoid bone, and the pars orbitalis ossis frontalis, the posterior ethmoidal artery usually enters the endocranial cavity, accompanied by some little nerves and veins (▶ Fig. 2.2). This small entrance is often covered by a little osseous lamella, so that it can be difficult to recognize. Posteriorly, a variable osseous ridge borders the olfactory fossa from the planum sphenoidale, which ends at the anterior margin of the prechiasmatic sulcus. This slight osseous margin is known as limbus sphenoidalis.

Lateral Area

The lateral parts of the anterior cranial fossa are formed by the partes orbitales ossis frontalis, which often show irregular prominences, the juga cerebralia, as well as depressions, the impressiones digitatae. It is important that the lateral parts are not horizontally oriented, but present a typical declination from lateral to medial. Moreover, two characteristic depressions must be described: the fovea endofrontalis lateralis and medialis. These two foveae are separated by the slight eminentia endofrontalis (▶ Fig. 2.2 and see also ▶ Fig. 2.16). In the posterior lateral part, the frontosphenoidal suture can be recognized, whereas in the medial part the variable sphenoethmoidal suture appears, especially in younger skulls.

Important Variations and Pathologies of the Anterior Cranial Fossa

1. In elderly people the pars orbitalis ossis frontalis often can be markedly thinned, and also with the formation of dehiscences.
2. In some patients, mostly females (90% female and 10% male[4]), a condition called the hyperostosis frontalis interna affects the frontal bone as well as the anterior cranial fossa (▶ Fig. 2.3). This pathology is characterized by smooth, white-colored osseous excrescences of the inner surface of the frontal bone, in many cases including the major wing of the sphenoid bone and the temporal bone. The affected structures are also greatly thickened, but the outer surface is always

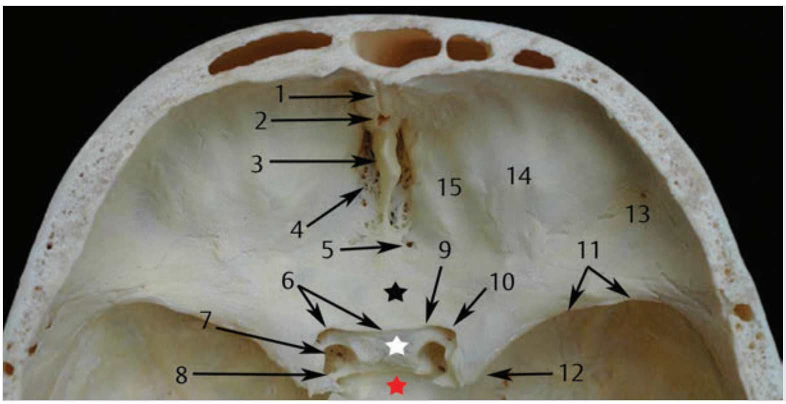

Fig. 2.2 Anterior cranial fossa.
1, Crista frontalis; **2**, foramen caecum; **3**, crista galli; **4**, lamina cribrosa; **5**, osseous corner, where the canalis orbitoethmoideus enters the endocranium; **6**, limbus sphenoidalis; **7**, foramen caroticoclinoideum (Henle); **8**, processus clinoideus medius; **9**, sulcus prechiasmaticus; **10**, canalis opticus; **11**, ala minor ossis sphenoidalis; **12**, processus clinoideus anterior; **13**, fovea endofrontalis lateralis; **14**, eminentia endofrontalis; **15**, fovea endofrontalis medialis. *Black star*, planum sphenoidale; *white star*, sulcus prechiasmatis; *red star*, sella turcica.

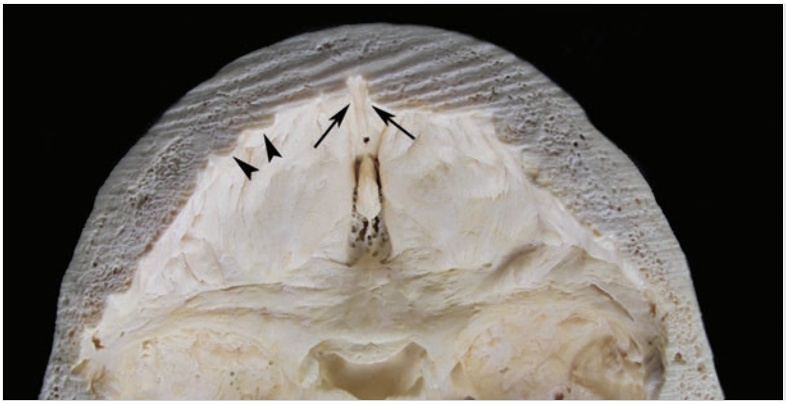

Fig. 2.3 Hyperostosis frontalis interna. Typical thickening of the frontal bone and anterior cranial fossa. Note the characteristic smooth osseous excrescences (*arrowheads*) and the pronounced sulcus for the superior sagittal sinus (*arrows*).

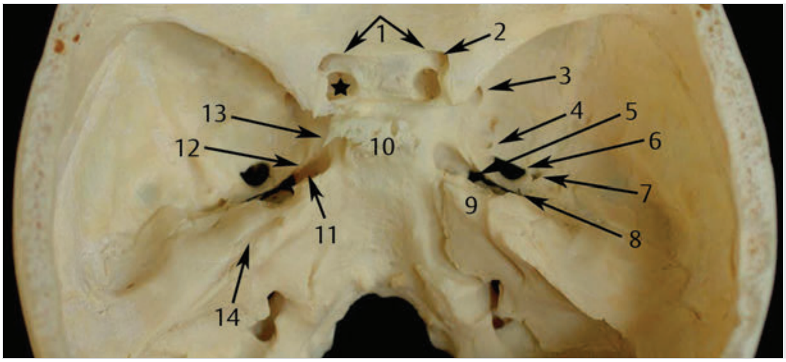

Fig. 2.4 Middle cranial fossa.
1, Limbus sphenoidalis; **2**, canalis opticus; **3**, canalis rotundus; **4**, foramen vesalianum; **5**, foramen lacerum; **6**, foramen ovale; **7**, foramen spinosum; **8**, fissura sphenopetrosa; **9**, incisura trigeminalis; **10**, dorsum sellae; **11**, sulcus caroticus; **12**, lingula sphenoidalis; **13**, processus clinoideus posterior; **14**, sulcus sinus petrosi superioris. *Star*, foramen caroticoclinoideum (Henle).

unaffected and smooth. Frequently the region of the superior sagittal sinus and the adjacent areas also remain unaffected, so that the condition is divided in the midline. The dura mater adheres strongly at the osseous excrescences and cannot be separated from the underlying bone. The hyperostosis frontalis interna is often part of a triad, including hirsutism and obesity. This triad is known as Morgagni syndrome. It is questionable whether this syndrome has any clinical significance beyond contributing to the differential diagnosis. For surgery it can be important because of the exhaustive thickening of the bone and the extremely fixed dura mater.

3. At the margin of the ethmoidal incisure, where the chondrially developed ethmoidal complex fits to the frontal bone, typical clefts can persist. These osseous clefts are positioned within the frontoethmoidal sutures or the directly neighboring osseous areas. These defects are responsible for the formation of celes in this region.[5]

2.1.3 Middle Cranial Fossa

Medial Area

The medial part of the middle cranial fossa (▶ Fig. 2.4) is dominated by the corpus ossis sphenoidalis and its typical surface structures. Anteriorly there is the prechiasmatic sulcus, which continues to the optic canal, positioned just anteromedial to the root of the anterior clinoid process. In 1 to 2% of individuals the optic canal presents a small inferior portion, separated by a complete or incomplete osseous bar termed the ophthalmic canal (foramen clinoideo-ophthalmicum), containing the ophthalmic artery.

The anterior clinoid processes, which are pneumatized in some cases, are important for fixing the anterior petroclinoid fold of the tentorium cerebelli. Furthermore, the anterior clinoid process is an important anatomical landmark for the internal carotid artery (ICA), which lies directly medial to the process. Just behind the prechiasmatic sulcus, the variable tuberculum sellae (s. eminentia olivaris) can be recognized. Behind this landmark the sella turcica is visible. The anterior edges of the sella can be bordered by variable small osseous protuberances known as the medial clinoid processes. The floor of the sella turcica presents in its center a small depression, called the fossa hypophyseos, which contains the hypophysis cerebri. The dorsum sellae borders the sella against the posterior cranial fossa. According to the shape of the dorsum sellae, four types can be distinguished[6]: forklike (10.4% of individuals), transitional form (37.5%), wall-like (45.8%), and sticklike (6.2%). In addition, the dorsum often presents as a filigree and fragile osseous structure with a cranially thickened margin. Laterally this