
Contemporary Review

Celebrating the Golden Anniversary of Anterior Skull Base Surgery: Reflections on the Past 50 Years and Its Historical Evolution

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With its inception nearly half a century ago through the pioneering work of Dandy, McLean, and Smith, anterior skull base (ASB) surgery is a relatively young discipline. It became a distinct entity in 1963 when Ketcham popularized the combined transcranial transfacial approach for en bloc resection of tumors of the paranasal sinuses extending into the anterior cranial fossa. However, because these procedures resulted in major morbidities and mortalities, alternative modes of treatment were sought. Since the 1970s, the introduction and promotion of the surgical endoscope by Messerklinger, Stammberger, and Kennedy, commenced the era of endoscopic sinus surgery. Thaler and colleagues described the utility of the endoscope for ASB surgery at the turn of the century. This allowed direct visualization and safer, more accurate removal of tumors. In 2001, Casiano reported the first purely endoscopic endonasal ASB resection, a novel technique that has been adopted by major skull base centers. The success of ASB surgery can be attributed to both the development of the skull base team as well as improvements in surgical techniques, instrumentation, and visualization technology. In this article, we review the historical evolution of ASB surgery as we approach the 50th anniversary since its recognition as a distinct entity.

Key Words: Anterior skull base surgery, open anterior craniofacial resection, endoscopic skull base surgery, endoscopic sinus surgery, nasal endoscope, Ketcham, Messerklinger, Stammberger, Kennedy, Casiano, Kassam.

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INTRODUCTION

Anterior skull base (ASB) surgery began in the early 1940s, when Dandy¹ and Ray and McLean² described transcranial excision of orbital tumors. In 1954, Smith et al.³ described a combined transcranial transfacial approach to resect malignancies of the paranasal sinuses and adjacent areas. This approach was later popularized by Ketcham et al.⁴ in 1963, thus marking the beginning of ASB surgery as an individual discipline. Since its inception, anterior craniofacial resection (ACFR) has been considered the gold standard for resection of ASB tumors, particularly for paranasal

sinus tumors extending into the skull base, by most head and neck surgeons.^{5–8}

Endoscopic sinus surgery (ESS) was first introduced to the field of otolaryngology in the 1970s by the Austrian surgeon Walter Messerklinger for treatment of chronic rhinosinusitis.⁹ In 1975, under the guidance of Messerklinger, his protégé, Heinz Stammberger, further championed the art of ESS.¹⁰ Across the Atlantic in 1985, David Kennedy and colleagues introduced ESS to the United States.¹¹

The utility of the endoscope was recognized for ASB surgery just before the turn of this century. In 1999, Thaler et al.¹² described endoscopic-assisted ACFR for tumors with intracranial extension. Direct endoscopic visualization with this technique allowed for safer and more accurate removal of tumors without sacrificing vital neurovascular structures.¹² The endoscopic-assisted ACFR technique became almost the standard in performing these procedures in major academic centers around the country.^{13–15} In 2001, Casiano et al.¹⁶ reported the first purely endoscopic endonasal ASB resection in five esthesioneuroblastomas, a technique adopted by many skull base centers for treatment of a variety of different pathologies.

The introduction of the endoscope in ASB surgery has since propagated the formation of a collaborative

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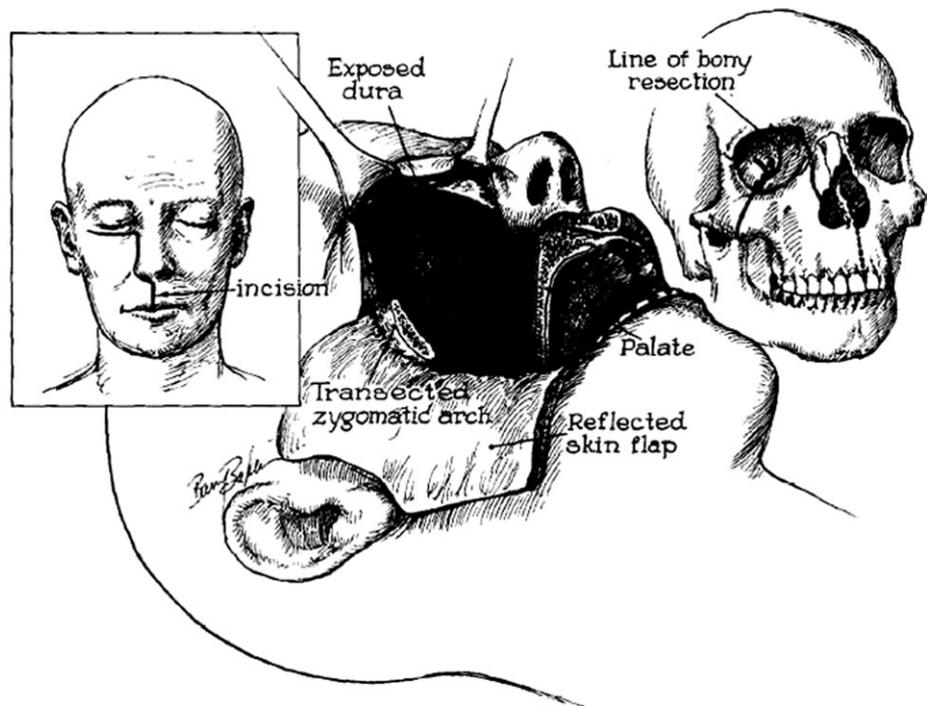


Fig. 1. Illustration of a combined transcranial, transfacial removal of malignant tumor involving the paranasal sinuses by Ketcham et al.⁴ in 1963 showing the intracranial facial resection and the defect in the floor of the anterior cranial fossa. The exposed dura is covered by a skin graft, which lines the entire defect. The insert on the left demonstrates the incision made to elevate the facial flap and the insert on the right outlines the facial bone that is removed. Reprinted with permission from Ketcham et al.⁴

effort between the otolaryngologist and neurosurgeon. In addition, a number of technological advances have enabled major evolutions in surgical technique. Over the past decade, the application of open and endoscopic approaches to the ASB has grown and continues to progress. In this article, we review the historical evolution of ASB surgery from open to endoscopic resection of complex pathologies.

THE NAISSANCE OF ANTERIOR SKULL BASE SURGERY

Anterior skull base surgery was first established as a distinct entity in 1963, when Ketcham et al.⁴ reported their results in 19 patients with paranasal sinus tumors with intracranial extension. Their procedure consisted of a combined transcranial transfacial approach (Figs. 1 and 2), in which the goal was en bloc resection of the malignant tumors. In 1968, Van Buren et al.¹⁷ concluded that this radical approach can achieve “en bloc resection of the antrum, orbital contents (if required), and both ethmoid sinuses including the base of the skull as needed”(Fig. 3).¹⁷ These initial reports laid the foundation for accepting the combined transcranial transfacial approach, better known as ACFR, as the standard surgical treatment of malignancies arising in the paranasal sinuses.¹³⁻¹⁵ Although successful under the purview of an experienced surgeon, these initial series using ACFR have reported several limitations such as a high incidence of operative complications and postoperative infection leading to high morbidity and mortality.^{5,15} The introduction of newer antibiotics, improvements in postoperative care, and advancements in surgical technique resulted in better surgical outcomes.¹⁸

By the early 1990s, many large centers published their results with ACFR for various primary and meta-

static sinonasal and ASB tumors, including esthesioneuroblastomas, squamous cell carcinomas, chondrosarcomas, melanomas, basal cell carcinomas, adenocarcinomas, malignant schwannomas, malignant hemangiopericytoma, adenoid cystic carcinoma, poorly differentiated carcinomas, as well as other miscellaneous

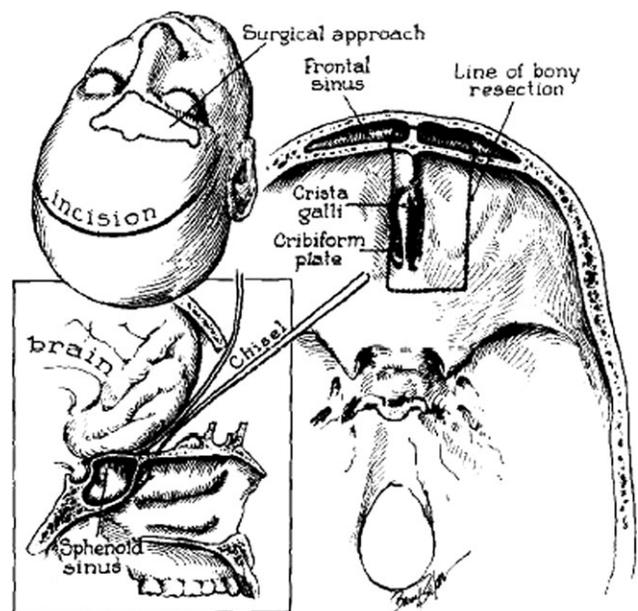


Fig. 2. Illustration depicting a combined transcranial, transfacial resection of a malignant tumor involving the paranasal sinuses by Ketcham et al.⁴ in 1963. The intracranial approach to the cribriform plate is done by reflection of a frontal flap and retraction of the frontal lobe. The area of the osteotome resections are outlined. The lateral view shows how the sphenoid sinus is avoided during resection. Reprinted with permission from Ketcham et al.⁴

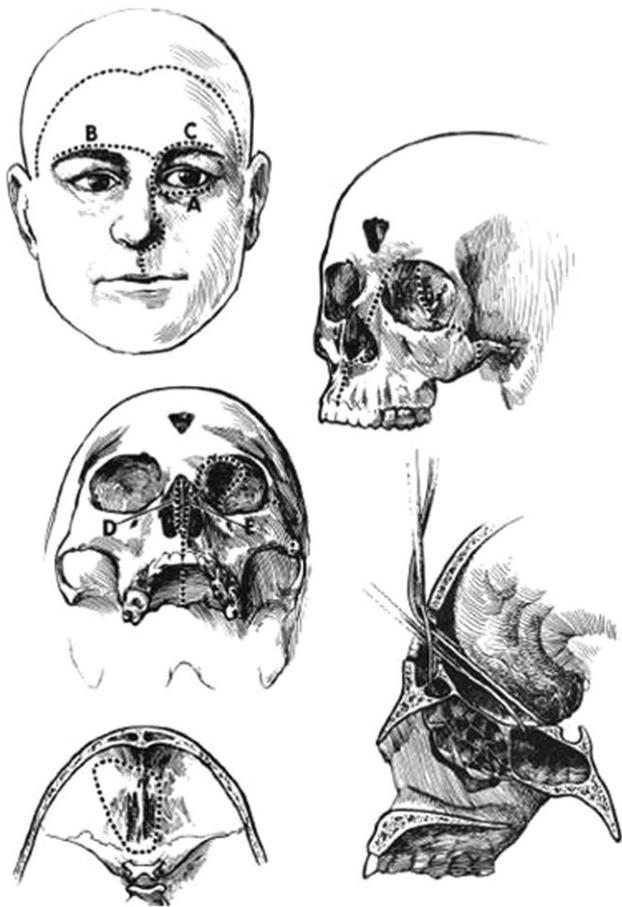


Fig. 3. Illustration of the incisions and lines of osteotomy described in Van Buren et al.¹⁷ A, B, and C refer to elective extensions of the basic paranasal incision. D and E indicate line of resection to include or avoid the nasal septum. When not directly involved, the septum is retained. Note low frontal osteotomy and exenteration of frontal sinus with its extensions. Reprinted with permission from Van Buren et al.¹⁷

benign and malignant tumors.^{19–34} In 1996, McCutcheon et al.¹⁹ compared the results from cases that required ACFR versus those that only required transcranial resection. They concluded that ACFR was useful for removal of erosive tumors originating from the sinuses that invade into the anterior cranial fossa or extend beyond the confines of the standard transfacial approaches. The results of these studies promulgated the use of ACFR and led to further modifications in technique and improvement in surgical outcomes. However, soon afterward, en bloc resection, one of the primary benefits of ACFR, was called into question due to the surgeon's inability to visualize key anatomic structures such as the orbital apex, frontal recess, and sphenoid sinus.^{12,19,35}

INTRODUCTION OF ENDOSCOPIC SINUS SURGERY

The introduction of the endoscope in otolaryngology by Messerklinger launched the era of ESS. Messerklinger applied the endoscope to examine the nasal passages

and sinuses, which when combined with computed tomography, allowed enhanced diagnosis of nasal and paranasal sinus disease. His technique demonstrated that the restoration of the normal mucociliary flow pattern in the sinuses was essential for treatment of chronic rhinosinusitis.¹⁰ This restoration was achieved by widening the sinus ostia in a relatively atraumatic fashion while preserving the sinonasal mucosa. Under the direction of Messerklinger, Stammberger learned ESS at the University Medical School at Graz. After completing his training in 1980, he went on to practice ESS and skull base surgery and further promoted the use of the endoscope in treating sinus disease.

It was shortly after in 1985, that Kennedy, a pupil of Stammberger, introduced ESS in the United States. The advantages conferred by the endoscope in ESS were: 1) enhanced visualization, 2) improved cosmesis given that the natural nasal corridor obviated the need for external incisions, 3) decreased operative complications, 4) decreased blood loss, and 5) shorter hospital stay.^{36–39} At first, otolaryngologists utilized ESS primarily as a treatment for chronic rhinosinusitis that was refractory to medical management.⁴⁰ ESS has thus progressed from a limited operative intervention to a viable approach for various pathologies including diffuse sinonasal polyposis, benign and malignant tumors of sinonasal cavities and skull base, cranial base defects, and orbital lesions.⁴⁰

APPLICATION OF THE ENDOSCOPE TO SKULL BASE SURGERY

As ESS gained popularity, in 1996, McCutcheon et al.¹⁹ first introduced the endoscope to facilitate removal of the extracranial portions of ASB tumors.¹² However, his report lacked a discussion of the indications and advantages that the endoscope provided in these procedures. In 1999, Thaler et al.¹² reported the indications and technique of endoscopically assisted ACFR of sinonasal tumors with extension into the ASB. This was performed through a standard bicoronal incision and frontal craniotomy²⁵ (Figs. 4 and 5) or subcranial approach. Although the intracranial portion of the tumors required a craniotomy, the authors were able to access the intranasal portion of the tumors purely using an endoscopic approach while still achieving en bloc resection.¹² If needed, certain cuts that would be difficult and potentially unsafe to perform externally were achieved transnasally. The authors concluded that although the endoscopic-assisted ACFR is by no means a replacement of the original open approach, it is an "important adjunct in the skull base surgeon's armamentarium."¹² As the endoscopic-assisted technique gained popularity for these procedures, its application has extended to tumors primarily arising from the anterior cranial fossa, parasellar regions, middle cranial fossa, paraclival regions, and craniovertebral junction.^{41–47}

The first purely endoscopic endonasal ASB resection was reported in 2001 by Casiano et al.,¹⁶ in which the authors reviewed their experience with esthesioneuroblastoma in five patients. The original technique

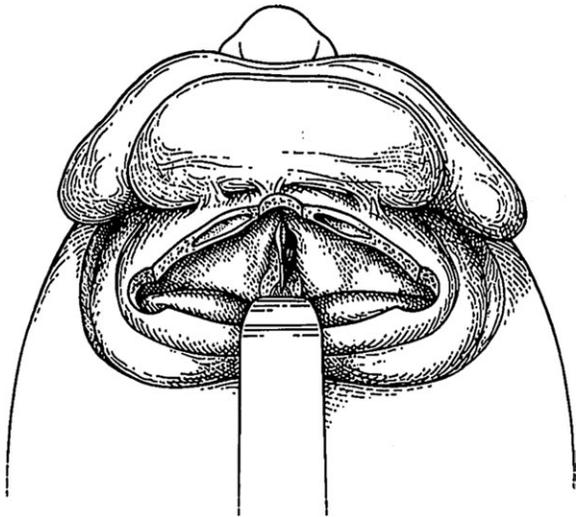


Fig. 4. Illustration showing the view of the anterior cranial fossa after a bicoronal craniotomy for anterior craniofacial resection. Reprinted with permission from Van Tuyl and Gussack.²⁵

involved an en bloc resection of the olfactory bulbs, cribriform plates and adjacent dura, and crista galli bilaterally, which are all delivered through the nose. Smaller tumors only required unilateral resection of these structures. Based on tumor extension and anatomical considerations, various procedural techniques could be employed on a case-specific basis including endoscopic modified maxillectomy, ethmoidectomy, extended sphenoid sinusotomy, etc. The nasal septum was then resected to achieve disease-free margins and to allow the use of binostril instrumentation. An endoscopic modified Lothrop procedure was performed and marked the anterior border of the skull base resection. After the surrounding bony structures were thinned down to an eggshell thickness, and adequate exposure of the underlying dura was achieved, the dura was resected around the tumor, and en bloc resection was attempted (Fig. 6A-C).^{16,48}

Since the original description of this method, it has been internationally recognized as an appropriate alternative for resection of select ASB tumors. In their conclusion, Casiano et al.¹⁶ stated that the endoscopic endonasal removal of these ASB tumors require a “great degree of experience,” and most experts in skull base surgery would agree that the technical acumen required by this procedure can only be acquired with practice and experience. In addition to the classic endoscopic endonasal approaches (EEAs), various extended or expanded EEAs to the skull base have been described.⁴⁹⁻⁷⁴

THE SKULL BASE TEAM

The challenges posed by complex ASB lesions due to their location and proximity to vital neurovascular structures have made them difficult to resect and reconstruct. In the past, neurosurgeons have utilized aggressive extracranial approaches for resection of these lesions, but faced increased morbidity and mortality, and poor cosmetic outcomes. With the introduction of the

endoscope and development of skull base EEAs, a new relationship formed between otolaryngologists and neurosurgeons. The tandem of neurosurgeon and otolaryngologist led to the development of minimally invasive surgical approaches using the endoscopic technique as a vehicle to visualize the entire ventral skull base.⁷⁵⁻⁷⁷

The collaborative efforts of this skull base team provide the option of treating tumors primarily using the EEA or combining it with an open transcranial approach when indicated. The purely EEAs preclude the need for craniotomy and brain retraction, which are potential causes of morbidity that would be unavoidable with a transcranial technique. In addition, the minimally invasive nature of the approach reduces the scarring and cosmetic deficits that may occur after open procedures, thus resulting in improved overall cosmesis.⁷⁸ Many groups have stressed the significance of “true team surgery,”⁵⁹ asserting the need for the two surgeons to use their unique perspectives and expertise to work side by side and “dance together”⁷⁹ to better serve their patients.

EVOLUTION OF THE OPEN AND ENDOSCOPIC APPROACHES

Although the original application of ACFR was associated with high rates of morbidity and mortality,¹⁷ with the advances in surgical technique, soft tissue reconstruction, postoperative care, and the use of broad-spectrum antibiotics, ACFR has managed to remain a mainstay of surgical treatment for the past 50 years with only slight modifications.¹⁸ Despite improvements in technique, many reports still quote a major complication rate as high as 30% to 40% and postoperative mortality of approximately 5%.^{5,24,80,81} In addition, a number of cosmetic concerns with these procedures due to disfiguring scars still remained.^{12,47}

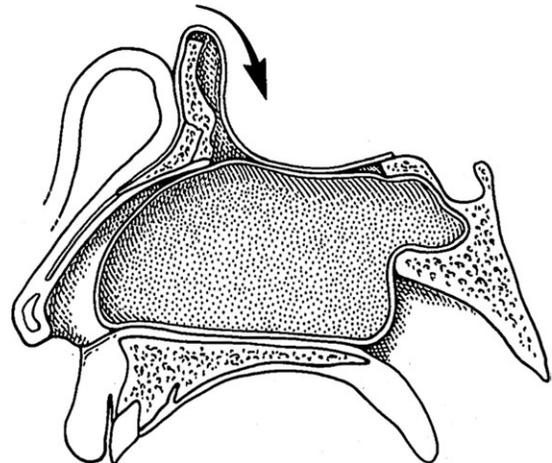


Fig. 5. Illustration from Van Tuyl and Gussack²⁵ in 1991 demonstrating that the intracranial osteotomies extend from the planum sphenoidale to the frontal sinus and laterally to include both ethmoid sinuses. Reprinted with permission from Van Tuyl and Gussack.²⁵

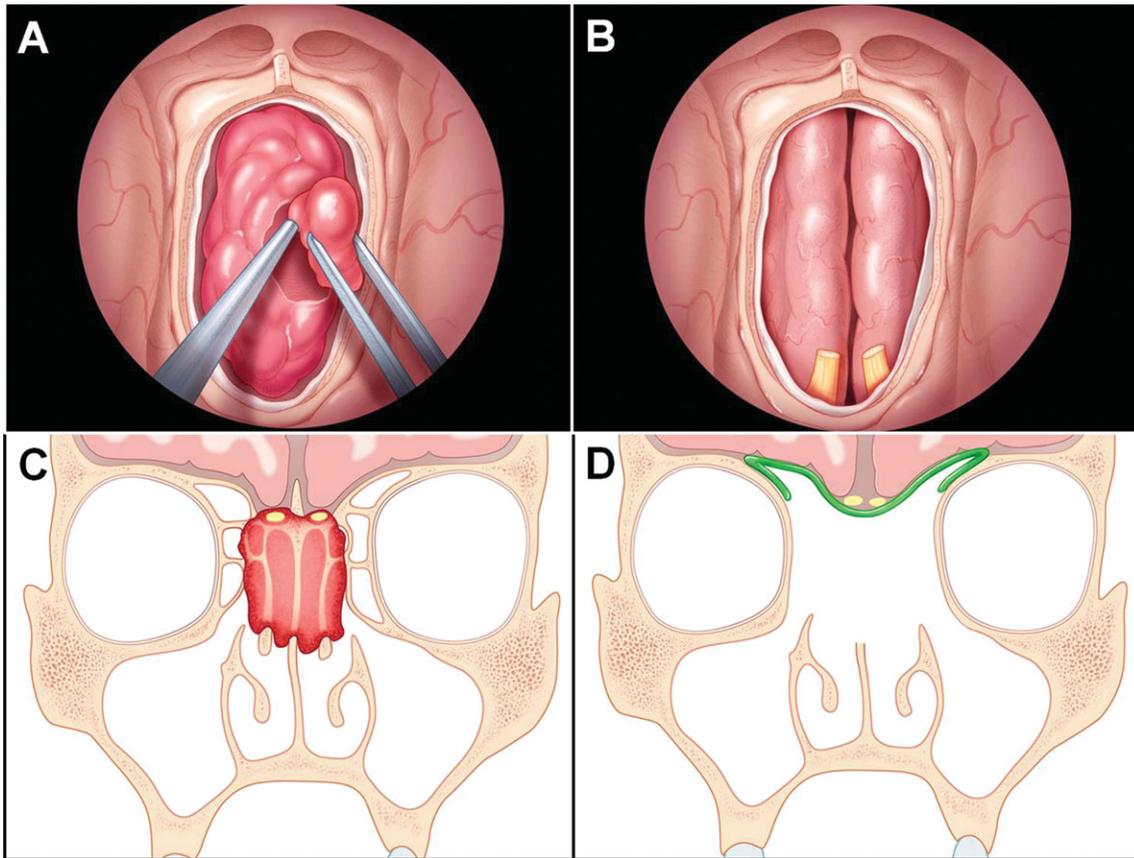


Fig. 6. (A) Illustrative depiction of the endoscopic view of the anterior skull base prior to tumor resection. (B) Endoscopic view of the anterior skull base after anterior skull base resection. (C) Illustration depicting the extent of resection for bilateral endoscopic anterior skull base resections in the coronal plane. (D) Reconstructive technique of the anterior skull base defect reconstruction using acellular dermal allograft. Reprinted with permission from Eloy et al.⁴⁸

Enhanced understanding of anatomy has led to changes in bony removal and the development of the subcranial, extended bifrontal, and orbitozygomatic approaches.⁸² In addition, several transfacial incisions have been used to supplement the bicoronal incision.⁸³ Most commonly the Weber-Fergusson incision is used to achieve en bloc tumor resection.⁸⁴ Increased grasp of surgical anatomy and new instrumentation has led to the formation of various zones of exposure to ensure safe and efficient access to ASB lesions (Fig. 7).⁸⁴ Zone I is exposed by the transbasal approach and provides access to the anterior cranial base, nasal cavity, and maxillary sinuses.⁸⁴ Zone II is reached by the transmaxillary approach and accesses the maxillary sinuses, the ethmoid sinuses, and ipsilateral anterior cavernous sinus.⁸⁴ Zone III is uncovered by the transsphenoidal approach, which provides access to midline structures.⁸⁴

The advent of the endoscope and the development of endonasal techniques have revolutionized the manner in which skull base lesions are viewed and treated.⁸⁵ Coupled with advancements in surgical instrumentation, use of the endoscope rose to prominence not only as a means for visualization of pathology and diagnosis but also for treatment.^{86,87} This development marked the beginning of endoscopic skull base surgery, which reached

popularity abroad primarily through the work of Stamm and Cappabianca.^{36,37,88,89}

Although the use of the endoscope was initially limited to sellar lesions, with the introduction of image-guided navigation the endoscope began to extend beyond the sella turcica.^{90–93} Since Casiano et al.¹⁶ introduced the use of the endoscope to resect skull base lesions, many others have emulated their technique to resect large malignancies using a variety of different approaches. The work of many skull base teams at major academic centers has broadened the scope of endoscopic skull base surgery.^{64–66,68–74,85,94–97}

Currently, there are a few surgical methods that strive to improve visualization and access for removal of ASB tumors. External ACFR is the gold standard for removal and ASB lesions. However, due to its poor cosmetic effects and the rise of endoscopic surgery, it is now mainly used for tumors with intraorbital involvement and large intracranial parenchymal extension or in revision cases that involve significant fibrosis.^{98,99} Endoscopic-assisted ACFR allows for superior visualization and safer margins without damaging vital structures. A purely endoscopic ASB resection without craniotomy or external incision has been adopted by some who claim that en bloc resection is not necessary with particular

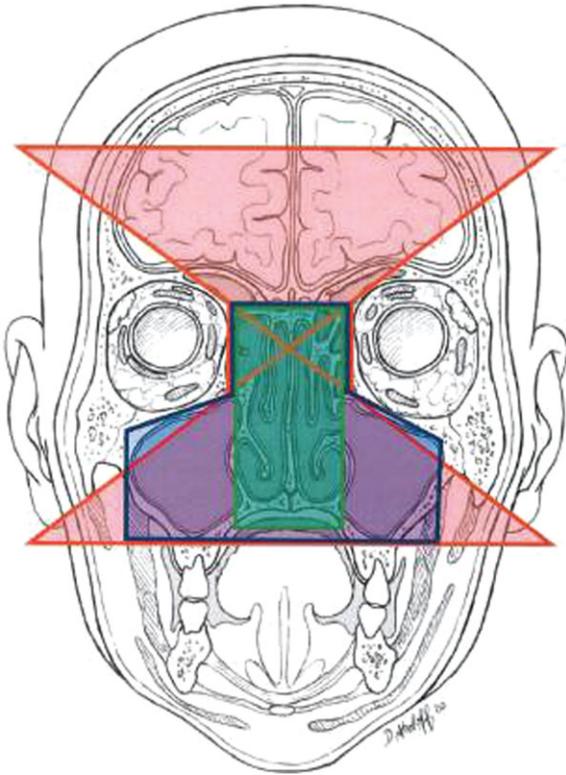


Fig. 7. Anatomic diagram demonstrating the three zones of exposure that have been defined for craniofacial resection. Zone 1 (red) is classically accessed through a transbasal approach, zone 2 (blue) is exposed using the transmaxillary approach, and zone 3 is defined by the transsphenoidal approach. Reprinted with permission from Liu et al.⁸⁴ [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

malignancies.¹⁶ With the addition of wide-angle endoscopes and high-definition cameras as well as three-dimensional endoscopes, approaches to the ASB continue to improve.^{59,79,100}

A SUBJECT OF CONTENTION: THE EFFICACY AND POSTOPERATIVE RESULTS OF ENDOSCOPIC VERSUS OPEN TECHNIQUES

A popular subject of contention involves the safety and efficacy of endoscopic skull base approaches compared to open techniques in resecting ASB malignancies. It is well known that ACFR can allow for safe, en bloc resection of ASB malignancies. The primary critique of endoscopic resection for these lesions is the ability to provide an oncologically safe en bloc resection. However, it has been argued that the primary purpose of these procedures is not for en bloc resection but for extirpation of tumor with negative surgical margins.⁸¹ The relative safety provided by endoscopic skull base approaches in comparison to ACFR can be compromised by the lack of the surgeon's familiarity with the surgical anatomy and microsurgical skills.⁵³ The most common complications that may occur during these endoscopic procedures include cerebrospinal fluid (CSF) leak and epistaxis.¹⁰¹ Other complications may include meningitis, pneumocephalus, intracranial hemorrhage, sinusitis, and other

intracranial infections.¹⁰² The sequelae of open procedures include ocular complications, most commonly diplopia and enophthalmos, infectious complications including osteomyelitis of the bone flap and abscess formation, and neurological complications such as mental status changes and CSF leak.²¹ In studies that compared transnasal endoscopic and ACFR for malignancies of the ASB, the authors noted that endoscopic resection was associated with decreased hospital and intensive care unit stay, decreased blood loss and transfusion rate, and faster recovery.^{98,99,103} In addition, the endoscopic technique has also been associated with excellent visualization for tumor removal and superior cosmetic outcome.^{98,99} No significant differences were found in survival, recurrence, metastases, or complication rates between endoscopically resected malignant ASB tumors compared to ACFR.^{98,99}

ADVANCES IN RECONSTRUCTIVE TECHNIQUE

Resection of tumors of the ASB often result in large defects that create a connection between the intracranial and sinonasal cavities, forming a potential source of CSF leak, postoperative meningitis, and intracranial abscess. A variety of reconstructive techniques have been described for closure of these defects. Pericranial and galeal flaps have traditionally been used to repair the defect created by ACFR (Fig. 8).²⁵ Since the utility of



Fig. 8. Operative illustration demonstrating the reconstructive technique in which the pericranial flap is passed through the craniotomy defect to reconstruct the floor of the anterior cranial fossa. Reprinted with permission from Van Tuyl and Gussack.²⁵

the pericranial flap was first described by Wolfe¹⁰⁴ in 1978, it became the mainstay for reconstruction of ASB defects and has been shown to be an effective barrier between the sinonasal and intracranial cavities in preventing CSF leak.^{105,106} One of the major complications of the pericranial flap was radiation necrosis and subsequent devitalization following postoperative radiation therapy.¹⁰⁷ To avoid this complication, various combinations of flaps have been proposed for reconstruction including galeal-pericranial, galeal-pericranial-frontalis with or without a temporal myofascial flap, and the occipital galeopericranial flap.^{5,19,105,106,108–120}

Despite the improvements and advantages offered by the EEA for resection of ASB lesions, adequate reconstruction of the resulting skull base defect after tumor removal has remained one of the significant complications. In a recent, large, single-center review of 800 patients, Kassam and colleagues⁶³ demonstrated that CSF leak was the most common complication following endoscopic endonasal cranial base resections, occurring in nearly 16% of their patient population. In a meta-analysis reviewing endoscopic endonasal reconstruction of the skull base, Harvey et al.¹⁰² reported a CSF leak rate of 11.5%. As larger, more invasive tumors of the ASB are resected, CSF leaks become even more concerning.

Reconstructive techniques in skull base surgery have evolved over the last decade, and arguably, one of the most significant advances in cranial base reconstruction is the vascularized pedicled nasoseptal flap (PNSF) repair technique, which was described by Hadad et al. in 2006.¹²¹ The vascularized PNSF is a sturdy, yet malleable flap that encompasses a large surface area with a flexible arc of rotation, thus providing excellent coverage of large ASB defects.^{121–123} In 2007, Germani et al., introduced their technique using a single layer of non-vascularized thick acellular dermal allograft for repair of large ASB cribriform defects, resulting in a postoperative CSF leak rate of only 3% (Fig. 6D).¹²⁴ Other innovations that have decreased the risk of CSF leak include various adaptations of multilayer techniques for reconstruction with or without PNSF repair, dural suturing techniques, external support using intranasal balloon catheters, and use of a lumbar drain or ventriculoperitoneal shunt in patients at high risk for CSF leak.⁵⁹

More recently, Zanation et al.¹¹⁹ introduced a new minimally invasive endoscopic technique for harvesting and using a pericranial flap for skull base reconstruction of large ASB defects. In a separate study by Patel et al.¹¹⁴ conducted at the same skull base center, the authors describe a series of 10 patients in which this method of reconstruction was used without any postoperative CSF leak, despite eight patients in their cohort receiving postoperative radiation therapy.

THE FUTURE OF ANTERIOR SKULL BASE SURGERY

The goals for ASB surgery remain the same as they always have: 1) resection of tumor with negative mar-

gins, 2) preservation of neurologic function, 3) reduction of operative complications, and 4) improved cosmetic outcome, with the overarching objective of better overall surgical outcomes. To achieve these goals, continuous advances and improvements must be made in optical devices, surgical instrumentation, surgical navigation systems, and effective collaborations between neurosurgeons and otolaryngologists with a special interest in skull base surgery. The future of ASB surgery resides in gaining more experience with ACFR, endoscopic-assisted ACFR, and purely endoscopic treatment of ASB lesions, and to appropriately determine which approach can best serve a specific pathologic entity of the ASB.

CONCLUSION

ASB surgery is a young discipline that originated nearly half a century ago through the pioneering work of Dandy, McLean, and Smith, and became a distinct entity in 1963 after Ketcham's popularization of the combined transcranial transfacial approach for en bloc resection of tumors of the paranasal sinuses with intracranial extension. Although initially these procedures were associated with major morbidities and mortalities, improvement and advancement of the field with better outcomes continued through the development of the skull base team as well as improvements in surgical techniques, instrumentation, and visualization technology.

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