Anterior and Anterolateral Resection for Skull Base Malignancies

Techniques and Complication Avoidance

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KEYWORDS

• Anterior craniofacial • Skull base malignancy • Pneumocephalus • Endoscopy

KEY POINTS

- Combined craniofacial resection remains the most effective approach for skull base malignancies, despite the evolution of endonasal endoscopic techniques.
- Meticulous dural reconstruction and skull base repair limit the major complications associated with craniofacial resections.
- Effective management of complications, such as CSF leak and pneumocephalus, limit the morbidity from these operations.

INTRODUCTION

The application of the combined craniofacial approach for skull base malignancies was first described by Ketcham, and colleagues[1] in 1963. Techniques have evolved significantly since the original description, but the basic premise of gross total resection with negative margins remains the goal of therapy. Technical advances in resection and reconstruction, improvements in intensive care management, and triple antibiotic therapy have reduced complications and allowed for the safe removal of anterior cranial base malignancies that involve not only the anterior skull base, but also the orbit, brain, and infratemporal fossa. The evolution of anterior cranial base surgery integrated with advanced imaging and adjuvant radiation and chemotherapy have shown improved outcomes over the last 2 decades. Gil and colleagues[2] reported a significant improvement in overall survival and disease-specific survival in patients who have undergone surgery since 1996 compared with those who underwent resection from 1973–1996. Of 106 patients operated on before 1996, the 5-year overall survival and disease-specific survival rates were 55% and 57%, respectively, whereas they improved to 66% and 70%, respectively, for the 176 patients in their series who were treated from 1996–2008. Despite advances in surgery, poor prognostic indicators include positive surgical margins, unfavorable tumor histologies (eg, squamous cell carcinoma, melanoma,

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high-grade sarcoma), intracranial or orbital invasion, and prior radiation therapy.[3–5]

Despite the evolution of purely endonasal endoscopic techniques, the combined craniofacial techniques continue to be the gold standard and principle strategy in treatment of anterior and anterolateral skull base malignancies. The obvious benefits of purely endoscopic techniques include less soft-tissue dissection and avoidance of the morbidity associated with a craniotomy and brain retraction[6]; however, these benefits may be more relevant for benign skull base tumors than for extensive skull base malignancies. Malignant tumors often present significant anatomic constraints to effective endoscopic resection because of involvement of neurovascular structures, optic nerves, and infiltration into the brain, orbit, or infratemporal fossa. Additionally, endoscopic resection obviates not only the ability to achieve en bloc resection for negative margins, but also necessitates dissecting through tumor to identify normal structures. Conversely, the craniofacial approach allows the identification of normal structures first rather than intralesionally dissecting through tumor to identify critical anatomy and normal tissue planes. The ability to separate the nasal cavity from the intradural compartment is limited via an endoscopic approach because of the frequent need to use a nasoseptal flap for reconstruction. The nasal septum often is resected in the treatment of malignancies because of tumor involvement or to achieve negative margins. Finally, clinical series showing improved local control with endoscopic techniques are not comparable with regard to prognostic categories based on tumor histologies. In a report from Eloy and colleagues,[7] local recurrence rates were 5.6% in the endoscopic group compared with 29.2% for the craniofacial cohort, which approached significance ($P = .051$). However, a lack of equipoise was demonstrated, as most patients in the endoscopic group had favorable prognostic histologies (eg, esthesioneuroblastoma, small cell carcinoma) compared with the craniofacial groups with poor prognostic histologies (eg, squamous cell carcinoma, high-grade sarcomas).[7,8] Soler and Smith reviewed published data on endoscopic compared with craniofacial techniques for esthesioneuroblastoma.[9] Short-term control rates seem to be equivalent, but endoscopic techniques are typically reserved for lower-stage tumors.

It is critical that surgeons treating skull base malignancies continue to understand the techniques and reconstructive strategies of combined anterior craniofacial approaches. The integration of endoscopic endonasal dissection is becoming more prevalent but has not currently replaced the need for a combined anterior cranial base approach. This article reviews the nuances of anterior and anterolateral resection of skull base malignancies and complication avoidance and management.

COMBINED ANTERIOR CRANIOFACIAL RESECTION

Imaging

Both magnetic resonance (MR) imaging and computed tomography (CT) scans are helpful in preoperative planning to define the extent of tumor and type of resection required. CT scans are useful for defining the myriad of anatomic variability in bone anatomy, including the size of the frontal sinus and crista galli, location of bony septae, length of the planum sphenoidale, and degree of bone erosion. The MR is important for tumor identification and the relationship to critical structures. The extent of resection and type of reconstruction is determined principally based on MR imaging. Contraindications to surgical resection can be evaluated, including extensive cavernous sinus involvement and involvement of the only sighted eye. However, even high-resolution MR may not provide enough detail to make preoperative decisions regarding periorbital invasion, which may require orbital exenteration or penetration of the skull base dura. Decisions regarding these issues may still require highly skilled intraoperative judgment and extensive informed consent. The propensity for some tumors to present with regional or distant metastases also plays a major role in determining treatment. A screening body scan, such as positron emission tomography or CT, is important for staging before treatment.

Preoperative Biopsy

Definitive preoperative pathologic diagnosis of anterior skull base malignancies is critical to decisions regarding treatment. Most biopsies can be done endoscopically by head and neck surgeons in the office, but occasionally deep lesions undergo biopsy in the operating room. Tumor management is highly dependent on whether the pathology results are benign or malignant and the relative responsiveness to radiation or chemotherapy. Malignant tumors such as lymphoma and rhabdomyosarcoma are treated with chemotherapy either as definitive therapy or as neoadjuvant treatment. Other tumors, such as squamous cell carcinoma, adenoid cystic carcinoma, sarcoma and melanoma are best treated with resection.

Surgery

Preparation

After induction of general anesthesia, the endotracheal tube should be positioned opposite the site of the lateral rhinotomy or the epicenter of the tumor. The eyelids are sutured, but the suture should be placed so that the pupils can be readily examined at surgery. A spinal drain is placed for intermittent drainage throughout the procedure to facilitate brain relaxation and for use in the postoperative period to ensure a water-tight closure. Triple antibiotic therapy (metronidazole ceftazidime, vancomycin) is initiated at the induction of anesthesia. The preparation should take into account all possible facial incisions and the need for a free flap.

SURGICAL TECHNIQUE

Craniotomy and Galeal Pericranial Graft: Smaller and Longer, Respectively

The head is positioned on a foam donut. A bicoronal incision is fashioned between the zygomas over the vertex of the skull starting 1.5 cm anterior the ear after injection of the skin with 1% lidocaine with epinephrine. The skin is incised with a 10 blade taking care to preserve the pericranium, which initially remains attached to the scalp. A hemostat is used to define the plane between the galea and pericranium. The superficial temporary arteries are preserved for possible free flap anastomosis at the end of the operation. A subgaleal dissection of the posterior skin flap is accomplished extending to the posterior parietal bone. The posterior pericranium is incised at this point with the Bovie cautery, and a subperiosteal dissection with a broad periosteal elevator is accomplished to the level of the supraorbital rims and nasion. The galea is then dissected from the anterior scalp flap beginning 1 cm anterior to the incision to facilitate subsequent galeal closure. The galeal-pericranial graft is harvested with a 15 blade, creating a long vascularized graft for skull base reconstruction. This flap is wrapped in bacitracin-soaked gauze and retracted with blunt hooks (**Fig. 1**).

The craniotomy is then turned. A single burr hole is placed in the midline overlying the sagittal sinus or through the frontal sinus approximately 3 cm superior to the nasion and laterally to the middle of the supraorbital rims. Dura is dissected from the underside of the bone, and the craniotomy is performed with a 1-mm matchstick bur. The mucosa of the frontal sinus is exenterated, and the posterior wall of the frontal sinus is removed with a 3-mm matchstick burr. The crista galli is identified extradurally and removed. The remainder of the dissection is intradural.

Dural Resection and Repair

The dura is incised anterior to the crista galli, and the olfactory nerves are sacrificed with bipolar cautery and suction. Intracranial tumor is resected to the level of the skull base. Dural incisions are made laterally and posteriorly with the goal of achieving negative margins. Typically, the dura is incised laterally over the fovea ethmoidales and posteriorly along the anterior planum sphenoidale. Frequently, tumor abuts or invades the dura, requiring more extensive dural resections. Lateral and posterior dural dissection from the skull base is accomplished using a Penfield 4 to create cuffs for dural reconstruction. Dural reconstruction is accomplished using an inlay graft of DuraGen (Integra LifeSciences Corporation, Plainsboro, New Jersey), creating a gasket seal and a bovine pericardial patch graft (DuraGard; Synovis Surgical Innovations, Minnesota) is sutured with a 4–0 nonresorbable continuous suture initiated at the posterior suture line. A tear in the posterior suture line is virtually impossible to repair primarily, but a muscle patch

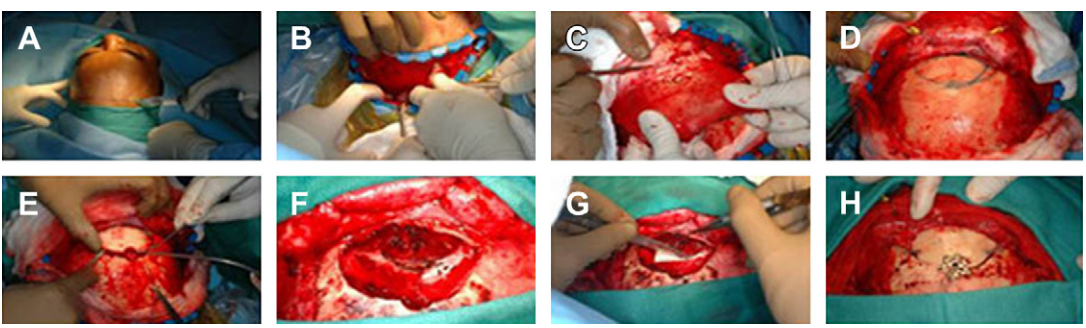

Fig. 1. Anterior cranial base resection. (*A*) Bicoronal incision. (*B*) Dissection of pericranial graft posterior to incision to create long pedicled flap. (*C*) Harvesting pedicled pericranial-galeal pericranial graft. (*D*) Outline of craniotomy flap. (*E*) Bone flap turned. (*F*) Resection of skull base dura. (*G*) Reconstruction with bovine pericardial patch graft. (*H*) Bone flap replaced with epidural drain. (*Adapted from* Bilsky MH, Bentz B, Vitaz T, et al. Craniofacial resection for cranial base malignancies involving the infratemporal fossa. Neurosurgery 2005;57(4):339–47; with permission.)

(temporalis muscle) stitched over the defect can salvage a water-tight dural repair.

Intranasal Dissection

The intranasal dissection is carried out by experienced head and neck surgeons. Traditionally, the nasal approach requires a lateral rhinotomy. When a maxillectomy is required, the lateral rhinotomy incision is extended in the midline to the lip. More recently, endoscopic techniques have been used for the intranasal dissection.

Skull Base Osteotomies

Skull base osteotomies are tailored to the extent of the tumor. Judicious use of spinal fluid drainage often makes placement of brain retractors unnecessary. Gentle retraction with the suction provides excellent exposure. The skull base osteotomies are made with an M8 bur, although many surgeons use thin osteotomes. The drill is preferred over osteotomes because of the improved ability to control the fracture lines. Resection of the tumor is accomplished by working from both intranasal and intracranial orientations. The osteotomies for a standard anterior cranial facial resection are created through the anterior frontal bone, bilateral ethmoid sinuses, and planum sphenoidale.

More extensive bone removal may be required depending on the degree of bone and soft tissue involvement, for example, in a type 3 infratemporal fossa resection (**Fig. 2**).[10–13] This resection is required for patients with malignancies involving the infratemporal fossa, maxillary sinus, orbit and anterior cranial base. A frontotemporal bone flap is created to perform a combined subtemporal-infratemporal fossa and anterior cranial base resection. The anterior cranial base is prepared in the same fashion as a standard anterior cranial base resection. An extradural dissection is extended across the squamous temporal bone and greater wing of the sphenoid in a lateral to medial direction to the level of the foramen rotundum and maxillary division of the trigeminal nerve (V2). Further extradural dissection is extended posteriorly along the greater wing of the sphenoid to create a posterior margin that includes the foramen ovale and mandibular division of the trigeminal nerve (V3). The dura is resected depending on the degree of dural abutment or invasion. Perpendicular osteotomies with the 3-mm matchstick bur are made from the lateral squamous temporal bone to the foramen ovale then extended anteriorly to the foramen rotundum. V2 is sacrificed with vascular clips. The resulting osteotomy is lateral to the carotid artery, cavernous sinus, and superior orbital fissure. Dissection of the pterygoid muscles posterior to the tumor is performed. The skull base osteotomies are extended in a coronal plane anterior to the superior orbital fissure. This osteotomy is extended across the lesser wing of the sphenoid anterior to the optic foramen and the posterior planum sphenoidale. The osteotomy then extends anteriorly to include the contralateral ethmoids and cribriform plate. The orbital contents are cut at the optic foramen. Rarely is the optic nerve resected intradurally because of

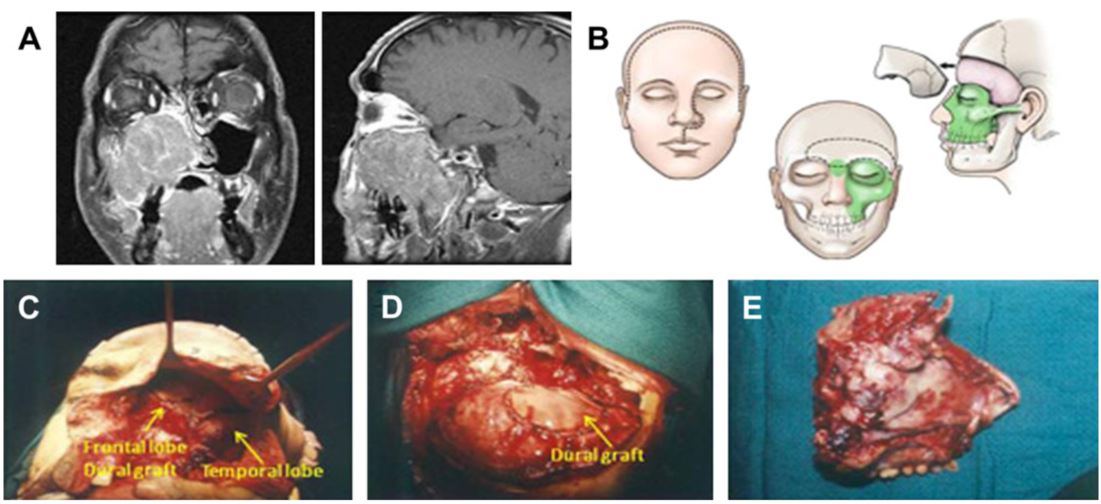

Fig. 2. 53 years old male, who presented with intermittent headaches and nasal obstruction. Chordoma was diagnosed after a biopsy. (*A*) Preoperative MR imaging. (*B*) Schematic representation of the operation. (*C*) Craniotomy with dural resection. (*D*) Dural repair using bovine pericardium. (*E*) Excised tumor. (*Adapted from* Bilsky MH, Bentz B, Vitaz T, et al. Craniofacial resection for cranial base malignancies involving the infratemporal fossa. Neurosurgery 2005;57(4):339–47; with permission.)

the small risk of producing a nasal field deficit in the remaining eye. The tumor is then resected.

In standard skull base reconstruction, after tumor resection, 3 drill holes are placed through the posterior skull base (typically posterior planum sphenoidale) using a wire pass, and the galeal-pericranial graft is sutured into place with 4–0 nonresorbable sutures. The graft is often longer than the skull base defect, but the redundant tissue can be folded to make a thicker skull base reconstruction. If an open nasal approach has been used, the galeal-pericranial graft is sutured to the skull base from the nasal side to ensure a complete seal. Otherwise the endoscope can be used to ensure the galeal pericranial graft covers the dural repair if the repair is performed from the cranial side. Extended resections, such as the type 3 infratemporal fossa resection, resulting in larger skull base defects, require free-flap reconstructions with a rectus abdominis flap. Smaller defects can be closed with radial forearm flaps or even omental grafts. Regardless of whether a free flap is required, the anterior skull base defect and dural repair routinely are reconstructed with the galeal-pericranial graft over the anterior dural repair.

The craniotomy flap is replaced with a rigid plating system. A drain is placed in the epidural space through the bur hole cover and connected to a Jackson-Pratt (JP) bulb suction. This drain facilitates removal of air in the event of postoperative pneumocephalus and the potential resultant complications. The nose is packed with Xeroform gauze (Covidien, Massachusetts) to facilitate intranasal hemostasis, promote mucosal healing, and most importantly, to prevent pneumocephalus by occluding the nasal air space.

POSTOPERATIVE MANAGEMENT

Postoperative management is institution dependent, and several strategies are effective, but our current practice has evolved to minimize the postoperative complications of cerebrospinal fluid (CSF) leak and pneumocephalus. Patients are treated in the intensive care unit until the lumbar drain is removed. Lumbar drainage typically is initiated on the day after surgery at 10 mL/h and continued for 48–72 hours. The epidural drain is placed to JP bulb suction and reinflated every 30 minutes until it holds suction. The lumbar drain is typically discontinued on the morning of day 4 followed by the epidural drain 6 hours later to ensure that pneumocephalus is not induced by an unregulated leak into the lumbar drain site. The nasal packing typically is discontinued on day 5–7. Triple antibiotics are maintained until the packing is removed.

Complication Avoidance

Advances in surgical techniques and reconstruction have redefined the indications and outcomes in craniofacial reconstruction.[10] Despite this redefinition, craniofacial resection still carries significant perioperative risk and complications. Complications can be divided into several subtypes: intracranial or neurologic, extracranial or wound, and systemic or orbital. Intracranial complications include cerebrospinal fluid leak, meningitis, subdural or intradural abscess, pneumocephalus, neurologic dysfunction, subdural or extradural hematoma, cerebrovascular accident, or seizure. Extradural complications include wound infections, dehiscence, necrosis, or flap failure. Systemic complications can involve the respiratory, cardiovascular, hematologic, or endocrine systems. Orbital complications include corneal abrasion, epiphora, ectropion, enophthalmos, diplopia, periorbital cellulitis, and loss of vision. With meticulous attention to techniques of resection and reconstruction, the morbidity and mortality have been reduced; however, the complexity of skull base resection in which the intracranial space communicates with the colonized, aerated intranasal space remains a significant challenge in malignant tumors. Trouble shooting complications to minimize the impact on morbidity is essential.

INFECTION/WOUND

Infection and wound complications remain the most frequently encountered postoperative complication. In reports from the International Collaborative Study and review of the literature, Ganly and colleagues,[5] reported an overall wound complication rate of 19.6%, which was consistent with a mean overall wound complication rate of 19.8% based on a review of several previously reported complication rates.[14–17] The presence of a medical comorbidity and prior radiation were independent significant predictors of wound complications ($P<.005$).[18] Dias and colleagues[16] reported that infectious complications occurred in 38.5% of all anterior skull base cases and accounted for 54.7% of all complications. Rates of infectious complications range from 1.3% to 27.9%.[18] Osteomyelitis of the frontal bone flap occurs in 0%–14.8% of cases.[18] Earlier reports of craniofacial resection reported intracranial infection as the most frequent complication. Reviews by Boyle and colleagues[19] and Cantu and colleagues[20] of several large series found that a disproportionate amount of perioperative mortalities occurred from meningitis or intracranial abscess. However, more recent literature reports a 0%–7.7% risk of meningitis and a 0%–11% rate of intracranial abscess.[5,14,16,17,20,21] Recently, we have seen delayed brain abscesses at 1–2 years after surgery. These abscesses have been managed with stereotactic needle aspiration and prolonged antibiotics.

Several factors have contributed to a reduction in infectious complications, including shorter operating times and wrapping the bone flap in a bacitracin-soaked gauze for the duration of the surgery. The most significant factor was a change in antibiotic regimens from a single antibiotic regimen to broad-spectrum coverage with a triple antibiotic regimen using vancomycin, ceftazidime, and metronidazole, as reported by Kraus and colleagues[22] The development of a standardized perioperative antibiotic regimen has led to significant reductions in both infectious and wound-related complications. In our previously reported experience,[22] the implementation of a standardized broad-range regimen covering gram-positive, gram-negative, and anaerobic bacteria (vancomycin, ceftazidime, and metronidazole) when compared with nonstandardized regimens improved local wound complication rates from 35% to 18% and infectious wound complication rates to 11% compared with 29% in the nonstandardized arm.

In addition to changes in perioperative antibiotics, surgical techniques have also contributed to lower infectious complication rates. Neurosurgical literature recommends stripping of the frontal sinuses and packing of the frontal sinus before durotomy. Others have described the use of synthetic bone or split calvarial graft for skull base reconstruction.[23] However, the vascularized galeal-pericranial graft has been sufficient for skull base repair and helps avoid the presence of nonvascularized bone adjacent to the nasal cavity. Split calvarial graft is used to reconstruct the orbit to prevent pulsatile exophthalmos but is enveloped in vascularized galeal-pericranial graft. Over a 2-year period, we used fibrin glue as a sealant at the skull base but experienced several infections in the area of application. Our recommendation is to avoid thrombin glue, because it may act as a nidus for delayed bacterial infection.

As previously mentioned, reconstructive advances have been essential in the prevention of infectious complications, because they serve as a formidable barrier between the intracranial space and sinonasal tract. In addition to antibiotics, Kraus and colleagues[22] reported the use of a free-flap reconstruction associated with significant reduction in the rate of infectious complications: 8.2% when free flap was used compared with 27% when alternate methods of reconstruction were used.

Wound complications caused by flap failure can be prevented with meticulous surgical technique as well as careful postoperative management. Vigilant flap monitoring is conducted hourly with an external Doppler probe and in buried flaps with an internal Doppler probe. In addition, the use of vascularized free flaps as supposed to previously oft-used pedicled flaps allows for superior and appropriately sized reconstruction.

CSF LEAK

Often reported with wound complications, noninfectious cerebrospinal fluid leak remains the second most common complication, with rates reported between 3% and 20%.[24] The presentation of CSF leak typically consists of rhinorrhea and orthostatic headaches. Additionally, patients may complain of nausea, tinnitus, hearing and vision disturbances, and even facial numbness or upper extremity radicular symptoms. Rhinorrhea is typically obvious, but its presence may not be immediately evident if the nose is packed with Xeroform and the CSF is mixed with blood products. A high index of suspicion should be maintained.

Prevention of CSF leak is accomplished with meticulous watertight closure of the skull base dura. In the early descriptions of the techniques for dural closure, the dural slits created by resecting the dura from the crista galli and cribriform plate were sutured primarily. In our experience, this strategy often is unsuccessful because of the need for more extensive dural resection and the propensity to create dural rents. Dural substitutes for large defects include pericranium, alloderm, bovine pericardium, and DuraGen. Pericranium is readily available but difficult to suture because of its delicate nature and tendency to fold on itself. A bovine pericardial patch graft is ideal for dural reconstruction because it can be sutured water tight, and the edges are easily identifiable for suturing. Most importantly, in our experience, it is remarkably resistant to infection or colonization. As an added measure of prophylaxis, a DuraGen inlay graft is used as a gasket seal before suturing the bovine pericardial patch graft. This seal may help prevent a CSF leak from small suture holes or an irreparable tear of a suture line. If a CSF leak is visualized after dural reconstruction, the site should be identified, because this is almost surely a problem postoperatively, even with spinal drainage. Any site that leaks is reinforced with at temporalis muscle graft.

To help facilitate a water-tight closure, lumbar drainage of CSF is instituted at 10 mL/h by intermittently opening the stopcock and then clamping when the desired amount has drained. With continued leak, drainage is increased to 15–20 mL/h. This strategy often helps seal the leak without the need to re-explore the repair either endoscopically or via a craniotomy.

PNEUMOCEPHALUS

Pneumocephalus implies a dural defect that allows air to pass from the sinonasal into the intracranial space. When clinically significant, pneumocephalus can cause severe neurologic deficits and even result in death.

The presence of pneumocephalus implies a CSF leak in communication with an aerated space, in this case the nasal passages or sinuses. Prevention of tension pneumocephalus rests with the ability to achieve a meticulous watertight dural closure or to occlude the air space. Although it most commonly occurs from a durotomy at the skull base, it must be recognized that a CSF leak anywhere along the neuraxis can cause pneumocephalus. Lumbar drainage can promote pneumocephalus, but controlled CSF drainage at 10 mL/h rarely results in significant problems. In the setting of postoperative pneumocephalus, the lumbar drain should be clamped. Uncommonly, when the lumbar drain is discontinued, an unregulated leak of spinal fluid can occur in the low back, causing an acute decompensation from tension pneumocephalus and brain herniation. In the even that this occurs, the patient should be placed in Trendelenburg and a lumbar blood patch placed. Our current practice is to place lumbar blood patches prophylactically after discontinuation of the lumbar drain in high-risk patients.

To prevent or treat pneumocephalus, an epidural drain is placed to JP bulb suction at the time of surgery. This simple device is effective for evacuating air in the event of tension pneumocephalus. The drain can be used to remove residual air at the end of the operation and typically will not hold suction for several hours after surgery. The JP allows for more aggressive lumbar drainage to seal a potential leak because it reduces the probability of tension pneumocephalus. On rare occasions, in our practice, the epidural drain has been used to evacuate air and reverse significant neurologic symptoms and brain herniation. Alternatively, a drain can be place through a bur hole postoperatively to evacuate air. The drain should be kept to JP bulb suction or a low suction reservoir. High-pressure reservoirs can create significant negative pressure leading to headaches, brain edema, or exacerbation of neurologic symptoms.

A third measure to prevent or treat pneumocephalus is occlusion of the air space. The nose is packed with Xeroform or Vaseline gauze (Covidien, Massachusetts). Nonocclusive packing, such as nasal tampons, is not nearly as effective. Although rarely necessary, airway control via intubation or tracheostomy can be used to reduce intracranial air extravasation. Free-flap reconstruction also facilitates occlusion of the air space but should be done in conjunction with primary dural repair. A recent patient had acute pneumocephalus with associated significant cognitive changes while flying to Europe for vacation. This event occurred 9 years after a craniofacial resection with galeal-pericranial reconstruction for esthesioneuroblastoma. No CSF leak was identified on endoscopic inspection. After repeated aspirations without successful resolution, an omental free flap was placed to occlude the nasal cavity and skull base with complete resolution of the pneumocephalus. (**Fig. 3**).

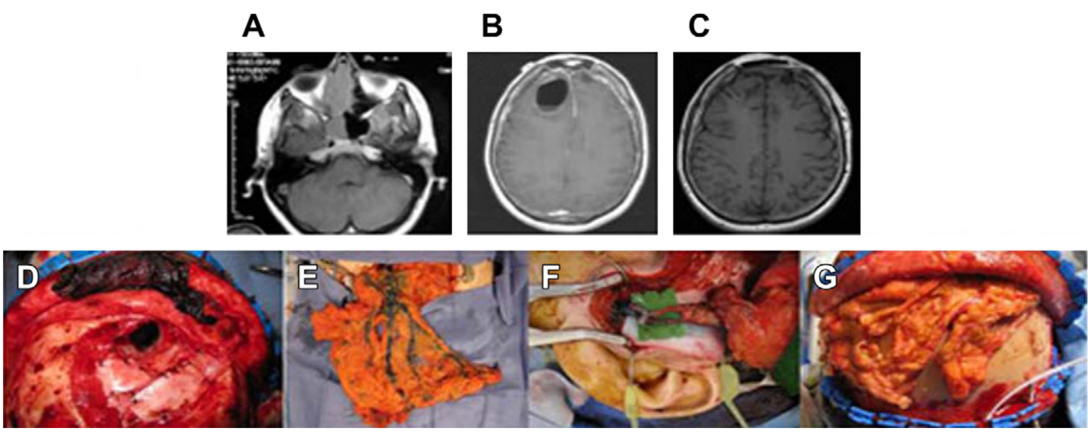

Fig. 3. Delayed pneumocephalus from resorbed galeal pericranial graft. (*A*) MR image shows right nasoethencidal esthesioneuroblastoma. (*B*) MR image shows delayed pneumocephalus. (*C*) Resolution of pneumocephalus with omental flap. (*D–G*) Intraoperative photographs of intracranial skull base repair base exposure. (*D*) Resorbed galeal pericranial graft. (*E*) Harvested omentum. (*F*) Anastomosis of superficial temporal vessels. (*G*) In-laid graft. (*Adapted from* Bilsky MH, Bentz B, Vitaz T, et al. Craniofacial resection for cranial base malignancies involving the infratemporal fossa. Neurosurgery 2005;57(4):339–47; with permission.)

SUMMARY

Combined anterior and anterolateral craniofacial resection remains the gold standard for the extirpation of skull base malignancies. Although purely endoscopic techniques are gaining traction for benign tumors, significant anatomic constraints, limitations regarding skull base repair, and the inability to achieve negative margins limit their effectiveness in the treatment of malignant tumors. The techniques of anterior and anterolateral skull base resection have evolved, as has the reconstruction using galeal-pericranial grafts combined with free-flap reconstruction when indicated. Complications are common, but meticulous attention to dural closure and early diagnosis and treatment can limit the significant morbidity associated with these procedures.

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