The Laryngoscope
Lippincott Williams & Wilkins

A Rational Approach to the Use of Tracheotomy in Surgery of the Anterior Skull Base

Yadranko Ducic, MD, FRCS(C), FACS; Vladimir Zuzukin, MD

Objective: To offer an algorithm for airway management in anterior skull base surgery.

Methods: This is a retrospective review of 109 patients undergoing major anterior skull base surgery from a single senior surgeon's experience from September 1997 to May 2006.

Results: We report only one (1%) postoperative mortality in this series and only seven major complications in six patients, including two cases of stroke, one case of cerebrospinal fluid (CSF) leak, and four cases of delayed osteoradionecrosis. No patients in this series developed tension pneumocephalus. The total major complication rate is 6%. Fifty-one (47%) patients received prophylactic tracheotomy, and 58 (53%) patients did not receive prophylactic tracheotomy. Eighty-eight (81%) patients received anterior skull base reconstruction with local flaps. Six (5.5%) patients required primary reconstruction with a free flap.

Conclusion: We attribute the very low rate of major complications in this series and, in particular, no cases of tension pneumocephalus and rarity of CSF leaks primarily to prophylactic tracheotomy in selected patients and to a reconstructive strategy that emphasizes use of local vascularized tissue to reconstruct the anterior skull base.

Key Words: Tracheotomy, skull base surgery, flap reconstruction of skull base.

***Laryngoscope,* 118:204–209, 2008**

INTRODUCTION

There has been considerable interest in the surgical treatment of diseases that involve the anterior skull base since the pioneering work of Ketcham et al.[1] in 1963, who described the original craniofacial approach to resect cancer of the paranasal sinuses. Modern surgical approaches to this area are as varied and diverse as the diseases they treat. The choice of approach often depends on the experience and personal preference of the surgeon. Irrespective of the specific approach, perioperative mortality for anterior skull base surgery tends to be low, with most series reporting a rate less than 5%. The International Collaborative Study[2] pooled the experience of 17 institutions to review 1,193 patients undergoing surgery of the skull base. The perioperative mortality rate was only 4.7%. Surgical morbidity, on the other hand, has historically been and remains to this day a significant problem. Ketcham et al.[3] used an avascular skin graft to separate the neurocranium from the upper aerodigestive tract after craniofacial resection and reported postoperative cerebrospinal fluid (CSF) leaks in 25% of their patients. The introduction of vascularized local flaps, such as the pericranial flap, in anterior skull base reconstruction and later followed by the introduction of free tissue transfer has realized a significant reduction in postoperative CSF leaks. However, despite advances in multidisciplinary team-based surgery, advanced imaging, modern reconstructive techniques, and intensive postoperative care, the overall rate of major complications remains high in many series. A review of the literature reveals rates of major complications ranging from 6% to 65%, with most modern series lying between 20% and 50%. The International Collaborative Study[2] reported an overall postoperative complication rate of 36.3%.

Few studies discuss strategies in postoperative airway management. Those that do discuss airway diversion to reduce the risk of tension pneumocephalus in surgery of the anterior skull base offer widely different recommendations.[4–9] There is no consensus on this issue. We decided to review the anterior skull base surgical experience of the senior author (Y.D.), offering an algorithm for prophylactic airway diversion via tracheotomy, and a review of the literature on this subject.

METHODS

This is a retrospective review of a single surgeon's experience from September 1997 to May 2006 of all operative cases that involved the anterior cranial fossa for which complete data were available for review. The study identified a total of 109 patients over a 9-year period who presented to the senior author's practice for surgery and met the inclusion criteria of having disease that penetrated

From Otolaryngology and Facial Plastic Surgery Associates, Fort Worth, Texas, U.S.A.

Editor's Note: This Manuscript was accepted for publication September 7, 2007.

Address correspondence to Dr. Y. Ducic, Otolaryngology and Facial Plastic Surgery Associates, 923 Pennsylvania Avenue, Fort Worth, TX 76104. E-mail: yducic@sbcglobal.net

DOI: 10.1097/MLG.0b013e31815a9eb7

the base of the anterior cranial fossa. The senior author personally supervised all head and neck ablative and reconstructive aspects of these cases. The surgical approaches to the anterior skull base included craniofacial, subcranial, cranioorbital, maxillofacial disassembly, maxillotomy, and transpalatal approaches.

RESULTS

We identified 109 patients with 44 malignant, 41 benign, 16 infectious, and 8 traumatic (Table I) (Fig. 1) cases. Fifty-one (47%) patients received prophylactic airway diversion with tracheotomy during their surgery. Fifty-eight (53%) patients did not receive tracheotomy intraoperatively and were extubated either in the operating room or in the intensive care unit. We based the decision to perform a tracheotomy for prophylactic airway diversion on the size of the bony defect between the anterior cranial fossa and the sinonasal cavity prior to the reconstructive portion of the case. This decision was made independently of the patient's presenting pathology or the specific surgical approach to the patient's lesion. A bony defect involving the cribriform plate, ethmoid roof, or floor of frontal sinus with associated posterior wall fracture/defect that was to undergo cranialization was tolerated up to 4 cm^2 in size without tracheotomy. If the frontal sinus was to be left intact or obliterated, then a posterior table defect up to 9 cm^2 was tolerated without tracheotomy. All anterior skull base defects above these limits were treated with tracheotomy (Fig. 2). These measurements came from personal experience and observations in prior patients that convinced the senior author this would be a reasonable threshold for defect size going forward.

TABLE I.
Pathology Type.

Diseases of Anterior Skull Base	No. (n = 109)
Malignant neoplastic	44
Squamous cell carcinoma	21
Adenocarcinoma	6
Basal cell carcinoma	6
Sarcomas (all types)	4
Adenoid cystic carcinoma	2
Esthesioneuroblastoma	2
Glioma	1
Melanoma	1
Plasmacytoma	1
Benign neoplastic	41
Meningioma	13
Juvenile nasopharyngeal angiofibroma	5
Adenoma	3
Fibrous dysplasia	3
Ossifying fibroma	3
Hemangioma	2
Inverting papilloma	2
Myxoma	2
Schwannoma	2
Craniopharyngioma	1
Hamartoma	1
Lipoma	1
Osteoblastoma	1
Osteoma	1
Pleomorphic adenoma	1
Infectious	16
Mucopyocele	7
Osteomyelitis	5
Allergic fungal sinusitis	3
Mucormycosis	1
Traumatic	8

Distribution of anterior skull base pathology

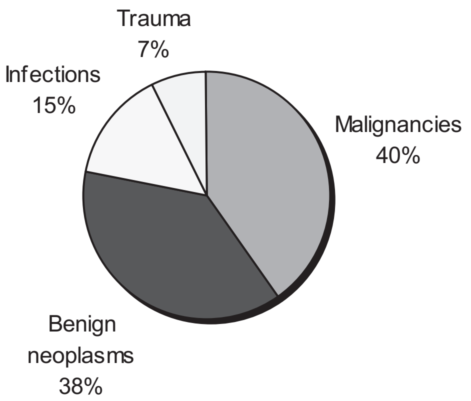

Fig. 1. Distribution of pathology.

All patients with tracheotomy had their tracheotomy tubes left in place for 5 days with cuff inflated to completely divert all airflow and pulmonary secretions away from their upper aerodigestive tract and surgical wound. These patients were automatically decannulated after 5 days without first deflating the cuff, changing the tracheotomy, or undertaking capping trials. The average hospital stay for patients without tracheotomy was 4.1 days compared with 6.2 days for those with tracheotomy.

The reconstruction of anterior skull base defects in this series was as follows. Thirteen (12%) patients did not receive any flap, 88 (81%) patients were reconstructed with local vascularized flaps, 6 (5.5%) patients received primary reconstruction with free tissue transfer, with 1 revision patient requiring a free flap after wound breakdown, and 2 patients required lateral temporal bone resections in addition to anterior skull base resection for massive squamous cell carcinoma, which were reconstructed with extended pedicled pectoralis myocutaneous flaps (Table II).

We followed a reconstructive algorithm, as summarized in Figure 3. If the anterior skull base defect was of sufficient size to warrant a tracheotomy, then it also required a flap to support the contents of the anterior cranial fossa and separate the anterior cranial fossa from the upper aerodigestive tract. Also, if the dura was penetrated, then it was sutured primarily in a watertight fashion if possible. If it could not be repaired with sutures, any dural defect was repaired with xenograft, tensor fascia

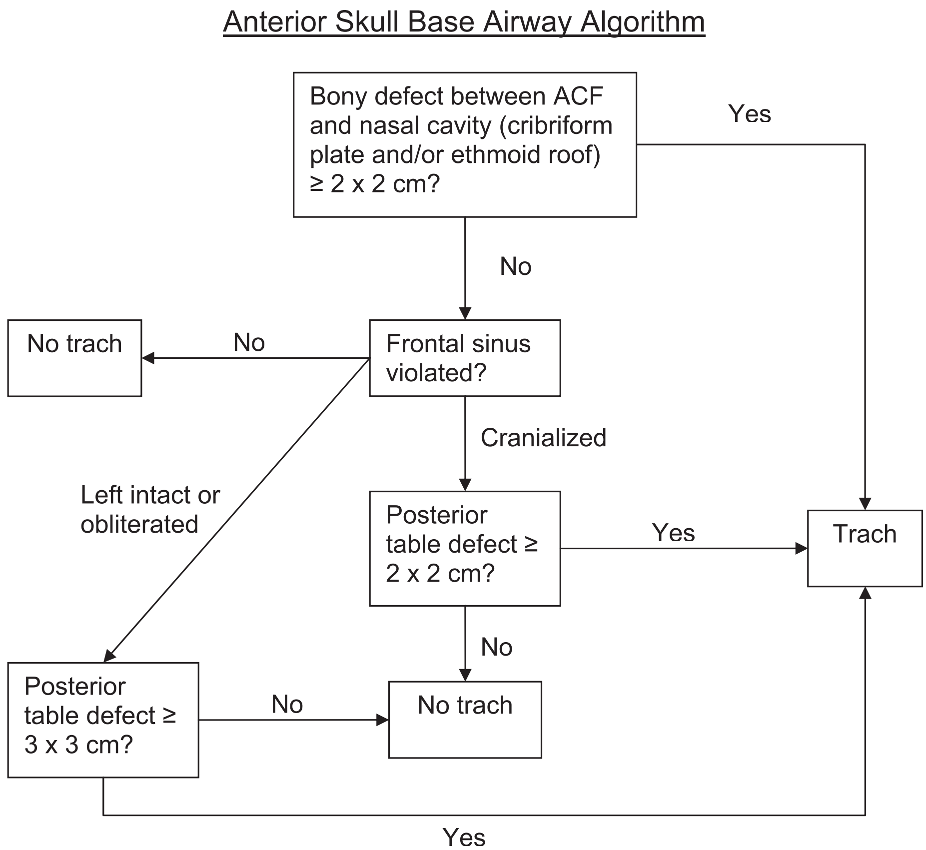

Fig. 2. Algorithm determining need for airway diversion in skull base surgery. trach = tracheotomy; ACF = anterior cranial fossa.

lata, or human dura allograft. Dural penetration was also an indication for flap reconstruction regardless of the size of the anterior skull base defect so as to provide a second barrier of separation from the sinonasal cavity.

Four patients reconstructed with local flaps and with a history of radiation therapy developed delayed osteoradionecrosis. All four were female patients, with three treated for meningioma and one treated for esthesioneuroblastoma. Two patients had localized osteoradionecrosis. One patient developed delayed necrosis of the craniotomy bone flap at 19 months. The last patient had three prior surgeries and two courses of radiation therapy elsewhere before presenting to the senior author with recurrent meningioma. After resection and reconstruction with a temporalis flap, she developed delayed osteoradionecrosis (9 mo postoperatively) followed by wound breakdown and CSF leak. She required revision skull base reconstruction with a latissimus dorsi myocutaneous free flap. All seven patients in this series who had free flap reconstruction had successful surgery and suffered no major complications after reconstruction.

All major complications in this series are summarized in Table III. Two patients suffered from stroke postoperatively. One had a massive stroke related to hypotension and ultimately required withdrawal of support. This was the only postoperative mortality in this series (1/109, 1%). The other patient recovered from her stroke with residual dysarthria and vertigo. There were no other neurologic complications (other than those related to deliberate cranial nerve sacrifice) among these 109 patients, including, notably, no incidence of tension pneumocephalus. Two of eight patients reconstructed with galeofrontalis local flaps developed scalp alopecia, both with history of radiation therapy. These were considered minor complications. Also, postoperative anosmia was considered an acceptable morbidity in cases

TABLE II.
Reconstruction of Skull Base Defects: Flap Type.

Reconstruction of Skull Base Defects	No.
No reconstruction	13
Local flaps	88
Pericranial	40
Temporalis	23
Galeofrontalis	8
Nasal septal	7
Pericranial + temporalis	6
Nasal mucosal	3
Palatal	1
Regional pedicled flaps	2
Extended pectoralis	2
Free flaps (6 primary and 1 revision)	7
Rectus	4
Radial forearm	2
Latissimus (revision)	1

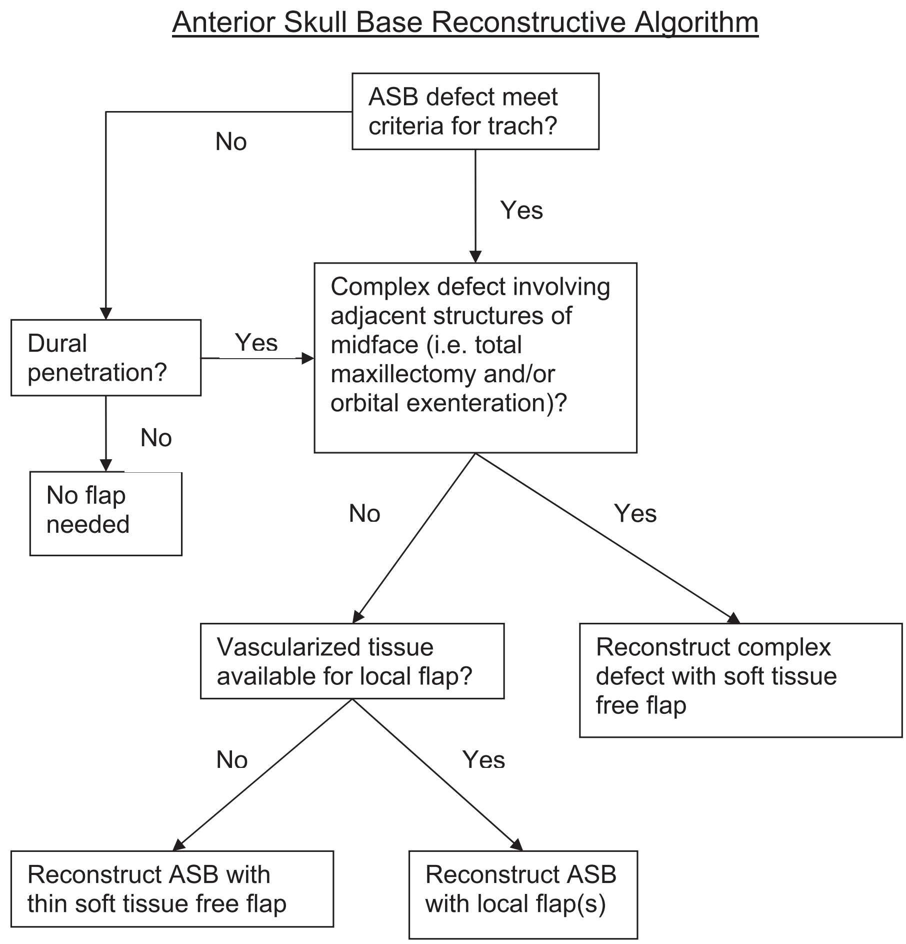

Fig. 3. Algorithm for flap selection in skull base surgery. ASB = anterior skull base.

requiring sacrifice of one or both olfactory bulbs as part of the surgical approach to the skull base. In total, there were 7 major complications in 6 of 109 patients, for a major complication rate of 6%.

TABLE III.
Classification of Complications.

Major Complications	No. (%)
Local	
ORN (delayed post-EBRT)	4 (4)
CSF leak (delayed)	1 (1)
Major wound infections	0
Loss of free flap (7 cases w/free flap)	0
Neurologic	
Stroke	2 (2)
Meningitis	0
Brain abscess	0
Tension pneumocephalus	0
Intracranial hemorrhage	0
Systemic	
Mortality (withdrawal of care after massive stroke)	1 (1)
Total major complications	7 (6)

ORN = osteoradionecrosis; EBRT = external beam radiation therapy; CSF = cerebrospinal fluid.

DISCUSSION

Reports of tension pneumocephalus are sporadic in the literature. Our review of large studies of anterior skull base surgery revealed this complication reported in 0 to 12 cases per series, making its true incidence difficult to determine. However, at least one study attributed three postoperative deaths to tension pneumocephalus.[10] This complication can occur rapidly and without warning, typically within 24 hours of surgery via a "ball-valve" mechanism I which a sudden drastic rise in upper airway pressure (from coughing, sneezing, nose blowing, or Valsalva maneuver) forces air intracranially through a defect in the skull base, which then seals as a one-way valve, preventing the trapped air from escaping.[4,5,9] The air can collect in the epidural space or force its way through a defect in the dura and remain trapped subdurally. The trapped air then acts as a space-occupying lesion, displacing and compressing the brain and raising intracranial pressure. Clinical symptoms include Cushing's triad (hypertension, bradycardia, and irregular respirations), papilledema, confusion, focal neurologic signs, seizures, depressed mental status progressing to coma, and finally brainstem herniation and death.[4,5,9] Treatment of recognized tension pneumocephalus can include placing the patient on 100% oxygen (for nitrogen gas washout), diverting the patient's airway via cuffed endotracheal tube or cuffed tracheotomy, hyperventilation, osmotic diuresis, aspirating the intracranial air collection through a burr hole, and re-exploring the surgical wound in cases of recurrent tension pneumocephalus to achieve airtight closure of the skull base defect.[4,5,8,9] Few studies have discussed strategies to minimize their risk of tension pneumocephalus. Studies by Clevens et al.,[5] Donald,[6] and Wanamaker et al.[9] all discuss early experience with tension pneumocephalus among their anterior skull base cases prior to instituting a policy of routine prophylactic tracheotomy with subsequently no further incidents of this complication in their respective series. Clevens et al. recommend prophylactic tracheotomy for cases in which factors are identified associated with the development of tension pneumocephalus, including penetration of the dura, advanced tumor with skull base invasion, resection of the cribriform plate, CSF drain, and development of upper airway pressure.[5] Donald notes that in addition to preventing postoperative tension pneumocephalus, airway diversion via tracheotomy eliminates the endotracheal tube, which helps keep a sterile operative field and maintains better control of the airway during a long case.[6] Studies by Origitano et al.[7] and Solero et al.,[8] on the other hand, both describe using routine prophylactic tracheotomy for anterior skull base cases in their early experience but then abandoning this procedure in their later experience from perceived lack of benefit. Origitano et al. instead place a subfrontal epidural drain above the reconstructive flap connected to bulb suction. They test the drain to make sure it is airtight and holds negative suction before the patient leaves the operating room. Their series of 120 patients reported two cases of "primary pneumocephalus" and six cases of "secondary pneumocephalus," but their overall rate of major complications was an impressive 17% and improved to only 10% among the last 50 consecutive patients in their series, despite no longer performing routine tracheotomies.[7] They recommend elective tracheotomy only for cases that involve the use of the transoral transpalatal approach. Solero et al. reviewed their extensive experience of 168 patients undergoing anterior craniofacial resection for tumors and noted 12 (7%) patients developed tension pneumocephalus, including 1 of 5 patients who received prophylactic tracheotomy.[8] They concluded that prophylactic tracheotomy was not helpful. Gil et al.[4] reviewed their experience of 85 anterior skull base cases via the subcranial approach without prophylactic tracheotomy. They reported only one patient developing tension pneumocephalus postoperatively. The authors of this study recommend against prophylactic airway diversion, citing no tension pneumocephalus among their routine cases with this one exception. They argued that immediate postoperative extubation is important after reliable neurologic examinations and that tracheotomy carries morbidity to the patient, has a risk of its own complications, can prolong the hospital stay, and interferes with postoperative rehabilitation without perceived benefit. They recommended stool softeners postoperatively to reduce Valsalva maneuvers and instructed their patients to avoid blowing their nose. They also stressed that positive pressure ventilation via a facemask is absolutely contraindicated postoperatively in patients undergoing anterior skull base surgery and that these patients should be intubated immediately if they need assisted ventilation.

We do not endorse a blanket policy of routine tracheotomy for all anterior skull base patients but only in those with significant bony defects between the anterior cranial fossa and sinonasal cavities, as per our proposed algorithm in Figure 2. The tracheotomy avoids prolonged postoperative intubation and allows for serial neurologic examinations in an awake patient. It completely diverts the airway, preventing the patient from building upper airway pressure from coughing, sneezing, or Valsalva. A tracheotomy tube with inflated cuff makes nose blowing impossible and does not rely on sedated and possibly confused postoperative patients to not blow their noses. Tracheotomy is considered superior to intubation for prevention of tension pneumocephalus and during treatment of tension pneumocephalus because there have been several case reports of tension pneumocephalus while patients are intubated.[5,9] Tracheotomy has some additional benefits such as removing the endotracheal tube from the operative field, helping maintain a sterile field, securing the airway during long cases, and allowing the anesthesiologist easy access to the airway circuit. Postoperatively, it also gives ready access to the airway should the patient require urgent assisted ventilation without concern about intubation or positive pressure from an airtight facemask. We believe that complete airway diversion may also assist in wound healing during the early postoperative period by diverting lower airway secretions from the wound and preventing shear and stress forces on the skull base reconstruction from positive pressure, thus allowing tension-free healing. We have not found tracheotomy to significantly prolong the hospital stay of our patients (6.2 d with tracheotomy vs. 4.1 d without tracheotomy compared with 13 d average hospital stay in study by Gil et al. in which no tracheotomies were performed), if it is considered that patients with tracheotomy also had more extensive resection of their anterior skull base, nor have we found tracheotomy to be a consideration for when patients are ready to be transferred from the intensive care unit.

We believe that judicious use of tracheotomy in select patients helps achieve a low complication rate, but we would also like to stress other points of the senior author's technique. First, all patients receive perioperative prophylactic antibiotic coverage with cephazolin and metronidazole to cover skin flora and anaerobes. Patients also receive routine perioperative steroids with intravenous dexamethasone for 24 hours to help reduce facial edema and brain swelling. We protect the eyes from corneal abrasions during the surgery with temporary tarsorrhaphy. Any penetration of dura requires watertight closure either primarily if possible or with suitable graft material as well as a flap for secondary reinforcement. We coat any flap brought into the anterior skull base with fibrin glue to help seal off dead space. We meticulously suture and tack dura to the bone defect edges through calvarial drill holes. We selectively perform dacryocystorhinostomy with silastic stents in cases in which there is concern for nasolacrimal duct injury or sacrifice. We do not routinely pack the nose except in cases in which we bring a pericranial flap into the midface to cover calvarial bone grafts or bone segments from midfacial disassembly. We do not believe nasal packs are necessary to support a skull base reconstruction nor have they been shown to prevent tension pneumocephalus.[5]

We do not routinely place a lumbar drain to assist with brain retraction, relying instead on other techniques such as intraoperative hyperventilation, steroids, and mannitol to achieve brain relaxation without sacrificing adequate exposure of the anterior cranial fossa. With only 1 case of CSF leak in our series of 109 patients, and this case being a delayed CSF leak secondary to another wound complication, we do not believe that a lumbar drain is helpful in preventing CSF leaks in these patients. A few other anterior skull base series do not routinely place a lumbar drain,[7,8] but the vast majority of published reports do recommend it, typically removing the drain after 3 to 5 days postoperatively. There are several reports of excessive CSF drainage from the lumbar drain causing tension pneumocephalus.[11,12] An "inverted pop bottle" mechanism explains this phenomenon, in which rapid loss of CSF causes build-up of negative pressure as air bubbles rush in to fill a cranial-dural defect.[4,5,8] Wary of this potential complication, several authors who rely on an intraoperative lumbar drain recommend its removal immediately after surgery.[11,13] Because we do not require one to obtain adequate exposure, we are able to avoid its complications and reduce preparative time by avoiding the lumbar drain altogether.

The senior author emphasizes the use of local vascularized tissue whenever possible to achieve these goals. Local flaps were used in 88 of 96 (92%) patients who required primary reconstruction of the skull base. We do not line the nasal side of the flap with a skin graft, preferring instead to allow the sinonasal cavity to remucosalize. The author's "workhorse" flap for these cases is the extended pericranial flap, which he used in 46 patients in this series. We described the utility of this flap in another article.[14]

CONCLUSION

We emphasize the importance of elective tracheotomy for prophylactic airway diversion in selected patients with significant bony defects of the anterior skull base. We believe this prevents tension pneumocephalus, assists in wound healing at the skull base, and helps account for our exceptionally low complication rate. We also emphasize the importance of reconstruction with vascularized tissue in cases with medium to large bony defects of the anterior skull base or to reinforce the closure of dura in cases with dural penetration. We recommend the use of local tissue whenever possible for anterior skull base reconstruction, reserving free tissue transfer for cases where local tissue is unavailable or is unable to adequately close the defect. These principles have resulted in a very low mortality rate of under 1% and a major complication rate of only 6%, which matches the lowest major complication rate reported in the literature.[15]

BIBLIOGRAPHY

1. Ketcham AS, Wilkins RH, Van Buren JM, et al. A combined intracranial facial approach to the paranasal sinuses. *Am J Surg* 1963;106:698–703.
2. Ganly I, Patel SG, Singh B, et al. Complications of craniofacial resection for malignant tumors of the skull base: report of an international collaborative study. *Head Neck* 2005; 27:445–451.
3. Ketcham AS, Hoye RC, Van Buren JM. Complications of intracranial facial resection for tumors of the paranasal sinuses. *Am J Surg* 1966;112:591–596.
4. Gil Z, Cohen JT, Spektor S, et al. Anterior skull base surgery without prophylactic airway diversion procedures. *Otolaryngol Head Neck Surg* 2003;128:681–685.
5. Clevens RA, Marentette LJ, Esclamado RM, et al. Incidence and management of tension pneumocephalus after anterior craniofacial resection: case reports and review of the literature. *Otolaryngol Head Neck Surg* 1999;120: 579–583.
6. Donald PJ. Complications in skull base surgery for malignancy. *Laryngoscope* 1999;109:1959–1966.
7. Origitano TC, Petruzzelli GJ, Leonetti JP, et al. Combined anterior and anterolateral approaches to the cranial base: complication analysis, avoidance, and management. *Neurosurgery* 2006;58:327–337.
8. Solero CL, DiMeco F, Sampath P, et al. Combined anterior craniofacial resection for tumors involving the cribriform plate: early postoperative complications and technical considerations. *Neurosurgery* 2000;47:1296–1305.
9. Wanamaker JR, Mehle ME, Wood BG, et al. Tension pneumocephalus following craniofacial resection. *Head Neck* 1995;17:152–156.
10. Califano J, Cordeiro PG, Disa JJ, et al. Anterior cranial base reconstruction using free tissue transfer: changing trends. *Head Neck* 2003;25:89–96.
11. Richtsmeier WJ, Briggs RJ, Koch WM, et al. Complications and early outcome of anterior craniofacial resection. *Arch Otolaryngol Head Neck Surg* 1992;118:913–917.
12. Yates H, Hamill M, Borel CO, Toung TJ. Incidence and perioperative management of tension pneumocephalus following craniofacial resection. *J Neurosurg Anesthesiol* 1994;6: 15–20.
13. Kraus DH, Shah JP, Arbit E, et al. Complications of craniofacial resection for tumors involving the anterior skull base. *Head Neck* 1994;16:307–312.
14. Smith JE, Ducic Y. The versatile extended pericranial flap for closure of skull base defects. *Otolaryngol Head Neck Surg* 2004;130:704–711.
15. Janecka IP, Sen C, Sekhar L, Curtin H. Treatment of paranasal sinus cancer with cranial base surgery: results. *Laryngoscope* 1994;104:553–555.