Microvascular Reconstruction of the Skull Base: A Clinical Approach to Surgical Defect Classification and Flap Selection

Andrea L. Pusic, M.D., M.H.S.,¹ Constance M. Chen, M.D., M.P.H.,¹
Snehal Patel, M.D.,² Peter G. Cordeiro, M.D.,¹ and Jatin P. Shah, M.D.²

ABSTRACT

Skull-base tumor resection and reconstruction produce a major physiologic and anatomic impact on the patient. At our institution, the use of vascularized, free-tissue transfer has replaced pedicled flaps as the preferred modality for reconstructing complex cranial base defects involving resection of dura, brain, or multiple major structures adjacent to skull base, including the orbit, palate, mandible, skin, and other structures. The goals of reconstruction are to: (1) support the brain and orbit; (2) separate the CNS from the aerodigestive tract; (3) provide lining for the nasal cavity; (4) re-establish the nasal and oropharyngeal cavities; (5) provide volume to decrease dead space; and (6) restore the three-dimensional appearance of the face and head with bone and soft tissues. Surgical management requires a multidisciplinary effort with collaborating neurosurgical, head and neck, and plastic surgical teams. Successful reconstruction of skull base defects is predicated upon a careful appreciation of the specific region. Defects may be classified based on their anatomic location and loss of volume, support, and skin cover. Free flaps provide reliable, well-vascularized soft tissue to seal the dura, obliterate dead space, cover exposed cranial bone, and provide cutaneous coverage for skin or mucosa.

KEYWORDS: Skull base, reconstruction, microvascular free flaps, classification

¹Plastic and Reconstructive Surgery, ²Head and Neck Surgery, Memorial Sloan-Kettering Cancer Center, New York, New York.

Address for correspondence and reprint requests: Andrea L. Pusic, M.D., M.H.S., Plastic and Reconstructive Surgery, Memorial Sloan-Kettering Cancer Center, Rm. C-1189, 1275 York Ave., New York, NY 10021 (e-mail: pusica@mskcc.org).

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THE PROBLEM

Malignant tumors of the skull base are rare. The complex anatomy of the vital structures in this area makes surgical resection of tumors involving the skull base extremely difficult. Resection may be by means of an anterior fossa approach, middle fossa approach, or a combined anterior and middle fossa approach. The exact location of the surgical defects varies depending on the nature and extent of the primary tumor. Cancers of the nasal cavity, paranasal sinuses, orbit, scalp, and calvarium may extend to the anterior cranial fossa through the base of the skull. Further spread of these tumors can lead to intracranial extension with involvement of the dura or brain. The middle cranial fossa involves many lesions that arise laterally in or around the temporal bone, infratemporal fossa, parotid gland, and surrounding skin. Tumors of the pterygomaxillary region and the infratemporal fossa require special attention to the surgical approach for exposure and resection. Prior to surgery, radiographic studies including MRI, CT scans, and angiograms should be reviewed, and they should be available in the operating room. A skull should also be available in the operating room (Fig. 1).¹

While operative mortality has remained low for craniofacial resection over the years, such resec-

tions continue to produce a major physiologic and anatomic impact on the patient. Multiple studies have reported postoperative complication rates ranging from 25 to 65%.²⁻¹⁰ Review of a collected series of 1193 patients from 17 institutions classified complications as systemic, wound, central nervous system (CNS), and orbit, with rates reported as follows: wound (19.8%), CNS-related (16.2%), orbit (1.7%), and systemic (4.8%).² Medical comorbidity, prior radiation therapy, and the extent of intracranial tumor involvement were independent predictors of postoperative complications.² In multiple studies, postoperative mortality rates range from 0 to 7.6%.²⁻⁹

In our institution, the use of vascularized, free tissue transfer has replaced pedicled flaps as the preferred modality for reconstructing complex cranial base defects; such defects may involve dura, brain, or multiple major structures adjacent to skull base, including the orbit, palate, mandible, skin, and other structures. Surgical extirpation of malignant tumors of the skull base can result in extensive defects, resulting in both facial disfigurement and a complex three-dimensional defect. Ablation using an anterior cranial fossa approach can result in loss of orbital content, palate, maxilla, bony skull base, and dura. Defects from a middle cranial fossa approach are often associated with a large cutaneous defect involving the external ear, preauricular and/or postauricular skin, temporal bone, maxilla, and/or mandible.¹¹ The size and location of these defects often encroach on or exceed the excursion of regional musculocutaneous flaps. The distal tip of the pedicled flap, where blood supply is most precarious, is usually the part of the flap that reaches the defect.¹¹

Successful reconstruction of skull base defects demands a large volume of reliable soft tissue to fill the dead space to minimize the chance of complications at the site of extirpation. Although regional musculocutaneous flaps are an option in many skull base defects, free tissue transfer is a more reliable means of accomplishing this task. Total or partial flap loss can lead to exposure of cranial bone devoid of periosteum, dura, and/or brain with the risk of

Figure 1 A skull should be available in the operating room.

infection. Complications in this setting are devastating in that they can lead to meningitis, osteomyelitis, and delay in the onset of adjuvant therapy.¹¹ Given these concerns, the goals of skull-based reconstruction are as follows (Table 1): (1) to support the brain and orbit; (2) to separate the CNS from the aerodigestive tract; (3) to provide lining for the nasal cavity; (4) to re-establish the nasal and oropharyngeal cavities; (5) to provide volume to decrease dead space; and (6) to restore the three-dimensional appearance of the face and head with bone and soft tissues.

THE TEAM

Successful management of skull base reconstruction requires a multidisciplinary effort. The ablative and reconstructive surgeons must communicate well in terms of both the expected defect and the possible reconstructive options. The cornerstone is the combined team effort by collaborating neurosurgical, head and neck, and plastic surgical teams.¹² In addition, the anesthesia and the critical care teams also must be well advised of the nature of the procedure and the hemodynamic stress that can be expected.

Many patients have undergone some form of therapy prior to craniofacial surgery for malignant skull base tumors.¹³ The radiation oncologist is therefore also an important participant in the overall treatment plan. Some patients have had previous radiation therapy, and it is important to be aware of previous radiation portals and dosage. Others may

need postoperative radiotherapy or adjuvant brachytherapy.¹³ These issues have important implications for the choice of flap, as both recipient and donor sites can be affected by radiation injury. Similarly, the medical oncologist is also integral to the planning of surgery since patients may receive both pre- and postoperative chemotherapy. Surgical procedures should be optimally timed to minimize chemotherapy effects on wound healing.

Most important to the ultimate success of the reconstruction is the full and informed involvement of the patient and the family. Despite the most accurate anatomic reconstruction, skull base resection can result in significant psychological morbidity. In one study of 105 head and neck cancer survivors, premorbid pessimism was consistently found to be the best predictor of postoperative quality of life.¹⁴ Indeed, head and neck cancer patients who experience low-level social support and face-disfiguring treatment are at greatest risk for psychosocial dysfunction.¹⁵ Pretreatment variables can be used to predict head and neck cancer patients who are likely to become depressed after treatment.¹⁶ Data regarding the benefits of setting up a formal rehabilitation program offering psychosocial support are conflicting, however.^{17,18} Furthermore, while head and neck cancer patients do not necessarily experience poor quality of life, the disease can have a significant impact on their partners.¹⁶ For these reasons, the psychologist should also be an integral part of the skull base surgery team. In addition, specialized nursing teams are crucial to help the patients and their families prepare for and adjust to any perioperative psychosocial distress that they may experience.

Table 1 Goals of Skull Base Reconstruction

1. To support the brain and orbit
2. To separate the CNS from the aerodigestive tract
3. To provide lining for the nasal cavity
4. To re-establish the nasal and oropharyngeal cavities
5. To provide volume to decrease dead space
6. To restore the three-dimensional appearance of the face and head with bone and soft tissues

CNS, central nervous system.

DEFECT CLASSIFICATION

Successful reconstruction of skull base defects is predicated upon a careful appreciation of the specific region. Defects may be classified based on their anatomic location and loss of volume, support, and skin cover (Fig. 2). There are two basic approaches

Figure 2 Defect classification.

to resection: anterior cranial fossa and middle cranial fossa. Both anterior and middle cranial fossa defects can involve the orbit, maxilla, mandible, nasal lining, palate, and skin.

Anterior cranial fossa defects may involve the central and/or lateral regions and result from resection of tumors involving the sinonasal tract or orbit. Extent of resection may be categorized into three groups: simple, complex, and other types. Simple anterior cranial fossa resections include the area of the skull base at the cribriform plate adjacent to the tumor and those resections that include additional resection of a portion of the palate or of the orbital contents. Complex anterior cranial fossa resections include the floor of the anterior fossa immediately adjacent to the tumor, dura, and/or brain with or without orbital contents, nasal cavity, maxilla, and the palate. Other types of anterior cranial fossa resections include the skull base as well as a single additional major structure other than dura, brain, palate, or orbital contents, such as amputation of the nose or frontal calvarium.¹²

Middle cranial fossa defects result from benign and malignant tumors in and around the temporal bone. Lesions vary from maxillary sinus tumors that extend into the pterygopalatine fossa or infratemporal fossa with involvement of the neural

foramina at the skull base to schwannomas of the lower cranial nerves (IX to XII) or the sympathetic chain, paragangliomas of either the jugular bulb or the vagus nerve, deep-lobe parotid tumors with significant retromandibular extension, soft-tissue sarcomas of the masticator muscles, carcinomas (squamous, basal, or minor salivary) of the external ear canal and temporal bone, and carcinomas of the nasopharynx.¹⁹

RECONSTRUCTIVE OPTIONS BASED ON DEFECT TYPE

Reconstructive technique used in craniofacial resection is dependent on the size and complexity of the surgical defect. The use of the galeal pericranial flap is well established for simple central defects of the anterior cranial fossa (Fig. 3), but free flaps are generally used for large, more complex surgical defects.² Indeed, free flaps have become the most frequently used and effective of procedures (Table 2). Many flaps have been described, none of which is ideal for all defect types. In our experience, four free flaps can be used to successfully reconstruct the majority of defects: the rectus

Figure 3 The use of the galeal-pericranial flap is well established for simple central defects of the anterior cranial fossa.

abdominis flap, the radial forearm flap, the latissimus dorsi flap, and the anterolateral thigh flap. Two pedicled flaps, the galeal-pericranial flap and the temporoparietal flap, can also be used in combination with free flaps or alone for less extensive defects.

The ideal reconstruction for a skull base defect must be reliable to minimize complications related to inadequacies of reconstruction. The traditional concept of the reconstructive ladder (use the simplest, least complicated procedure available) is

not necessarily valid. In skull base reconstruction, the simplest procedure must be the procedure with the highest success rate regardless of technical complexity. As a result, free tissue transfer has become widely accepted as the best method of reconstructing defects of the skull base.^{11,20–26}

Anterior cranial fossa resection begins with a bifrontal craniotomy, followed by facial exposure via a Weber-Fergusson incision, with or without sub-ciliary extension.¹⁹ Once the tumor has been resected with tumor-free margins, reconstruction of the anterior skull base defect can proceed. Dural defects are closed primarily or with a free fascial or pericranial graft. The frontal sinus is cranialized. A galeal-pericranial flap is elevated from the scalp flap, with preservation of blood supply from the anteriorly based pedicle consisting of supraorbital and supratrochlear vessels. This may be draped over the bony defect in the floor of the cranium, without placement of free bone graft for support. The flap is secured with sutures through drill holes in the bony margins of the resection.¹²

Middle cranial fossa resection begins with either a retroauricular incision from the frontal area down to the neck or a hemicoronal incision posterior to the hairline and carried into the preauricular region to the neck. A pterional or temporal craniotomy is performed. The facial skeleton may be mobilized, with careful dissection of nerves, vessels, and muscles to gain adequate exposure of the tumor. Once resected, reconstruction of the middle cranial fossa defect can proceed.¹⁹

Table 2 Anterior Cranial Base Reconstruction Studies Using Free Tissue Transfer Techniques

Authors	Year	Institution	Study Period	#	RAM	Lat	RFF	DM
Yamada*	1992	University of Tokyo	1980–1990	25				
Izquierdo	1993	Loyola	1989–1991	6	100%	—	—	—
Clayman	1995	MD Anderson	1988–1992	41	46%	37%	3%	Other 14%
Neligan	1996	Toronto Hospital	1982–1992	20	85%	—	15%	—
Dias	1999	Hospital do Cancer	1981–1996	45	91%	—	—	9%
Chang	2001	MD Anderson	1993–1999	52	75%	14%	6%	Other 5%
Heth	2002	University of Iowa	1991–1999	32	48%	31%	16%	—

*Yamada, # flaps 25 (groin 12, dorsi 6, scapular 4, thigh, 1, deltapectoral 2).

RAM, rectus abdominis myocutaneous flap; RFF, radial forearm flap; LAT, latissimus flap; DM, dorsalis major flap.

The mobilized temporalis muscle may be used to partially reconstruct or seal off the surgical defect. Large soft-tissue defects are reconstructed using free tissue transfer to prevent cerebrospinal fluid (CSF) leak and to provide orbital support or support to the dura and brain.¹⁹

Free flaps provide reliable, well-vascularized soft tissue to seal the dura, obliterate dead space, cover exposed cranial bone, and also provide cutaneous coverage for skin or mucosa (Fig. 4).¹¹ In the event of vascularized free tissue transfer reconstruction, recipient vessels are prepared by performing a limited lymphadenectomy of levels I, II, and III. This provides superior exposure to a range of possible arterial and venous recipient vessels. The preferred recipient arteries include the facial artery, lingual artery, and superior thyroid artery. The preferred recipient vein is the internal jugular vein or, if that was previously sacrificed, the external

jugular vein, transverse cervical vein, or the facial vein. For the internal jugular vein, anastomosis is accomplished in an end-to-side orientation; all other anastomoses are performed end to end. An intramuscular dissection technique lengthens the vascular pedicle, obviating the need for vein grafts.¹¹

As stated previously, one of the four flaps can be used to reconstruct the majority of defects: the rectus abdominis, the latissimus dorsi, the antero-lateral thigh, and the radial forearm. When used, these flaps are harvested with a skin island, which can be used for coverage or lining, or de-epithelialized for bulk. For most skull base reconstructions, the rectus abdominis is the workhorse, and it is often used because of its ability to provide extensive skin coverage and allow for reconstruction of orbital and palatal defects simultaneously (Fig. 5).¹² The location of the donor site allows simultaneous flap harvest and tumor resection, decreasing operative

Figure 4 (A) Patient with squamous cell carcinoma of the ethmoid perforating through the nasal bone and involving the overlying skin. (B) Through-and-through surgical defect with resection of the skin of the nose, nasal bones, ethmoid complex, and cribriform plate. (C) Reconstruction completed with a folded radial forearm free flap and a free bone graft. Photos reproduced with permission.

Figure 5 (A) Patient with extensive basal cell carcinoma involving the scalp, calvarium, and right orbit. (B) MRI scan in coronal plane shows extensive infiltration of the tumor through the calvarium into the extradural space of the anterior cranial fossa. (C) Surgical defect shows repair of the dural defect accomplished using a bovine pericardial graft. (D) Reconstruction of the defect of the calvarium and the scalp, accomplished with a rectus abdominis free flap. Photos reproduced with permission.

time and eliminating the need to reposition the patient. The anatomy of the blood supply enhances its versatility, as skin islands can be tailored to reconstruct external skin losses and internal mucosal defects simultaneously. Finally, the pedicle is reasonably long with vessels of adequate diameter (Fig. 6).¹¹

RECONSTRUCTIVE OPTIONS BASED ON PATIENT CHARACTERISTICS

While defect size and complexity are the primary determinants of flap selection, individual patient characteristics must also be considered. In heavily irradiated patients, free flap reconstruction is necessary, and the rectus flap may be desirable even for small defects as its muscle bulk can aid in revascularization. For patients who have previously

undergone abdominal surgery, however, or who have failed reconstruction with the rectus abdominis muscle, a second-line free flap option may be necessary. Likewise, obese patients may not be candidates for reconstruction with the rectus abdominis due to inadequate blood supply and lipodystrophy. In obese patients, the anterolateral thigh flap is frequently selected as it provides appropriate volume with a reliable skin paddle.²⁷

FLAP DESIGN AND ELEVATION

The Rectus Abdominis Flap

The flap is dissected with the patient supine. The skin incision is carried down to the level of the anterior rectus sheath; subcutaneous tissue and skin

Figure 6 (A) Patient with a locally advanced carcinoma of the maxillary antrum involving the orbit, nasal cavity, ethmoid complex, and the overlying skin. (B) Surgical defect showing through-and-through resection of the tumor with skin of the face, nose, contents of the orbit, maxilla, nasal cavity, and ethmoids. (C) Surgical specimen showing three-dimensional resection of the entire tumor in a monoblock fashion. (D) Rectus abdominis free flap seen in the oral cavity replacing the resected part of the hard palate, providing a water-tight closure in the oral cavity. (E) Second island of skin on the rectus abdominis free flap used to cover the skin defect with the underlying muscle, providing coverage for the dead space. Photos reproduced with permission.

are then elevated off the sheath to allow an incision through the fascia to be made 1 cm from the lateral edge of the muscle. The dissection is then carried around the anterior and lateral surfaces of the muscle to the posterior surface. The muscle can be divided above the level of the costal margin if necessary. The muscle is then dissected away from the abdominal wall in a distal-to-proximal direction along the posterior rectus sheath toward the inferior epigastric pedicle. The insertion of the muscle is detached, and microvascular anastomosis is performed with the recipient vessels as described above.²⁸

The Radial Forearm Flap

The course of the radial artery and the superficial veins is marked, with the flap axis slightly medial to the course of the radial artery. Using a pattern taken from the skull base defect, the size and shape of the wound is transferred to correspond with the

recipient structures, including nerves and vessels. The flap is incised down to the underlying antebrachial fascia to lift the flap subfascially, identifying the subcutaneous veins and nerves that will be used in the transfer. The medial and lateral sides of the flap should be dissected toward the fascial septum, leaving a bed of muscle proximally and tendons with intact paratenon distally. The flexor carpi radialis and brachioradialis should be spread apart with retractors and the radial artery and venae comitantes divided distally. A dissection plane should be developed under the radial artery along its length until the flap is free. Finally, the proximal pedicle should be divided for anastomosis to the recipient vessels as described above.²⁹

The Latissimus Dorsi Flap

The skin paddle is designed in an oblique fashion over the latissimus dorsi muscle. After incisions are

made, the flap is elevated off the thorax from its multiple origins in a cephalad direction toward the axilla. Segmental perforating vessels are ligated sequentially. During the dissection toward the humeral insertion, the serratus anterior muscle and its vascular pedicle, a branch of the thoracodorsal artery, are identified. To obtain the longest vascular leash, the pedicle to the serratus muscle is divided unless the slips are to be carried with the latissimus dorsi. Microvascular anastomosis is performed to the recipient vessels as described above.

The Anterolateral Thigh Flap

With the patient in a supine position, a line is drawn between the anterior superior iliac spine to the superolateral border of the patella. This line represents the muscular septum between the rectus femoris and the vastus lateralis muscles. The cutaneous vessels are mapped by portable handheld pencil Doppler probe centered over the midpoint of this line, with the majority of skin perforators located within a 3-cm radius of this midpoint. The flap is centered over these vessels, with the long axis designed parallel to that of the thigh. Dissection begins at the medial border of the flap over the rectus femoris muscle. An incision is made through the deep fascia and the flap is raised laterally for a short distance until the intermuscular septum between the rectus femoris and the vastus lateralis is reached. The descending branch of the lateral femoral circumflex artery is then identified in the groove between the rectus femoris and vastus lateralis, and a septocutaneous vessel may be identified to facilitate further dissection. If a septocutaneous vessel is not available, then flap harvest requires careful dissection of a suitable intramuscular perforator back to the main descending branch of the lateral circumflex femoral artery. The flap is then raised suprafascially with a small cuff of fascia maintained around the perforator. Microvascular anastomosis of the perforators is then performed using the recipient vessels described above.³⁰

PREVENTION AND MANAGEMENT OF COMPLICATIONS

Early complications following skull base reconstruction include partial or total flap loss, palatal fistula, delayed recovery of neurological status, hematoma, facial nerve weakness, pneumocephalus, seizure, and CSF leak. Late complications include ectropion, enophthalmos, orbital dystopia, persistent diplopia, bone flap infection or necrosis, wound infection, delayed wound healing, intracranial abscess, meningitis, and infected hardware.^{11,12} Even with flap reconstruction, the risk of infection (cellulitis or abscess) is approximately 1.4 to 7.4%.¹² Important preventative measures include perioperative antibiotics, adequate irrigation, and drain placement. At our institution, antibiotic coverage includes intraoperative use of vancomycin, ceftazidime, and metronidazole, which continues postoperatively until packing is removed from the nasal cavity 1 week later.¹² If infection develops, operative exploration, irrigation, and drainage may be necessary. Intracranial abscess requires neurosurgical intervention.

Medical comorbidity and prior treatment with radiation therapy are statistically significant predictors for postoperative wound complications.² Minor wound separation may occur between the flap and the wound bed, but most such wounds will heal with local wound care.¹¹ Delayed wound healing should also be treated conservatively, as surgical revision is only rarely required.

For CNS complications, prior treatment with radiation therapy, dural invasion, and brain invasion are independent risk factors.² The use of the galeal-pericranial flap or pericranial flap as opposed to other types of reconstruction has been reported to decrease the incidence of cerebrospinal fluid leaks from 25 to 6.5% due to superior vascularity.^{31,32} Neligan³³ and Califano¹² and their colleagues reported that the use of free flaps significantly reduced postoperative complications after craniofacial resection, especially CNS complications. While a multi-institutional study analyzing the effect of vascularized versus nonvascularized tissue showed no reduction in

overall complications when vascularized tissue was used, this may be explained by the fact that reconstructive technique is dependent upon the size and complexity of the surgical defect. Therefore, free flap reconstruction is most likely to be used when the soft-tissue defect is very large. Thus, comparing complication rates from different reconstructive methods is not meaningful, since different types of reconstruction will be used for different defects.

Finally, with regard to postoperative mortality, when investigators from 17 institutions were asked to complete questionnaires about patients who underwent craniofacial resection over a 30-year period, there were 56 deaths out of 1193 patients with complication and mortality-related data recorded (4.7%). Statistically significant predictors of postoperative death included patient age greater than 50 years and the presence of medical comorbid conditions. The only independently significant risk factor, however, was medical comorbidity. The relative risk was 1.9 ($p = 0.05$), suggesting that patients were twice as likely to die postoperatively if they had a major medical comorbidity.²

Mortality and overall postoperative complications appear to have remained steady for the past few decades. While it may seem that improvements in imaging, surgical technique, reconstruction, antibiotics, and postoperative care should have resulted in a reduction in complications, such advances have also allowed surgeons to undertake larger and more complex operations for tumors that were previously considered unresectable. Thus, any improvement in outcomes after more common "routine" skull base reconstruction may be offset by the increased complication rates after more challenging situations. In sum, skull base reconstruction is a safe operative procedure after resection of malignant tumors of the skull base. Factors that are predictive of complications and mortality include medical comorbidity, prior radiation, and dural and brain involvement. These factors should be carefully considered when planning therapy for patients amenable to resection and

reconstruction for malignant tumors of the skull base.²

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