Reconstruction of Lateral Skull Base Defects after Tumor Ablation

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ABSTRACT

Neoplasms located in the lateral skull base region present a challenge for evaluation and management due to their difficult anatomic location and the complex reconstruction that is required following extensive tumor resection. Repair following tumor ablation requires a watertight dural seal, obliteration of the dead space, and coverage with vascularized soft tissue. Advances in radiologic imaging, diagnostic pathology, and surgical techniques and a multidisciplinary team for tumor ablation and reconstruction have significantly improved the treatment of these patients, minimized the occurrence of postoperative complications, and maximized patient outcome and quality of life. In this article, we present our experience in the reconstruction of extensive lateral skull base defects after tumor ablation.

KEYWORDS: Skull base, head and neck cancer, reconstruction

Lesions located in the lateral skull base region present a difficult problem for evaluation and management due to the complex anatomic location and the challenging reconstruction that is required following extensive tumor resection. Advances in various medical and surgical specialties and the development of the multidisciplinary team have led to successful treatment of many skull

base lesions that were previously thought to be inoperable. These resections often create large defects that require challenging soft-tissue and/or bony reconstruction. Failure of this reconstruction can lead to potentially fatal complications. The purpose of this article is to present our management in the reconstruction of lateral skull base defects following tumor ablation and an algorithm

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to assist with the selection of the optimal form of reconstruction.

ANATOMY AND PATHOLOGY

The internal skull base forms the floor of the cranial cavity and is composed of three fossae: the anterior, middle, and posterior cranial fossae. The anterior cranial fossa is formed by the anterior and cribriform plate of the ethmoid, the lesser wings of the sphenoid, and the jugum sphenoidale. The middle cranial fossa is composed of the body and the greater wing of the sphenoid, the anterior surface of the temporal pyramid, and parts of the temporal squama. The posterior cranial fossa is bordered by the clivus, the pyramid of the temporal bone, and the occipital bone.

To assist in the evaluation and management of tumors in the skull base, this area has been classified into different “surgical” regions. Jackson and Hide’s classification in 1982¹ divided the skull base into the anterior and posterior areas. The anterior area corresponded anatomically with the anterior cranial fossa, whereas the posterior area was divided into the posterior-anterior, the posterior-central, and the posterior-posterior segments. In 1987, Jones and associates² divided the skull base into three segments, the anterior, middle, and posterior regions, corresponding to the respective anatomical cranial fossae.

Irish and coworkers³ in their 1994 review of 77 skull base malignancies developed a classification system of three regions which was based upon the anatomic boundaries and tumor growth patterns (Fig. 1). Region I consists of the anterior cranial fossa and because of a similar tumor growth pattern, this region also comprises the area of the clivus extending to the foramen magnum. Tumors originating in Region I are commonly resected via an anterior approach. Region II includes the infratemporal and pterygopalatine fossa, with possible tumor extension into the middle cranial fossa. Region III involves the temporal bone with a

Figure 1 The skull base is divided into three regions based on anatomic borders and the growth pattern of malignancies.

possible tumor extension into the posterior or middle cranial fossa.

Lateral Skull Base

In this article, the “lateral skull base” is defined as the combination of Regions II and III as described by Irish et al³ (Fig. 2).

Region II extends from the posterior wall of the orbit to the petrous temporal bone and is formed by the infratemporal and pterygopalatine fossae and the overlying part of the middle cranial fossa. In this region, there are several important neurovascular structures which include the internal carotid artery, the facial nerve, the vestibulocochlear nerve, and the maxillary (V2) and mandibular (V3) divisions of the trigeminal nerve.

Region III is located mainly in the posterior cranial fossa and also includes the posterior segment of the middle cranial fossa. Vital structures located in this region include the internal jugular vein and

Figure 2 The "lateral skull base" is defined as the combination of Regions II and III.

the vagus, the glossopharyngeal, the spinal accessory, and the hypoglossal nerves.

Pathology

Lesions located in Region II include tumors of the nasopharynx, clival chordomas, meningiomas, and glomus jugulare tumors. Neoplasms that originate outside of this region and subsequently invade Region II are mainly squamous cell carcinomas or basal cell cancers of the scalp and ear⁴ or the parotid gland.

As reported by Jones and coworkers,² common neoplasms of Region III include glomus tumors and schwannomas. However, in their series, Irish et al³ found that 60% of patients had a squamous cell carcinoma. The discrepancy in the tumor pathology reported in these studies may reflect diversity in the referral patterns to the different surgical specialties.

Irish and colleagues³ reported that tumors of the lateral skull base, especially those located in Region II, had a worse prognosis compared with those of Region I, and none of the patients

with a Region II tumor survived 4 years. However, considering all tumor types and regions together, the International Collaborative Study group on skull base tumors⁵ reported a post-operative mortality of 4.7% in a large cohort of patients, and the presence of comorbidity was the only statistically significant predictor of mortality.

SURGICAL APPROACHES FOR TUMOR ABLATION

The surgical approach necessary for tumor extirpation will depend on several factors including the location, characteristics, and size of the tumor. There are two main surgical approaches⁶ to access tumors located in the lateral skull base: the infratemporal and the transtemporal approaches.⁷

Those tumors located primarily in Region II may be surgically exposed through an infratemporal approach using a hemicoronal incision, which may be extended via a preauricular incision. In some cases, it may be necessary to increase the surgical exposure and this may be achieved by combining the infratemporal approach with a mandibulectomy or a mandibulotomy (anterior or lateral). Some surgeons have described using a transtemporal approach for these tumors.⁷ This approach requires a postauricular extension to the hemicoronal incision and transection of the external auditory canal. Those lesions located in the mid region with intradural invasion may be accessed through a frontotemporal craniotomy. However, some tumors of the lateral skull base (Region II) can be resected using a mandibular osteotomy and swing with appropriate neck dissection.

Lesions located in the posterior aspect of the lateral skull base are best exposed using a transtemporal approach, and in some cases, resection of the area surrounding the carotid artery and the sigmoid sinus is necessary.

RECONSTRUCTION OF THE LATERAL SKULL BASE

The main goals of reconstruction in the head and neck region are to provide structural support and adequate soft-tissue coverage for optimal function and cosmesis. In addition to these goals, there are often more challenges facing the reconstructive surgeon after tumor ablation in the skull base. Because of the extensive resection required for tumor extirpation, additional procedures are often needed to minimize the risk of postoperative complications and to increase the likelihood of a successful reconstruction. It is necessary to obtain a watertight dural seal, to eradicate dead space, to support neural structures, and to ensure coverage with well-vascularized tissue.

Technical Considerations

In many cases, tumor ablation in the cranial base will result in exposure of the meninges to the upper aerodigestive tract, thus increasing the risk of possible fatal complications and adding to the reconstructive challenges. Numerous techniques have been described to provide closure of the dura and some of these techniques have been less successful than others. Ketcham and coworkers⁸ reported as early as 1966 a high rate of cerebrospinal fluid (CSF) leak after closure of the dura using a skin graft. With the advancement of surgical techniques and the increased use of vascularized tissue, it was found that as a dural seal, vascularized tissue was superior to nonvascularized tissue and decreased the rate of complications associated with a CSF leak. Therefore we advocate the use of vascularized tissue for dural closure.

To decrease the risk of postoperative complications following lateral skull base reconstruction, it is imperative to ensure obliteration of the dead space. This can be accomplished by using vascularized tissue to fill the cavity. In some patients, a local muscle or myocutaneous flap can provide sufficient vascularized tissue to pack into the dead space.

Because the scalp is composed of well-vascularized soft tissue which can be advanced or rotated into adjacent skull base defects, local flaps such as the pericranial,⁹ galeal or galeal-myofascial,¹⁰ glabellar, or temporalis¹¹ flaps may be used in some regions of the skull base. However, for reconstruction of the lateral skull base, many of these local flaps cannot reach to this region and the temporalis flap is the only local flap that can be advanced into this area. In patients who have undergone a radical neck dissection, the local flaps may be devascularized or included in the resection and therefore may not be used in the repair.

In many cases, a local flap will not provide sufficient vascularized soft tissue for the reconstruction or cannot reach the target area and distant pedicled flaps may be employed. These flaps include the pectoralis,^{12,13} the latissimus dorsi,¹⁴ the trapezius, and the sternocleidomastoid¹⁵ muscle flaps. In more recent years, the advancement of microvascular technique and of free tissue transfer has made the pedicled flap a less desirable option. The free flap provides an abundant supply of vascularized soft tissue and the opportunity for repair of more complex large defects. With consideration of the specific characteristics and dimensions of the defect, the free tissue transfer can be uniquely designed based upon the requirements of the reconstruction. The use of a free flap also provides the opportunity for two surgical teams to work simultaneously: one for the tumor ablation and the second for harvest of the free tissue transfer. The use of two teams will decrease the operative time and the perioperative morbidity that is associated with a lengthy procedure. The use of free flaps^{16,17} has been recognized as a safe and reliable method to repair skull base defects. In many cases, after large tumor ablation in the lateral skull base and a significant resultant defect, the facial nerve and the auricle may have been sacrificed to obtain histologic tumor-free margins.

The reconstructive surgeon must take into account many aspects when selecting the optimal method of reconstruction following tumor extirpation. These factors include the size of the defect, the type of tissue required, if the dura was breached,

patient comorbidities, and other patient factors. It is with consideration of these factors that the surgeon must then evaluate the merits of a local vascularized flap or a free tissue transfer to meet the requirements of the reconstruction. Our experience with reconstruction of the skull base has led to the development of an algorithm to assist with this decision (Fig. 3).

Dural Seal

Regardless of the size of the defect, in cases where the dura has been breached, a watertight dural seal is mandatory to minimize the risk of potentially fatal complications. This seal can be established by creating a partition wall between the defect and the adjacent paranasal sinuses or the exterior environment. In cases where only a small breach of the dura has been created, one might consider nonvascularized alternatives to repair the dura. However, because of the high risk of postoperative complications associated with the use of nonvascularized tissue, in most cases a vascularized flap is recommended to ensure a watertight seal. Because of the anatomic position and orientation of the lateral skull base, there can be a downward gravitational pull on the

dural repair, which may result in migration and separation of the flap from the repair site. This downward traction can create difficulty in maintaining a watertight seal and also may result in more dead space. To rectify this problem, the flap is secured to the surrounding bone by suspension sutures, which help to maintain the position of the flap in the skull base (Fig. 4). If the rectus abdominus muscle is used, the sutures for suspension are placed in the tendinous intersection to provide a more secure attachment and thus minimize the risk of wound dehiscence. Fibrin glue can then be used to seal the dural repair.

Vascularized Tissue Transfer

If the dural defect and the dead space are minimal, this area may be closed by using an advancement scalp flap. Because of the close proximity and the capacity of the temporalis muscle flap¹⁷ to reach this area, it is the local flap that is used most often in the lateral skull base.

Figure 3 Algorithm for the management of lateral skull base defects.

Figure 4 This photomicrograph shows the use of drill holes for securing the flap to the adjacent bone, thereby achieving a watertight dural seal.

Large size defects are preferably reconstructed with a free tissue transfer. The rectus abdominis muscle flap¹⁸ provides a long pedicle, substantial soft-tissue bulk, and very reliable vascularity. Therefore this free tissue transfer is frequently used for large defects in the skull base. The selection of the reconstructive method will also depend on the availability of reliable donor vessels. For the venous and arterial anastomosis of the free flaps in the lateral skull base, donor vessels from the neck are recruited and these vessels should be evaluated for suitability, including vessel size, required pedicle length, and pedicle geometry. Vein grafts are rarely required to complete the anastomosis. Because the flap is deep in the skull base, postoperative external monitoring of the flap is impossible and therefore venous pedicle patency should be monitored with an implantable Doppler probe.

Bony Reconstruction

Many of these patients undergo postoperative adjuvant radiotherapy and therefore the use of avascular bone should be avoided due to the increased risk of infection and osteonecrosis. In most cases, it is possible to successfully reconstruct the defect with only soft tissue, but if bony support is necessary, vascularized bone, or alternatively, alloplastic materials such as titanium mesh, should be used. This inert, nonallergenic metal with a low risk of infection is an excellent selection when structural support is necessary. There is no contraindication for follow-up radiographic studies, including CT scans and MRI.

Facial Nerve Reconstruction

Facial nerve palsy may occur in patients with neoplasms located in the skull base as a result of tumor pathology and growth, tumor ablation, or operative trauma, including traction on the facial nerve. Facial paresis can significantly affect the patient's

self-image, function, and socialization and therefore to minimize patient morbidity and to improve patient outcome and quality of life, reconstruction to achieve optimal facial reanimation and/or symmetry is recommended.

Following injury to the facial nerve, the degree of injury should be determined. In cases of facial palsy due to operative trauma, facial paresis may be due to a neurapraxic¹⁹ or a Sunderland first-degree²⁰ injury and complete recovery would be anticipated following remyelination of the nerve. In cases due to greater trauma, the degree of nerve injury may be more severe and complete recovery may occur but would require an adequate time for nerve regeneration (1 mm/day) and reinnervation of the facial muscles.²⁰ These patients, however, do not require any operative intervention to regain facial nerve function. Postoperative electromyography (EMG) should be performed about 4 weeks following surgery to determine the degree of nerve injury and the potential for recovery. EMGs performed before this time may be too early to detect the presence of fibrillations in the muscle and may not adequately assess the degree of nerve injury.

In cases where a Sunderland fifth degree²⁰ injury (no continuity of the nerve) has occurred, immediate reconstruction to achieve reinnervation of the facial muscles should be considered when possible. If the facial nerve has been transected or only a small segment of the nerve has been resected and both the proximal and distal nerve stumps are available, the facial nerve may be repaired primarily at the time of tumor ablation. If the nerve cannot be coapted without tension, then a primary repair should not be attempted and an interpositional cable nerve graft or nerve transfer should be utilized. For cable grafts, there are several small-diameter sensory nerves that are commonly used as donor nerves, including the medial antebrachial cutaneous nerve, the sural nerve, and on occasion the greater auricular nerve.²⁰⁻²² Consideration should be given to the length of the nerve segment deficit, the number of cables required, and the resultant sensory deficit. If the proximal or distal stump of the nerve is not available and immediate

reconstruction is preferred, nerve transfers such as the partial hypoglossal^{23,24} to facial nerve or muscle transposition of the temporalis or masseter muscle are excellent alternatives.^{22,25,26} Previous studies have illustrated that postoperative radiation does not negatively affect nerve regeneration.^{27–29} Gullane and Havas²⁹ showed that postoperative radiation after extensive resection of parotid cancers with sacrifice of the facial nerve in four of six patients and reconstruction with nerve grafting resulted in excellent function. Therefore patients who may undergo postoperative radiation should not be denied facial nerve repair. Because facial nerve function may inhibit complete eyelid closure, patients with facial paresis should be evaluated for injury to the cornea. In patients with reduced eyelid closure and thus at risk for corneal abrasion, eyelid closure may be achieved by inserting a gold weight toward the medial edge of the upper lid³⁰ (Fig. 5).

When excision of the facial nerve has been extended intratemporally or intracranially and no proximal nerve stump is available for reconstruction, many options for facial reanimation are available and should be considered for delayed reconstruction. These include a cross facial nerve graft with a free muscle transfer, free muscle transfer innervated by the trigeminal nerve motor branch to the masseter muscle, or muscle transposition of the temporalis or masseter muscles.^{22,25,26,31} Procedures that do not involve

reinnervation of the facial muscles and utilize a free tissue muscle transfer innervated by a cross facial nerve graft, or the masseter branch of the trigeminal nerve, or a temporalis muscle transfer may be performed even after long periods of denervation of the facial muscles.^{22,25,26,31} In patients with a poor prognosis or who do not wish to undergo a complex procedure, static slings such as that created with the palmaris longus may be a good alternative to restore facial tone at rest.

Auricular Reconstruction

Patients with tumor ablative auricular defects are mostly adults and the scarring and soft-tissue/skin loss make standard autogenous reconstruction difficult. In addition, pre- or postoperative radiotherapy might further complicate this type of repair. A multistep auricular reconstructive surgery may not be indicated in patients with a poor prognosis. Therefore, prosthetic restoration of the ear with a premanufactured auricular prosthesis is a valuable option.³² The prosthesis can be “glued” directly to the skin by using a tissue adhesive, or as more recently described, can be attached onto a metallic framework which is then fixed into the temporal bone using titanium screws for osseointegration³³ (Fig. 6). In cases in which the tragus can be preserved and the anterior border of the prosthesis may be hidden, the aesthetic outcome is generally more acceptable.³⁴

Figure 5 Complete eye closure is achieved with implantation of a gold weight into the upper eyelid.

COMPLICATIONS

Complication rates following skull base reconstruction vary from 11.5 to 63%.³⁵ The International Collaborative Review⁵ reported postoperative complications (systemic, wound, and central nervous system) occurred in 33% of patients and there were significantly more complications reported in patients with comorbidities, intracranial tumor

Figure 6 Position of the osseointegrated implant for aural reconstruction (left). Postoperative appearance of the prosthesis (right).

involvement, and prior radiation treatment. The decrease in complication rates in the more recent publications may be the result of several factors, including improved surgical technique, improved postoperative care, and increased use of the free tissue transfer.

Early Complications

Early complications include wound infection, CSF leak, cranial nerve dysfunction, and meningitis. Because many of the early complications relate to inadequate closure of the dura, postoperative monitoring is important along with prompt treatment of any postoperative complication. However, effective operative treatment of the dural seal will minimize the potential for these complications and therefore selection of the optimal reconstruction with consideration of the defect and patient comorbidities is essential.

WOUND INFECTION

As reported by Patel et al,³⁶ the most common early complication is wound infection. To minimize the morbidity that may occur following a wound infection, cultures should be taken promptly and the appropriate antibiotics instituted. Prophylactic anti-

biotics, such as a broad-spectrum cephalosporin with an anaerobic agent (such as Flagyl), may be indicated in cases where the oral and/or nasal cavities have been exposed.

FLAP COMPROMISE

Neligan and associates¹⁷ reported that free flap reconstructions significantly decreased the incidence of postoperative complications when compared with reconstruction with pedicled flaps. When analyzing the patients reconstructed with pedicled flaps, the authors found compromised wound healing in 36.3%, wound infection in 17.6%, CSF leak in 11.8%, and meningitis in 5.9%. However, in patients reconstructed with a free tissue transfer, compromised wound healing was reported in only 10% of cases and a CSF leak occurred in 5%. In this patient group no case of meningitis occurred. Therefore the use of free flaps for the reconstruction of skull base defects is advocated in most patients with large defects.^{37,38}

Arterial and venous flow should be monitored postoperatively with urgent treatment of any vascular compromise. Nonoperative techniques such as leeches may reverse venous congestion, but in most cases operative intervention will be necessary to establish good venous and/or arterial flow.

CSF LEAKAGE

As the size of the dural exposure increases, the risk of a complication associated with a cerebrospinal leak increases. A watertight seal is essential to minimize the risk leakage and may be achieved with the use of vascularized tissue. Conservative measures such as head elevation, lumbar drainage, and avoidance of Valsalva's maneuvers may be used for small leaks. However, for unresolved leaks, operative intervention or a lumbar drain may be necessary.

INTRACRANIAL INFECTIONS

The increased use of free flaps has significantly reduced the prevalence of postoperative ascending meningitis.¹⁷ If an intracranial infection does occur, broad-spectrum antibiotics are advocated.

CRANIAL NERVE DYSFUNCTION

Because tumor ablation may be extensive, cranial nerve dysfunction may result from the close proximity of these structures. If the nerve was included in the resection, nerve graft or repair should be used to minimize postoperative morbidity.^{39,40} Sacrifice of the vagus nerve may result in dysphagia and early thyroplasty is recommended. However, in cases in which the nerve has not been transected, the patient should be monitored and appropriate postoperative intervention done as indicated.

Late Complications

Late complications are usually the result of bony instability, soft tissue atrophy, and/or fibrosis and include malocclusion, trismus, diplopia, facial asymmetry, and nasal obstruction. These complications are not associated with mortality but can negatively affect the patient's quality of life.

CONCLUSION

Reconstruction of the lateral skull base is complex due to its location in the cranial base and the vital

vascular and neural structures that traverse this region. Repair following tumor ablation requires a watertight dural seal, obliteration of the dead space, and coverage with vascularized soft tissue. Advances in radiologic imaging, diagnostic pathology, and surgical techniques for tumor ablation and reconstruction have significantly improved the treatment of these patients, minimized the occurrence of postoperative complications, and maximized patient outcome and quality of life.

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