REVIEW ARTICLE

Principles of Skull Base Reconstruction After Ablative Head and Neck Cancer Surgery

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Abstract

"Resection of malignancies of the skull base can result in significant functional and cosmetic morbidity as well as mortality. Reconstructive efforts provide not only functional and cosmetic rehabilitation, but also allow for the avoidance of potentially disastrous complications such as cerebrospinal fluid leak or meningitis. The optimal reconstruction is determined both by a patient based approach and a defect based approach. Skull base defects can be addressed by the separate components of the craniofacial skeleton in which they involve, and therefore the individual reconstructive issues which must be addressed. In this article, we describe an approach to skull base reconstruction and the technical aspects of the available reconstructive options.

Keywords: Skull base surgery, reconstruction, head and neck cancer, free flap.

INTRODUCTION

Ablative surgery for head and neck cancer can result in a significant degree of cosmetic and functional morbidity; therefore, reconstruction is essential to optimal treatment and rehabilitation. In fact, before the relatively recent evolution of current reconstructive techniques, many patients routinely treated today would have been considered inoperable.[1] With the introduction of pedicled myocutaneous flaps, reconstruction of complex defects could be performed with an increased chance of success and decreas morbidity. Reconstructive surgery made another leap in the 1970's with the development of microvascular surgical techniques that allow for free tissue transfer of healthy tissue to operative site. Since that time, numerous free flaps from various donor sites throughout the body have been described, and the utility and versatility of microvascular surgery have greatly expanded the options for reconstruction in the head and neck offering multiple solutions to optimize reconstruction. This has been critical to the advancement of skull base surgery, where reconstructive efforts are critical to success and avoiding morbidity and mortality. This review is focused on reconstruction of the anterior and lateral skull base and the associated anatomic structures, which present a number of complex issues surrounding the adjacent vital structures.

Skull base ablative surgery initially was limited by the ability of surgeons to reconstruct a watertight barrier to separate the upper aerodigestive tract or outside world from the central nervous system, carrying with it the risk of cerebrospinal fluid leak, meningitis, abscess, and the sequelae of such complications. Early reconstructive efforts were fraught with complications and difficulty.[2] Nevertheless, operative mortality has significantly decreased with the evolution of modern skull base surgery and reconstruction; for example, in a recent collaborative study of nearly 1200 anterior skull base surgeries, perioperative mortality was less than 5%, with an overall complication rate of 36%.[3] We will review approaches to reconstruction and techniques to optimize reconstruction in an effort to minimize morbidity.

PATIENT-BASED APPROACH TO RECONSTRUCTION

Reconstruction cannot be planned based on the defect alone; the patient's comorbidities must first be considered as they may affect the patient's ability to tolerate the technically optimal reconstruction. Significant cardiac, pulmonary, and hepatic disease and overall general health are important to consider as the may significantly impact the likelihood of postoperative morbidity and mortality. The reconstructive surgery is preceded by a lengthy extirpative procedure, which results in an overall long operative and anesthesia time, sizeable wounds, occasionally significant blood loss, and a considerable recovery period often requiring feeding tube, tracheotomy, and physical rehabilitation. Extirpation of lesions at the skull base can carry varying risks, such as aspiration (with cranial nerve injury), or meningitis. Immunosuppression associated with poor nutritional states, HIV, or other diseases can impair wound healing and threaten reconstructive efforts.

At times a simplified reconstruction may shorten the surgery and possibly the recovery, while sacrificing the functional benefits of the optimal technique. This may generally mean that a pedicled flap is used to replace free tissue transfer; however, with regards to skull base surgery this decision is more difficult and must be carefully considered. Most pedicled flaps are limited in their utility to reconstruct skull base defects, as inadequate pedicle length can result in tension at the distal aspect of the reconstruction (Figs 1A to D). This can predispose the patient to higher rates of postoperative wound complications and distal flap loss. Such complications can subsequently delay timely radiotherapy. Free tissue transfer may obviate this problem. Neligan published some of the earliest suggesting that free tissue transfer may offer a safer reconstruction than pedicled flaps for reconstruction of the skull base.[9]

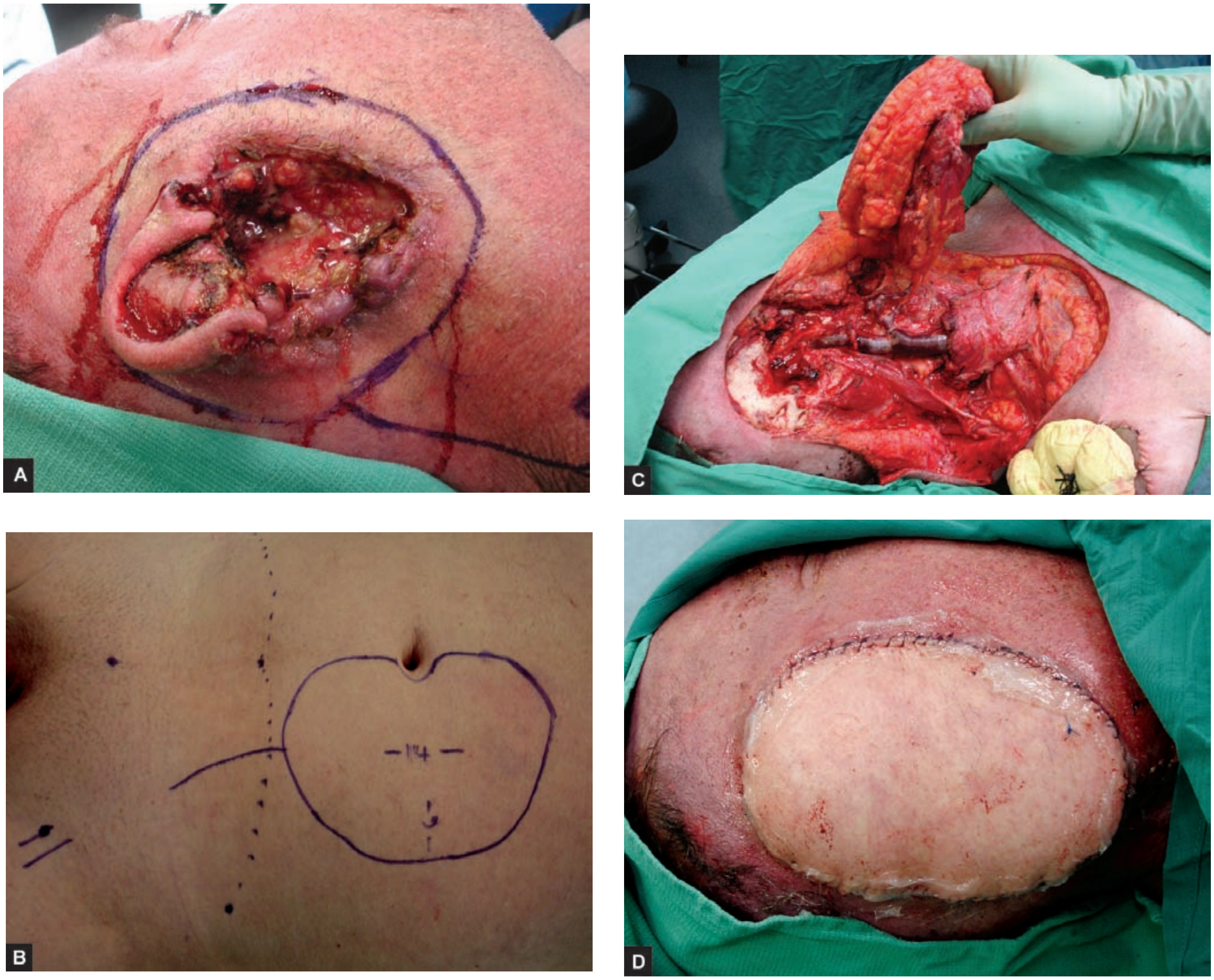
The impact of medical comorbidities on perioperative morbidity and mortality in head and neck surgery has been investigated by a number of studies. Using the American Society of Anesthesia (ASA) criteria, the Charlson index, or other indices to assess predictors for complications several studies have investigated the prognostic variables for head and neck cancer patients.[4] Such indices can be useful in predicting the immediate perioperative risk to patients, while others have been developed to assess patients long-term morbidity and mortality. The ASA criteria are fairly straightforward to establish and has been found to be an independent risk factor for perioperative morbidity and mortality for head and neck cancer patients, and can be useful in anticipating such problems.[4]

Additionally, authors have identified other specific factors such as age (usually pt's over 65 to 70 years old), current tobacco or alcohol use, hemoglobin (<11 gm/dL), and other factors may be important predictors of morbidity and mortality.[4] Advanced age alone is rarely a contraindication to reconstructive surgery, but should be taken into account and warrant careful preoperative optimization and intensive intraoperative and postoperative monitoring. Ongoing tobacco use is an important factor in head and neck surgery, but plays an important role in head and neck surgery. Smoking cessation should strongly be encouraged, especially in the perioperative period. It is suspected not to result in a higher rate of anastomotic thrombosis after microvascular surgery; however may result in a greater rate of skin loss.[5] Additionally chronic anemia is likely a surrogate for poor nutritional status, and therefore, may be an indicator for likelihood of poor wound healing and its incipient complications.[4] These factors should be taken into account when planning the operative and reconstructive procedures, and may require careful management. Alcoholism, and subsequently liver disease has a high prevalence among head and neck cancer patients and may pose a significant risk during the postoperative period, and some data suggests a higher rate of free flap failure with the development of delirium tremens.[6]

Despite the potential pitfalls, numerous large studies have reported great success in reconstruction with various techniques. For example, microvascular free tissue transfer is often reported to have a success rate of greater than 95%.[7,8] And, in skull base surgery may result in lower morbidity than with the use of regional flaps.[9,33] But, success must be measured not only by flap viability, but also by functional rehabilitation and quality of life after surgery. The optimal outcome can only be obtained by the careful choice in ablative and reconstructive techniques. Therefore, intertwined with the process of determining that assessing and optimizing the patient's medical status, it must be determined which reconstruction is best for the anticipated defect.

DEFECT-BASED APPROACH TO RECONSTRUCTION

Tumors involving the skull base are comprised of a heterogeneous group of pathologic entities that can affect numerous critical structures. Tumors of the sinonasal tract (thus often involving the anterior skull base) can be epithelial, salivary, or neuroendocrine (e.g. esthesioneuroblastoma), though melanoma, metastatic (e.g. breast and renal cell carcinomas) lesions can occur. Advanced cutaneous malignancies may also involve the skull base and present a similar set of management issues. Lateral skull base malignancies are frequently cutaneous and salivary in nature. Management of these lesions may necessitate a multidisciplinary surgical approach including a head and neck cancer surgeon, neurosurgeon, ophthalmologist, otologist, rhinologist, and reconstructive surgeon. An approach addressing all of the critical structures involved is essential to optimizing outcome. Given that the defects often involve multiple structures and subsites, it may be helpful to address these complex problems by addressing each separate component.



FIGURES 1A to D: Patient with a large cutaneous squamous cell carcinoma of the auricle, mandible, and lateral skull base. (A) The plan for the rectus abdominis free flap is seen here. This was used for the large surface area coverage it provides as well as the thickness needed to reconstruct a deep defect including a portion of the mandible. (B) The patient underwent resection including auriculectomy, lateral temporal bone resection, partial mandibulectomy, and modified radical neck dissection. The flap is seen here revascularized prior to inset (C), and after inset (D)

Scalp and Forehead Defects

Defects of the scalp alone represent the simplest step in the algorithm and are commonly managed in adjunct with defects of the skull base. The primary issues surrounding reconstruction of the scalp involve replacing the lost soft tissue to provide coverage of the calvarial bone or dura to prevent osteomyelitis or meningitis and, secondarily to optimize cosmesis.

At times, a single reconstructive technique can be used to close the entire ablative defect, but in some instances additional maneuvers can be employed to minimize the primary defect. Small soft tissue defects of the scalp (usually less than 3 cm in size) can often be addressed with primary closure, but closure of larger defects can be difficult as the galea is relatively inelastic.[10] Excessive tension resulting from an over-aggressive attempt at primary closure can result in wound breakdown, unsightly scar and alopecia. Vertical closure may be better to avoid distortion of the hairline or eyebrow. Scalp defects larger than 3 cm can be closed with advancement flaps. Some authors report closing defects up to 10 to 60% of the scalp with local advancement flaps based off of the supraorbital, supratrochlear, occipital or superficial temporal arteries.[11] Galeal scoring may also be useful to decrease wound tension, though it does not greatly increase flap length. Flaps for larger defects require skin grafting to the donor site. Alternatively, a skin graft can be directly applied to the pericranium, but this provides poor contour, and a fragile graft site. If the pericranium is involved, the outer cortex can be drilled away and a split thickness skin graft can be directly to the medullary bone of the skull. Each of these simpler techniques can be used alone or in combination with larger scale techniques to obtain closure of the ablative defect.

Few regional flaps are applicable for scalp and forehead defects because of distance that the pedicle must travel. But the temporoparietal fascia flap and temporalis muscle can be useful for orbital and temporal bone defects among other sites, if the pedicle is not sacrificed during ablation. A modified deltopectoral flap can reach as high as the ear.[12] The pectoralis can reach as high as the orbit,[13] and the lattisimus dorsi pedicled flap can reach as high as the floor of the middle fossa but requires repositioning which can make the 2-team approach difficult. The lower island trapezius muscle flap can also reach the skull base for reconstruction as well. Moore et al described the use of an occipital rotational flap for reconstruction of a lateral temporal bone defect.[14] However, most defects requiring large flap coverage may better served with free tissue transfer as this may result in fewer wound complications.[9] The tension on the wound from a pedicled flap at its maximum reach can result in increased wound complications at the most distal portion of the flap which can be the most critical portion of the reconstruction.[9]

Several schemas have been proposed regarding reconstruction of the scalp. Beasley proposed a system based on wound size and several other factors.[15] Lutz described a system based on cause and depth of the defect.[16] If the site is surrounded by compromised tissue or if postoperative radiation is likely to be needed then a free flap is used. Larger defects of the forehead or scalp may not be favorable to primary closure or local flap closure (< 50 cm^2 for forehead, < 200 cm^2 for scalp)[10,15] (Temple, Beasley). Various free flaps may be use, both muscle and fasciocutaneous. The most commonly used muscle flaps include the lattisimus dorsi and rectus, and the fasciocutanous flaps include scapular system, the anterolateral thigh, and radial forearm flap. Defects in the range of 200-600 cm^2 can be covered by latissimus dorsi flap. Larger defects may be better served with muscle flaps covered with skin grafts so as not to create too large a donor site defect. Defects > 600 cm^2 may require dual flap reconstruction.[17] The scapular fasciocutaneous flap can be useful for total forehead resurfacing as it provides optimal thickness. The anterolateral thigh has a long pedicle and can be a thin fasciocutaneous flap or can provide thickness when muscle included to fill defects, and has a less donor site morbidity than the rectus. While reconstruction of large defects often creates a significant cosmetic deformity, several key esthetic features should be addressed if possible, such as maintaining the natural hairline, symmetry of facial structures such as the brow. The forehead is divided into esthetic subunits of the paramedian lateral, and temporal regions, and the eyebrows.[18] Maintaining natural contour is also an important esthetic goal.[19]

Calvarial and Dural Defects

If calvarial bone and dura are involved the issues can become more complex and present the potential risk of neurologic sequelae such as meningitis. If full thickness calvarial bone must be resected, then plating with or without free or vascularized bone grafts can be used with soft tissue coverage provided by a vascularized flap. Alternatively, no bony reconstruction may be necessary or preferred at all with adequate soft tissue coverage. Split thickness calvarial graft provides a useful readily available bone source. Free rib grafts may also be used as well, though they require an additional donor site and morbidity.[20]

The dura should be assessed on preoperative imaging to anticipate a defect, and if violated neurosurgical assistance may be required. Reconstruction of the dura is dependent on the size of the defect. Small defects can be repaired primarily or with a patch of synthetic (e.g. Duragen, etc.) or biologic material (e.g. lyophilized dura, alloderm, etc). If pericranium is available, this provides a simple and effective method to achieve a water tight seal for significant defects of the dura. Additionally, a fascial layer or deepithelialized layer of a free flap can be used. Lumbar drainage is often beneficial in aiding watertight healing at the suture line. Biological glues (e.g. Duraseal) can often be used to reinforce the suture lines, but are merely an adjunct to a technically good watertight closure.

Defects of the Anterior Skull Base

Defects of the skull base are frequently addressed according to the classification scheme described by Irish et al. Zone I is comprised of defects of the anterior cranial fossa, which can include resection of portions of the orbit or orbital roof, nasal cavity and sinuses and cribriform plate. Zone II involves the middle cranial fossa, the pterygopalatine and infratemporal fossae. Zone III involves the posterior aspect of the middle cranial fossa and the posterior fossa.[21] The goals of reconstruction of the skull base are as follows: (1) separation of the central nervous system from the upper aerodigestive tract, (2) re-establishment of the oral and orbital cavities, (3) restoration of the normal three dimensional appearance of the bony and soft tissue structures of the face.[22]

Numerous approaches can be applied and represent an extension of some of the previously described techniques. Temporoparietal or galeal flaps are useful for achieving dural closure if the tissue is available; however, it may not be adequate for large volume defects. The anterolateral thigh flap has been applied as a fasciocutaneous or musculocutaneous flap, and can be very useful to fill the orbit or bony defects of the supraorbital rim.[34] If the defect requires soft tissue bulk muscle can be included in an anterolateral thigh flap. While small or shallow defects may only require a fasciocutaneous flaps, such as the radial forearm. This flap provides a substantial amount of thin, pliable tissue with a lengthy pedicle.

Defects of the anterior and lateral skull base are often reconstructed without bone, but bone may be useful in the areas of cosmetic significance, such as the forehead and supraorbital rim. In the setting of likely need for adjuvant treatment, the use of bone must be judicious in order to avoid the risk of osteoradionecrosis.[23] Various vascularized bone flaps such as the fibula, scapular system or iliac crest could be used in the setting of significant defect and are preferred over free bone grafts.

Defects of the Lateral Skull Base

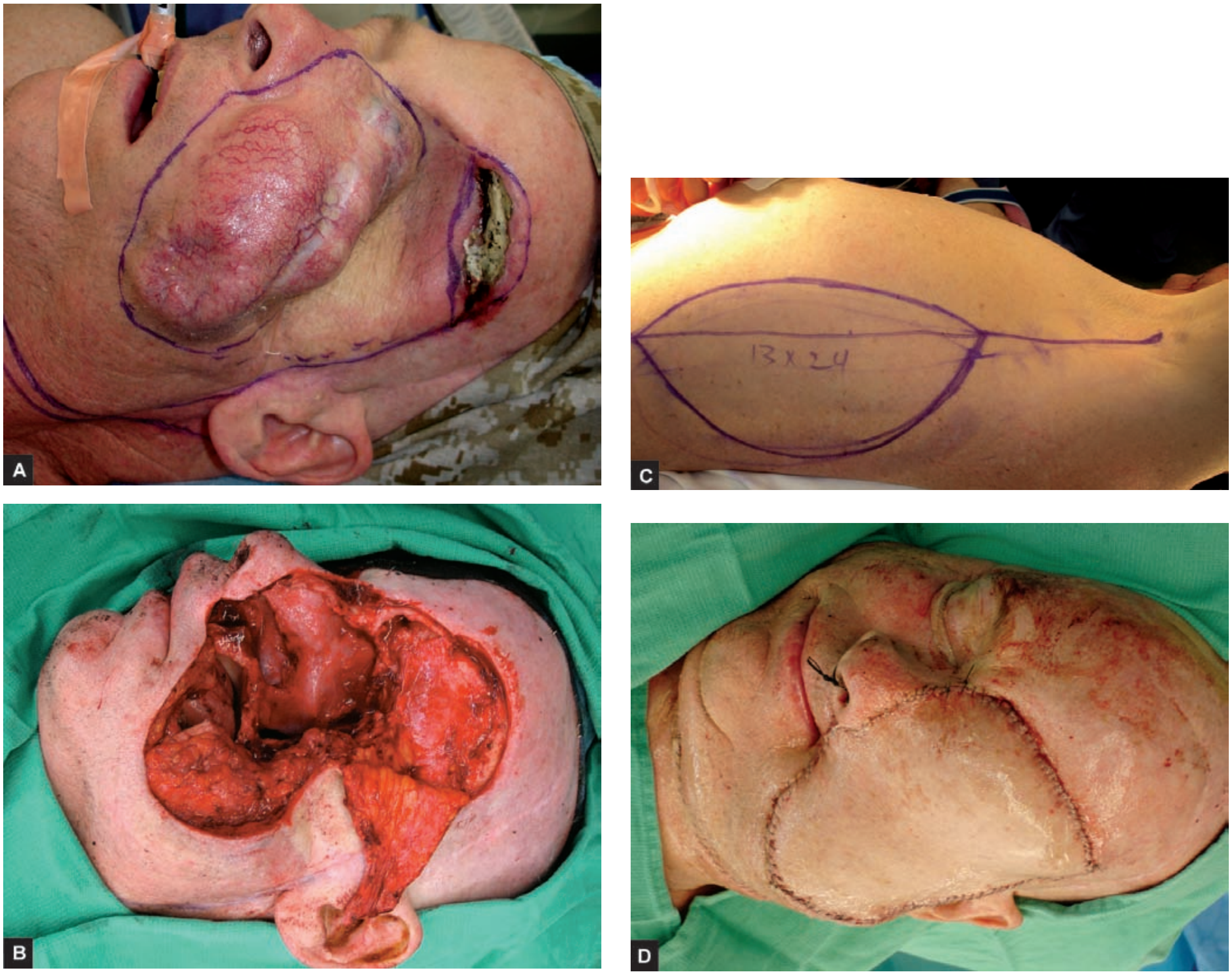
Using the categorization described by Irish et al, such defects consist of Zone II and III defects. Such defects often arise from parotid malignancy or malignancy of the auricle, external auditory canal or temporal bone, infratemporal fossa, or pterygopalatine fossa which generates a specific subset of issues. But generally soft tissue must be provided to fill the defect and if necessary a water tight dural seal must be obtained. If necessary the pinna can be replaced with prosthesis.

Regional flaps such as the temporalis are occasionally an option; however, this leaves a significant soft tissue defect in the temporal fossa. Also, it can frequently be devascularized during ablation eliminating it as an option or resulting in high rate of failure.[9] Nevertheless, for smaller defects this may provide effective soft tissue coverage. Such defects may often be best served with free tissue transfer as suggested by Neligan et al.[9] This allows for large amounts of soft tissue in a reliable technique, avoiding the potential wound healing complications of regional flaps to prevent a delay in postoperative radiotherapy as needed in many cases.

If the auricle is preserved after lateral temporal bone resection, the external auditory canal is often sewn shut. If the auricle is sacrificed, the best reconstructive option may be with a prosthesis, which can be fixed in place with glue or via posting on an osteointegrated screw or magnet. While this may require an additional procedure and replacement of the prosthesis every 2 or 3 years, it improves cosmesis and the social acceptability of the defect.[25] In the setting of malignancy, and the potential need for multiple surgeries to reconstruct an auricle and the potential need for radiotherapy to the region, it is rare that surgical reconstruction of the auricle is indicated. Often, the middle ear cavity is obliterated with soft tissue and Eustachian tube is plugged as in formal lateral temporal bone resection. Hearing loss can be managed with bone anchored hearing aid, whether ipsilateral sensorineural function is intact or lost.

Defects of the Midface

Midfacial defects are often generated simultaneously in the ablation of skull base tumors during craniofacial resection and thus separate subsites of reconstruction must be considered. Therefore, extensive reconstruction of the midface may require bony augmentation after resection, which involves primarily re-establishing the structural buttresses of the face. Some authors find it unnecessary to replace midfacial defects with bone, but rather rely on soft tissue transfer alone.[26] If bony reconstruction is undertaken, key elements of bony structure of the midface must be addressed. Attention to preservation of reconstruction of the malar eminence and the orbital framework can optimize re-establishment the closest approximation of anatomic contour.[27] Bony reconstruction of the malar region may offer some support to the soft tissue of the flap or the remaining nasal structures. This can be augmented with plating as well. Scapula, fibula and iliac crest can all be used to provide good bony support to the midface and after substantial craniofacial resection. However the limitation of the fibula is the relatively small amount of soft tissue available and its limited mobility with respect to the bone. Although the iliac crest affords a large amount of soft tissue with both the skin flap and internal oblique muscle, this flap similarly is considered difficult to use for this purpose secondary to tethering of the skin paddle to the bone.[28]



FIGURES 2A to D: Patient after orbital exenteration and free flap reconstruction for anterior skull base squamous cell carcinoma. (A) Note recurrence deep to previous flap and exposure of supraorbital rim. After resection of the tumor, the orbital, sinonasal and anterior skull base defect is seen.(B) A latissimus dorsi myocutaneous free flap was used for reconstruction, because of the large skin coverage and soft tissue bulk needed.(C) While the rectus would have been a suitable option, this was used for the previous flap. Another option available for such defects is the anterolateral thigh. The flap after inset (D)

Palatal reconstruction is a complex issue which may be accomplished with free tissue transfer local flaps or palatal obturators and is beyond the scope of this paper, but is thoroughly addressed is several other reports.[29]

Defects of the Orbit

The rectus muscle can be used to provide soft tissue bulk to fill the orbital defect. Additionally, the rectus can be harvested with the 7th and 8th ribs for bony reconstruction of the orbit and peritoneum can be used for a vascularized dural repair, but this is complex and adds difficulty to the flap harvest. Multiple skin paddles can be used for large defects.[23] With large defects of the orbitomaxillary complex and orbital exenteration, some authors prefer the scapular system flap for reconstruction, as the independent soft tissue and bony pedicles of the scapular system flap may offer the most versatility for reconstruction (Figs 2A to D).[27] If the orbit is to be exenterated then the defect may require a large amount of tissue to reconstruct. The temporalis muscle if available can be used for reconstruction, or the anterolateral thigh, rectus, or scapular systems can provide adequate bulk to fill this defect. A prosthesis may be used to provide the most natural appearance; however, the exposure of bone in the cavity, mucosal scarring, and mucous collection can lead to osteomyelitis, crusting, bleeding, and foul odor. While a prosthesis may allow for easier surveillance, reconstruction can help avoid such complications and may still allow for use of a prosthesis.

If the globe is to remain, optimal reconstruction can be difficult as normal globe and eyelid position are difficult to maintain.[30] Use of any residual bony shelf around the orbit can be used to fix the graft to restore optimal anatomic configuration.[31] Preservation of the native eyelid structures when the eye is preserved is critical, but difficult to avoid postoperative dysfunction.[32] The patient must be informed of the likely need for postoperative adjustment and revision as they will likely be necessary, these structures must be sacrificed.

Defects of the Sinuses and Nasal Cavity

Defects of the nasal cavity and sinuses represent a point of potential contamination and thus risk of ascending meningitis and high-risk site for CSF leak. The tissue support can be provided by titanium mesh or plates as support for the soft tissue reconstruction. As skull base surgery has extended into the endoscopic endonasal realm, a multitude of techniques have been described for the reconstruction of such defects. Such a discussion is beyond the scope of this article, but numerous works review such techniques.

The primary goal is skull base reconstruction is separation of the central nervous system from the upper aerodigestive tract. Thus the sinonasal tract is reconstructed primarily for this goal and secondarily to support the orbit. Further separation of the sinonasal tract from the oral cavity is also important for rehabilitation.[26] Maintenance of a patent nasal airway is also a secondary goal, especially if the contralateral nasal cavity is patent. However, if possible maintaining a patent nasal cavity can provide more optimal reconstruction and function. Nasal obstruction may result from several sites. Externally, the lateral aspect of the nasal soft tissues may collapse without bony support immediately or overtime with scarring. Alternatively, soft tissue bulk within the nasal cavity may additionally result on occlusion. Nasal packing or trumpets can be used in the immediate period which may offer some stenting. In some cases a skin graft can be used to reconstruct the lateral nasal wall, if this is sutured tightly and anchored with sutures to bone the flap can lay against this area and the nasal cavity can theoretically be kept open.[26] Suspension of the external soft tissue can prove to be a difficult problem secondary to the bulk of the tissue. Some authors have had better results when a less bulky flap is used such as a radial forearm. If the orbital contents are salvageable, then postoperative epiphora is also a possibility. This can be managed expectantly with dacrocystorhinostomy.

CONCLUSION

Reconstruction of the skull base after ablative surgery for head and neck cancer can be complex requiring the optimal technique for the specific patient and their defect. This task should be approached by addressing all of the vital components of the defect, and utilizing the technique that minimizes the potential morbidities of those components.

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