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Microsurgical Reconstruction of the Head and Neck
Microsurgical Reconstruction of the Head and Neck

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We dedicate this book to our teacher, mentor, and friend,

Ralph Manktelow

He taught us the importance of careful planning, meticulous technique, and a thorough knowledge of anatomy
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Foreword

It is a distinct pleasure and honor to have been invited to write the Foreword to this timely text that highlights current approaches to, and techniques for, reconstructing complex defects following major ablation in the head and neck. I have had the good fortune to know Drs. Neligan and Wei, and to collaborate with Dr. Neligan, for some 20 years. Their collective experience is beyond question, because they are the products of the learning curve that I have had a unique opportunity to be part of during that time.

For this book, Drs. Neligan and Wei have selected an outstanding group of experts in the field who thoughtfully and skillfully present the range of reconstructive options for repairing complex head and neck defects. They demonstrate a variety of selective extirpation techniques and provide a menu of flaps that can be used to produce the best functional and cosmetic outcomes. The material is presented in a clear and concise manner that includes both critical and contrasting points of view.

This superb text chronicles the breadth and depth of understanding necessary for implementing current microsurgical reconstruction techniques that optimize the quality of life for this patient population. It is a major contribution to head and neck ablative and reconstructive surgeons, and, in my opinion, should be compulsory reading for residents and fellows in training, as well as for practicing head and neck reconstructive surgeons.

This landmark work is the most important and timely account of our present knowledge of free tissue transfer in the head and neck. It reflects considerable personal experience, combined with a deep concern for patient welfare. I congratulate the editors for their vision and creativity and the numerous authors for their contributions, which have resulted in a most impressive and comprehensive reference text.

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Preface

Our collaboration in this writing effort has grown out of a long-standing relationship that began on a professional level with mutual interest in and admiration for each other's work and a common bond in our microsurgical training under Drs. Ralph Manktelow and Ron Zuker in Toronto. Over the years our relationship has blossomed into a personal friendship that has been further strengthened by our common interests—not only in microsurgery, but specifically in microvascular head and neck reconstruction. With this history of shared experiences and knowledge it seemed logical for us to come together to edit this book and to enlist other experts and colleagues worldwide for this venture. This book is truly a global initiative that underscores the exciting work being done in head and neck surgery by colleagues around the world.

During our original meeting to plan this book and devise a table of contents, our thoughts were remarkably similar: we wanted a work that focused on microvascular head and neck reconstruction, but also provided a general overview of contributions from related specialties. We both recognized the importance of understanding the disease processes that we help treat as well as other treatment modalities to which our patients may be exposed and that influence what we do and how we care for our patients.

We have carefully chosen our contributing authors to represent the subspecialties involved in the care of head and neck surgery patients. These recognized experts are drawn from different geographic regions so that we can obtain a global view of how various problems, some of which may have a geographic prevalence, are dealt with from different perspectives. This book, by nature of its content, editors, and contributors, is multidisciplinary, multinational, and comprehensive. It is an eminently practical book that is intended for experienced surgeons as well as for surgical trainees who have an interest in microvascular head and neck reconstruction.

Although we have included some information about local flaps, we have confined this discussion to a single chapter that highlights those areas where local tissue is the best option. More detail on local flaps is available in a companion volume, titled *Local Flaps in Head and Neck Reconstruction*, by Dr. Ian T. Jackson, that complements this book beautifully.
Our book is divided into seven comprehensive parts. Part One is a discussion of the fundamentals of head and neck cancer management that includes important chapters on head and neck surgery, radiation oncology, and medical oncology. These chapters discuss surgery, radiation therapy, and chemotherapy and help put these approaches into perspective. This part also includes a key chapter on the assessment of reconstructive outcomes—a topic that is intimately associated with disease outcomes in the context of head and neck disease.

Part Two focuses on the fundamentals of head and neck reconstruction, with chapters on preoperative and postoperative care, microsurgical technique, choosing recipient vessels, and the use of local flaps. Part Three explores the common free flaps used in head and neck reconstruction and is organized to facilitate access to information on specific flaps. The chapters in this section provide technical details as well as tips and tricks to aid surgical planning. Part Four contains information on reconstruction by region. These chapters detail various flap choices and emphasize patient selection, flap selection, and step-by-step technique with attention to donor vessel selection and avoidance of complications.

Patient rehabilitation is covered in Part Five with comprehensive chapters on prosthetics and osseointegrated implants. Part Six focuses on refinements and complications, including the management of osteoradionecrosis, indications for multiple flaps, and the management of flap failure, which all of us must deal with from time to time. We conclude with Part Seven, and a look at the future, discussing exciting new developments such as prefabricated flaps and composite tissue allotransplantation.

We have devoted considerable time to designing a format for this book that is consistent and easy to navigate. All chapters share common elements that facilitate access to key information. We begin each chapter with a box of Highlights and conclude with Critical Points. These latter are intended as memory joggers for the surgeon seeking a quick answer to a pressing problem; it provides a review of “Must Know,” “Should Know,” and “Synopsis” information. To enhance the learning experience, we have included numerous illustrations and photographs of operative sequences and case descriptions. Additionally, to encourage readers to further study individual topics, key references are annotated in each chapter.

Although long-distance collaboration can be challenging, it can also be highly rewarding and educational. Such has been the case with this endeavor—we have learned from each other and from our contributors. It is our hope that our readers will derive similar benefit from our efforts and that this book will provide a foundation for further investigation and innovation, ultimately contributing to improved care for our patients.

Peter C. Neligan
Fu-Chan Wei
Acknowledgments

This book would not have been possible without our publisher, Karen Berger. Her foresight, diligence, and tenacity helped guide us through the process of editing this book, and, with the help of her skilled and dedicated staff at QMP, she brought the project to fruition and produced this book of which we both feel very proud.

We are grateful to our colleagues not only for supporting us during the preparation of this book but for the encouragement, support, and collegiality they offer us on a daily basis: Drs. Hung-Chi Chen, David Chwei-Chin Chuang, Seng-Feng Jeng, Chih-Hung Lin, Ming-Huei Cheng, and Yur-Ren Kuo in Taiwan, and Drs. Hakim Said, David Mathes, Otway Louie, Craig Birgfeld, and Nick Vedder in Seattle.

Finally, none of this would be possible without our families. We are forever grateful to our wives, Nancy and Gabrielle, for their uncompromising love and support and to our children, William and Shirley, and Kate and David, who make us proud.

Peter C. Neligan
Fu-Chan Wei
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Microsurgical Reconstruction of the Head and Neck
The term head and neck cancer refers to a large number of neoplasms that arise in one anatomic region of the body and have diverse natural histories. The neoplasms traditionally included in this category are mucosal carcinomas of the upper aerodigestive tract, including those in the oral cavity, pharynx, larynx, nasal cavity, and paranasal sinuses. Most of these are squamous cell carcinomas; however, this group also includes tumors of minor salivary gland origin, mucosal melanomas, and other rare and esoteric tumors. Also included are tumors of the salivary glands, thyroid gland, and parathyroid glands; soft tissue and bone tumors; and tumors of the skin and adnexa. This chapter emphasizes treatment strategies for patients with mucosal...
cancers of the upper aerodigestive tract, nasal cavity, and paranasal sinuses. It also includes a brief description of the treatment philosophies for tumors of the thyroid gland, salivary glands, soft tissue, bone, and skin.

**INCIDENCE AND ORIGIN**

Significant geographic variances in the incidence of various mucosal cancers of the upper aerodigestive tract are seen worldwide. A significantly high prevalence of squamous cell carcinomas of the oral cavity and oropharynx occurs in Southeast Asia, particularly in India, largely attributable to the habit of chewing tobacco and pan masala. Oral cancer also has high incidence rates in Brazil. Over the past decade, a rising incidence of oral cancers has been reported in Eastern Europe, particularly Hungary. Lifestyle habits associated with alcohol and smoking are known to be major etiologic factors influencing these geographic variations. For example, there is a significantly high incidence of carcinomas of the hypopharynx and larynx in southern Europe, with high rates of laryngeal carcinomas reported in Italy and Spain. Although the cause of squamous cell carcinoma of the upper aerodigestive tract is generally attributed to consumption of tobacco and alcohol, in recent years, exposure to human papillomavirus (HPV) has emerged as a significant associated factor influencing the development of carcinomas of the oropharynx, particularly in the tonsil and base of the tongue. The exact mechanism of carcinogenesis in this setting, however, remains unclear.

**THERAPY**

Surgery had been the mainstay of therapy for most neoplasms of the head and neck for more than a century (Fig. 1-1). The introduction of ionizing radiation in the early part of the last century following the discovery of radium became an important means of nonsurgical treatment of head and neck cancer. However, in most patients with advanced cancer, radiation therapy has been used in conjunction with surgery, most often as postoperative adjuvant therapy. Chemotherapy was introduced in the management of carcinomas of the head and neck in the 1950s and 1960s, initially with a palliative intent. However, the addition of cisplatinum to the armamentarium of treatments led to the development of clinical trials, initially for induction chemotherapy. Squamous cell carcinomas of the upper aerodigestive tract demonstrated a significant response. Early induction chemotherapy trials also showed that tumors that were chemosensitive were also highly radiosensitive. From this observation, organ preservation trials were developed for laryngeal carcinomas in patients requiring total laryngectomy. Unfortunately, however, these early clinical trials failed to demonstrate improvement in long-term control and survivorship following use of induction chemotherapy. Later trials with concurrent use of chemotherapy and radiation therapy demonstrated an increased therapeutic index, with a larger propor-
tion of patients showing complete response at the primary site and in cervical lymph nodes. These observations were noted in primary tumors of the larynx, hypopharynx, and oropharynx. Concurrent chemotherapy and radiation therapy have remained the choice of therapy for organ preservation in patients requiring total laryngectomy and in patients with advanced carcinomas of the oropharynx. Currently, targeted therapies with epidermal growth factor receptor (EGFR) inhibitors are an active area of investigation. Immunotherapy and gene therapy are also areas for further research in the years to come.

**Fig. 1-1** History of the development of therapeutic modalities for head and neck cancer. Surgery has been the mainstay of treatment.

**DIAGNOSIS, WORKUP, AND STAGING**

Most neoplasms of the head and neck area are readily accessible for adequate initial clinical examination. Thus a complete head and neck examination is the initial diagnostic step in treatment planning. This includes careful examination of the scalp and skin of the face and neck, followed by palpation of the neck for cervical lymph nodes or any other masses. The thyroid and parotid glands are included in this assessment. The auditory canal is examined and anterior rhinoscopy is performed. Movement of the extraocular muscles is assessed by testing eye movement. The oral cavity is inspected and palpated. Evaluation of patients with head and neck neoplasia generally requires the use of a flexible fiberoptic laryngoscope to view the nasal cavity, nasopharynx, oropharynx, hypopharynx, and larynx. This examination provides an ex-
cellent overview of the mucosal surfaces of the upper aerodigestive tract and allows assessment of velopharyngeal competence and vocal cord motion. Palpation of the tongue base is an integral part of a head and neck examination. If a flexible fiberoptic laryngoscope is not available, a careful mirror examination of the hypopharynx and larynx must be performed.

A tissue diagnosis is warranted for all tumors identified during examination of the head and neck area. Generally, tumors of the oral cavity are readily accessible through the patient’s open mouth. A biopsy sample can be obtained after the administration of topical or local anesthesia in an office setting. Similarly, masses in the neck, including enlarged cervical lymph nodes, thyroid nodules, and masses in the parotid glands, are readily accessible for fine-needle aspiration, either with or without the use of ultrasound. Tumors of the nasal cavity, nasopharynx, hypopharynx, and larynx require endoscopy with the patient under general anesthesia for proper evaluation, followed by a tissue biopsy to confirm the diagnosis.

Based on the location and extent of the tumor, radiologic imaging is required for accurate assessment. Radiologic assessment is generally used with the following modalities for select locations. Nodules and tumors in the thyroid gland are best assessed with an ultrasound examination, which also facilitates evaluation of regional cervical lymph nodes. Tumors of the paranasal sinuses, oral cavity, larynx, and pharynx are best evaluated using a contrast-enhanced CT or MRI scan. Neoplasms at the upper part of the neck in the parapharyngeal space and involving the base of the skull may require both a CT and MRI scan, and may occasionally need more sophisticated imaging studies such as angiography and three-dimensional reconstructions.

**Staging**

Staging of the primary tumor is essential for the selection of therapy, estimation of prognosis, and comparison of outcomes with different treatment modalities at different institutions or for different study populations. The currently used staging system is uniform in all parts of the world. It has been developed and approved by the American Joint Committee on Cancer (AJCC) and International Union Against Cancer (UICC). The most recent modifications of the staging system have been published in the sixth edition of the AJCC Cancer Staging Manual (Box 1-1). Lymph node metastases are staged based on clinical and radiologic assessment. $N0$ is absence of nodal metastasis; $N1$ is ipsilateral, single lymph node metastasis less than 3 cm in diameter; $N2a$ is a single positive lymph node measuring 3 to 6 cm on the ipsilateral side; $N2b$ is multiple lymph node metastases on the ipsilateral side; $N2c$ is bilateral or contralateral lymph node metastasis; and $N3$ is any lymph node metastasis greater than 6 cm in diameter.

Primary tumors of the oral cavity are staged based on surface dimensions. $T1$ tumors are less than 2 cm in diameter, $T2$ are 2 to 4 cm, and $T3$ are greater than 4 cm in diameter. Advanced tumors are staged as $T4a$ and $T4b$, based on the extent of local invasion. The AJCC Cancer Staging Manual provides further details.
Current Approaches to Head and Neck Cancer: An Overview

Factors Affecting Choice of Treatment

The factors that influence the choice of initial treatment for malignant neoplasms of the head and neck are related to the characteristics of the primary tumor (tumor factors), characteristics of the patient (patient factors), and characteristics of the treatment team (physician factors). In the selection of optimal therapy for patients with head and neck cancer, these three sets of parameters must be considered in the initial treatment planning. The ultimate goal of treatment for patients with cancer of the head and neck is to eradicate the cancer, preserve or restore form and function, minimize the sequelae of treatment, and prevent any subsequent new primary cancers. To achieve these goals, the currently available treatment modalities consist of surgery, radiation therapy, chemotherapy, targeted therapies, combined modality treatments, and primary and secondary prevention strategies, including lifestyle changes.

It is well known that for early-stage squamous cell carcinomas of the head and neck, single-modality treatment is effective in tumor control and provides expeditious treatment delivery with minimal sequelae of therapy. Thus most patients with tumors staged at T1 or T2 (stage I and stage II) are considered for single-modality treatment. The choice of surgery versus radiation therapy in this setting depends on the primary site and the functional sequelae of surgical or nonsurgical treatment. For example, early-stage cancer of the oral cavity is best treated with surgery, without any long-term sequelae of therapy. However, early-stage cancer of the glottic larynx is best treated with radiation therapy, which retains an excellent functional outcome for voice quality compared with surgery, which has an adverse impact on voice quality. The outcomes of either treatment modality, in terms of tumor control, are comparable.

Single-modality treatment for advanced-stage disease gives a poor outcome. Multiple treatment modalities must be considered for these patients. Historically, the combination of surgery and postoperative radiation therapy has been the standard of...
care for patients with stage III or IV disease for most primary sites in the upper aerodigestive tract. Treatment outcomes with surgery followed by postoperative radiation therapy have remained unchanged for the past 20 years. Despite adding chemotherapy either sequentially or concurrently to the multidisciplinary treatment programs, survival rates have not improved. However, the addition of chemotherapy to radiation therapy avoids the need for surgery in select patients with primary carcinomas of the larynx and hypopharynx, thus preserving the larynx. Over the past two decades, these organ preservation treatment strategies have emerged as important therapies for advanced-stage squamous cell carcinomas of the larynx, hypopharynx, and oropharynx, reserving surgery for salvage. Adding chemotherapy to postoperative adjuvant radiation therapy has achieved modest gains in locoregional control and disease-free survivorship in two prospective randomized trials\(^8\) (Fig. 1-2).

In selecting initial therapy, other factors must be considered in addition to those mentioned previously (Box 1-2). These include complications and sequelae of therapy, compliance by and convenience for the patient, the cost of therapy, and competence of the treatment-delivery team. Thus, all of these tumor- and patient-related factors, as well as those pertaining to the treatment-delivery team and patient preferences, must be reviewed when selecting an initial, definitive treatment for optimal outcome. The following section presents treatment preferences based on the primary tumor site.

**Box 1-2  Factors Affecting Choice of Treatment**

<table>
<thead>
<tr>
<th>Site</th>
<th>Nodal status</th>
<th>Convenience</th>
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<tbody>
<tr>
<td>Size</td>
<td>Complications</td>
<td>Cost</td>
</tr>
<tr>
<td>Stage</td>
<td>and sequelae</td>
<td>Competence</td>
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<tr>
<td>Histology</td>
<td>Compliance</td>
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</table>
The tumor factors that affect the choice of initial treatment for oral cancer are the site of origin, T stage, location (anterior or posterior), proximity to bone (mandible or maxilla), status of cervical lymph nodes, previous treatment, and histology (type, grade, and depth of invasion).9-11 The biologic behavior of primary squamous cell carcinomas in the oral cavity varies by site. Lip cancer, for example, behaves in a fashion similar to skin cancer, with an excellent potential for long-term cure and a very favorable prognosis. Similarly, squamous carcinomas of the hard palate and upper gum have relatively indolent behavior with a low risk of regional lymph node metastasis. Alternatively, cancers of the oral tongue, floor of the mouth, and lower gum have a high risk of regional metastasis with an adverse impact on prognosis. In addition to increasing size, increasing depth of invasion by the primary tumor increases the risk of regional lymph node metastasis and requires considering the management of regional cervical lymph nodes in the initial treatment planning. The presence of clinically palpable cervical lymph node metastases requires a neck dissection as an integral part of surgical treatment. The extent of neck dissection varies, depending on the extent of nodal metastasis and the location of palpable lymph nodes. The patterns of regional lymph node metastasis from primary cancers of the oral cavity are well known, and sequential progression of metastatic spread occurs from primary oral cancers.12 The first-echelon lymph nodes for oral cancer are limited to levels I, II, and III in the neck, with relatively infrequent dissemination to level IV. Therefore, in planning elective dissection of regional lymph nodes for micrometastasis, clearance of lymph nodes at level V is not necessary. However, when gross metastases are present in the anterior triangle of the neck, a comprehensive neck dissection of all five levels of lymph nodes is recommended.
The planning of surgical resection for the primary tumor should include appropriate reconstructive measures following resection. Small intraoral resections can be easily handled by primary closure. Large mucosal defects on the buccal mucosa, hard palate, or the floor of the mouth are eminently suitable for resurfacing with split-thickness skin grafts. Larger defects with significant depth require reconstruction with free flaps. These include major partial glossectomies, composite resections with marginal mandibulectomy and resection of the floor of the mouth, buccal mucosa, or larger mucosal or soft tissue defects extending into the oropharynx. A radial forearm free flap or an anterolateral thigh flap is suitable to repair such defects. Segmental mandibulectomy requires reconstruction with a composite free flap. Currently, the fibular free flap appears to be the optimal choice for mandible reconstruction. Maxillectomy defects are rehabilitated with a prosthesis or reconstructed with a composite free flap.

**PHARYNX**

The pharynx is the part of the upper aerodigestive tract that extends from the superior surface of the vault of the nasopharynx cephalad up to the lower border of the cricoid cartilage at the pharyngoesophageal junction caudad. The pharynx has three regions: the nasopharynx, oropharynx, and hypopharynx. The biologic behavior of primary squamous cell carcinomas arising in each of these three divisions of the pharynx is different, and each region has a distinctly different natural history and response to therapy. Primary carcinomas arising in the nasopharynx are infrequent in the western world, but have a high prevalence in individuals of Chinese origin. The highest prevalence exists in southern China and Southeast Asia. In the recent
past, a rising incidence of primary carcinomas of the oropharynx in general, and of the tonsils in particular, has been observed in nonsmoking, nondrinking young individuals in the western world. Many of these HPV-associated squamous cell carcinomas apparently have a somewhat favorable prognosis compared with similarly staged tumors occurring in the elderly who have a smoking/drinking history. The highest incidence of carcinomas of the hypopharynx is observed in southern and eastern Europe. Alcohol and smoking remain the most identifiable etiologic factors.

**Nasopharynx**

The highest incidence of nasopharyngeal carcinoma has been observed in people of Chinese origin, and particularly in people from southern China. A somewhat increased incidence has also been observed in Mediterranean countries. A significant proportion of squamous cell carcinomas of the nasopharynx shows lymphoid predominance and a high degree of response to radiation therapy. The mainstay of therapy for nasopharyngeal carcinoma is therefore external beam radiation. In addition, combining chemotherapy with external radiation has significantly improved outcomes and, at present, concurrent chemoradiation therapy with cisplatinum is considered the standard of care. Emerging evidence shows that the addition of EGFR inhibitors offers further improvement in tumor control when added to concurrent chemoradiation therapy treatment programs. The role of surgery in the treatment of nasopharyngeal carcinoma is extremely limited, and used only in the setting of salvage therapy in selected patients with recurrent tumors. Recurrent carcinomas of the nasopharynx are effectively treated by repeat irradiation in a significant number of patients.
The primary sites in the oropharynx are the tonsil, base of tongue, pharyngeal wall, and soft palate. The tonsil and the base of the tongue are the most predominant sites for primary squamous cell carcinomas. The most common etiologic factors are alcohol and smoking. In the past decade, an increasing number of patients have had HPV-positive squamous cell carcinomas of the tonsil and base of tongue. Whether previous HPV exposure is a causative factor is still not known.

Historically, carcinomas of the oropharynx were treated with primary surgery followed by postoperative radiation therapy. However, over the last 20 years, treatment programs of chemoradiation therapy used for organ preservation in primary carcinomas of the larynx and pharynx have provided an impetus to extend that philosophy to primary carcinomas of the oropharynx, in an attempt to reduce morbidity. At present, concurrent chemoradiation therapy is the standard of care for most patients with carcinoma of the oropharynx, with excellent long-term tumor control. Surgery is reserved for salvage of treatment failures either at the primary site, in the neck metastases, or at both locations. PET scanning offers an important tool for identifying residual or recurrent disease at the primary site or in the neck after chemoradiation therapy. When surgery is required for persistent or recurrent tumors of the oropharynx following chemoradiation therapy, a free flap is usually required for reconstruction of the surgical defect.
Primary carcinomas arising in the hypopharynx are one of the most aggressive cancers in the head and neck and have the worst prognosis. Three primary sites are described in the hypopharynx: the piriform sinus, pharyngeal wall, and postcricoid region. The piriform sinus is by far the most common primary site in the hypopharynx. Early-stage primary tumors of the piriform sinus can be managed with transoral laser microsurgery, open partial laryngopharyngectomy, or radiation therapy with or without chemotherapy.\(^{16}\) Patients with advanced-stage tumors requiring laryngectomy are offered a treatment combination of chemotherapy with radiation therapy for larynx preservation.\(^{17}\) At present, concurrent chemoradiation therapy is preferred over sequential treatment. However, response rates are not as good as those observed in the larynx, and the sequelae of concurrent chemoradiation therapy are significant, with swallowing difficulties, the development of pharyngoesophageal strictures, and the need for gastrostomy for nutrition maintenance and occasionally tracheostomy for airway maintenance. Very advanced carcinomas of the hypopharynx with invasion of the thyroid or the cricoid cartilage require primary surgery with pharyngolaryngectomy and immediate, appropriate reconstruction. Reconstruction of partial pharyngeal defects can be easily accomplished with a regional myocutaneous flap, such as a pectoralis major myocutaneous flap, a radial forearm free flap, or anterolateral thigh free flap. Circumferential defects of the pharyngoesophageal region require reconstruction with transthoracic gastric transposition, a jejunal free flap, a tubed radial forearm flap, or an anterolateral thigh flap.

Primary carcinomas of the hypopharynx have a very high proclivity for early dissemination to regional lymph nodes. Nearly 70% of patients with carcinomas of the hypopharynx will have involvement of regional lymph nodes during the course of this primary cancer.\(^{18}\) Therefore management of the neck is integral to any multidisciplinary treatment program for carcinomas of the hypopharynx.
Anatomically, the larynx is divided into three regions: supraglottic, glottic, and subglottic. Primary carcinomas of the subglottic larynx are exceedingly rare. Nearly 60% of all laryngeal carcinomas arise in the glottic larynx. Carcinomas of the glottic larynx produce symptoms early, and therefore most patients with this neoplasm present at an early stage of the disease. In addition, the lymphatic network in the glottic region is relatively poor; therefore regional lymph node metastases are exceedingly rare. In general, carcinomas of the glottic larynx offer an excellent prognosis. Conversely, carcinomas of the supraglottic larynx do not produce symptoms early on, have an increased proclivity to early dissemination to regional lymph nodes, and patients usually present with an advanced stage of disease at diagnosis. The overall prognosis for patients with carcinoma of the supraglottic larynx is much worse than for patients with carcinoma of the glottic larynx. Early-stage laryngeal cancer can be treated with single-modality treatment, either with radiation therapy or conservation surgery of the larynx. External radiation therapy is the preferred treatment for early carcinomas of the vocal cord (glottic larynx). Early-stage carcinomas of the supraglottic larynx (T1 and T2) are suitable for endoscopic laser resection with partial laryngectomy. Occasionally, these patients require an open partial laryngectomy for complete excision of the tumor. Elective dissection of first-echelon lymph nodes in the neck should be considered if a patient is to receive treatment of the primary tumor with surgical excision.

Patients with supraglottic or glottic carcinomas at an advanced stage (T3 and T4) who require total laryngectomy are considered candidates for a multidisciplinary treatment program of organ preservation with chemoradiation therapy. Currently, the most active drugs in these combined treatment programs are cisplatin,
Primary tumors of the nasal cavity and paranasal sinuses are rare. Tumors of the nasal cavity cause epistaxis or nasal obstruction; therefore most patients present with early-stage tumors. However, most patients with primary carcinomas of the maxillary antrum present with advanced-stage disease. Generally, symptoms do not occur until the tumor breaks through the bony walls of the sinus and extends outside the sinus cavity. Tumors of the maxilla are the most common site among primary tumors of the paranasal sinuses.

Ohngren described an imaginary plane connecting the medial canthus of the eye to the angle of the mandible, dividing the maxillary antrum into infrastructure and suprastructure. The anteroinferior part of the maxillary antrum is the infrastructure, and the posterosuperior part of the maxillary antrum is suprastructure. Tumors arising in the infrastructure cause early symptoms and are easily amenable to a satisfactory surgical resection, offering an excellent prognosis. Conversely, tumors of the suprastructure rarely cause early symptoms, are difficult to resect surgically with sat-
isfactory margins, and offer a poor prognosis. In general, primary carcinomas of the
paranasal sinuses are managed with initial surgical treatment. In most instances, ad-
juvant postoperative radiation therapy is used for advanced-stage tumors. Extension
of primary carcinoma of the maxilla or nasal cavity into the orbit warrants orbital ex-
enteration. Similarly, primary carcinomas of the nasal cavity, ethmoid, or maxillary
antrum extending to the anterior skull base require a craniofacial approach for sat-
isfactory surgical resection. Adjuvant postoperative radiation therapy is recom-
mended for nearly all patients undergoing craniofacial resection.

Select patients with centrally located, limited tumors of the nasal cavity, ethmoid,
and anterior skull base are suitable for endonasal endoscopic resection. However,
significant surgical expertise and stringent criteria for case selection should be exer-
cised for a satisfactory surgical outcome with endonasal resection of malignant tu-
mors. Significant experience is reported with open craniofacial surgery from vari-
ous parts of the world, so that reproducible results are achieved with that surgical

**SALIVARY GLANDS**

Three pairs of major salivary glands (parotid, submandibular, and sublingual) and
numerous minor salivary glands (scattered throughout the mucosa of the upper
aerodigestive tract) are present in the head and neck region. The parotid gland is
the most common site for primary neoplasms of salivary origin. Surgery remains the
mainstay of therapy for salivary gland tumors. Management of the facial nerve is
crucial to the surgery of parotid tumors. A functioning facial nerve that is not grossly
affected by cancer seldom requires sacrifice. However, facial paralysis or gross infil-
tration of the facial nerve by a malignant tumor requires sacrifice of the facial nerve and rehabilitation of the paralyzed face. Facial nerve grafting or other methods of facial rehabilitation should be used under appropriate circumstances. The prognosis for patients with salivary gland tumors depends on the histologic grade and T stage of the primary tumor. Adjuvant postoperative radiation therapy following surgical resection for advanced-stage tumors significantly improves local regional control and offers a longer disease-free interval. Surgery for minor salivary gland tumors is stage and site dependent, and general principles of surgery for squamous cell carcinomas for similarly staged tumors at similar sites are followed.

**THYROID GLAND**

During the past three decades, there has been a significant rise worldwide in the incidence of primary differentiated carcinomas of the thyroid gland. Fortunately, most newly diagnosed thyroid carcinomas are relatively small, well-differentiated tumors with an excellent prognosis. Despite a nearly 300% rise in the incidence of differentiated carcinoma of the thyroid gland, mortality from the disease has remained stable. Prognostic factors in differentiated carcinoma of the thyroid gland are well established and shown to be independent parameters of prognosis on multivariate analysis in several large series. The commonly observed prognostic factors are the patient’s age, the tumor size, tumor histology, extrathyroid extension, presence of distant metastasis, completeness of tumor excision, and the patient’s gender. Risk-group stratification based on these prognostic factors should be used in the selection of therapy. Low-risk patients are young, with small intrathyroidal tumors without evidence of distant metastasis. The prognosis for patients in this group is excellent, with nearly 100% long-term survivorship. Older patients with larger tumors and poorly differentiated histology have an aggressive thyroid cancer requiring aggressive surgery and adjuvant radioactive iodine therapy or external radiation therapy. The prognosis is guarded for these patients. Anaplastic carcinoma of the thyroid
gland is one of the most aggressive cancers in the head and neck area, with a fatal outcome in most patients. The median survival time for patients with anaplastic carcinomas of the thyroid gland is 1 to 2 years. Research to identify new treatment modalities for aggressive variants of thyroid carcinomas and anaplastic carcinoma is essential for improvement in prognosis. Adjuvant postoperative radioactive iodine therapy is effective in well-differentiated carcinomas of the thyroid gland; patients with poorly differentiated thyroid carcinoma whose tumors are not amenable to radioactive iodine need external radiation therapy. Targeted therapy with newer angiogenesis inhibitors offers promise for patients with metastatic disease.

**SKIN, SOFT TISSUE, AND BONE TUMORS**

Primary surgical excision of malignant neoplasms remains the mainstay of initial definitive treatment of the skin, soft tissues, and bone. Basal cell carcinomas and small squamous cell carcinomas are effectively treated with a simple surgical excision and primary repair. Basal cell carcinomas located in critical locations, such as adjacent to the eyelids, around the nose, and other parts of the face, are more adequately treated with Mohs surgery followed by secondary reconstruction. Malignant melanomas of face and neck skin require appropriate surgical excision; however, wide surgical margins are often not feasible because of the anatomic location of some tumors, such as cutaneous melanomas on the eyelid, glabellar region, and ala of the nose. Sentinel node mapping for cutaneous melanomas of intermediate thickness effectively identifies occult metastasis and helps assess prognosis. Other aggressive skin cancers, such as Merkel cell carcinomas or sweat gland carcinomas, require appropriate surgical resection and regional lymph node dissection followed by adjuvant postoperative radiation therapy.

General principles of surgery for sarcomas of soft tissues and bone elsewhere in the body are also used for these tumors in the head and neck region. Unfortunately, however, the anatomic location of the tumor in the head and neck region does not permit wide surgical margins, generally secured in sarcomas of the extremities and trunk. Thus the margins of resection for sarcomas in the head and neck are determined by the anatomic site of origin of the primary tumor. Osteosarcomas in the head and neck region of adults do not manifest the same degree of chemosensitivity as those arising in the pediatric age group. Therefore preoperative chemotherapy is generally not used in adult patients with sarcomas of osseous origin in the head and neck. Surgery followed by postoperative radiation therapy or chemoradiation therapy and maintenance chemotherapy is currently considered the standard of care.

The need for reconstructive surgery after resection of soft tissue or bone sarcomas in the head and neck depends on the site of origin of the sarcoma and the extent of surgical resection. In general, free flap reconstruction is warranted for extensive resections of soft tissues, skin, or bone.
CONCLUSION

Head and neck tumors are a unique group of neoplasms with a variety of histologic origins and diverse natural histories. They occur in a part of the body with complex anatomy responsible for several unique, vital functions. Specialized training in head and neck surgery and oncology is therefore crucial to deliver optimal care to patients with disease in the head and neck. Knowledge of the anatomy, physiology, pathogenesis, and clinical progression of neoplasms in the head and neck is fundamental to a surgeon’s ability to deliver contemporary, multidisciplinary care. An understanding of the natural history of various neoplasms has led to the development and increasing application of organ- and function-preserving surgery, as well as organ- and function-preserving nonsurgical, multidisciplinary treatment programs with the aim of improving survival and the quality of life for surviving patients. Research in molecular biology is crucial for identifying genetic predisposition in high-risk populations, making accurate diagnoses, assessing response to therapy, and thus determining the prognosis. Providing optimal care for patients with head and neck tumors requires the efforts of a multidisciplinary treatment team consisting of head and neck surgeons, radiation oncologists, medical oncologists, diagnostic radiologists, pathologists, reconstructive surgeons, maxillofacial prosthodontists, endocrinologists, and other allied specialists.

CRITICAL POINTS

Must Know
- The staging system for head and neck cancers must be understood.
- Thorough knowledge of head and neck anatomy is required.

Should Know
- Single modality treatment is generally adequate for early squamous cell carcinoma cases.
- Prognosis can be determined by location, tumor type, or stage of disease.

Synopsis
- Head and neck cancers have geographic variations in incidence.
- Multiple treatment modalities are available and are used either alone or in combination.
- Optimal care is provided in a multidisciplinary setting.
References


   This review article summarizes the global incidence of mouth cancer using cancer maps. Significant geographic variation is noted in the incidence of mouth cancer, with high rates reported for the Indian subcontinent and parts of Asia. It is also noted that, as with other forms of oral cancer, most of the population-based data for mouth cancer comes from the Western world, with little reliable data from developing countries.


   High-risk types of human papillomavirus (HPV), including HPV-16, cause a subgroup of head and neck squamous cell carcinomas (HNSCCs). The authors examined whether the risk factors for HPV-16-positive HNSCCs are similar to those for HPV-16-negative HNSCCs. HPV-16-positive HNSCC was independently associated with oral sex and exposure to marijuana but was not associated with tobacco smoking, alcohol drinking, or poor oral hygiene. By contrast, HPV-16-negative HNSCC was associated with tobacco smoking, alcohol drinking, and poor oral hygiene, but not with sexual behavior or marijuana use.


   For this study, 547 patients with locally advanced cancer of the larynx were randomly assigned to one of three groups. After 2 years, the proportion of patients who had an intact larynx after radiation therapy with concurrent cisplatin (88%) differed significantly from the proportions in the groups given induction chemotherapy followed by radiation therapy (75%) or radiation therapy alone (70%). The rate of locoregional control was also significantly better with radiation therapy and concurrent cisplatin. However, overall survival rates were similar in all three groups. The authors conclude that, for patients with laryngeal cancer, radiation therapy with concurrent administration of cisplatin is superior to induction chemotherapy followed by radiation therapy or radiation therapy alone for laryngeal preservation and locoregional control.


14. Adelstein DJ, Rodriguez CP. Current and emerging standards of concomitant chemoradiotherapy. Semin Oncol 35:211-220, 2008. The authors discuss the concomitant use of chemotherapy and radiation, which has proven to be more consistently successful than radiation therapy alone, and it produces both locoregional control and survival benefits. Large group studies have established high-dose single-agent cisplatin and concurrent radiation therapy as the standard of care for select patients. This same treatment regimen also has been demonstrated to be the most effective multimodality strategy for larynx preservation.


18. Candela FC, Kothari K, Shah JP. Patterns of cervical node metastases from squamous carcinoma of the oropharynx and hypopharynx. Head Neck 12:197-203, 1990. This paper is a retrospective review of 333 patients with primary squamous cell carcinoma of the oropharynx or hypopharynx to ascertain the prevalence of neck node metastases by neck level. The study revealed a predominance of neck node metastases in levels II, III, and IV for both oropharyngeal and hypopharyngeal primaries. Isolated “skip” metastases outside of levels II, III, or IV occurred in only 1 patient (0.3%). Otherwise, level I or V involvement was always associated with nodal metastases at other levels.


Ionizing radiation has been used in the treatment of cancer almost since the discovery of x-rays by Wilhelm Conrad Röentgen in 1895. In 1899, a physician in Stockholm, Thor Stenbeck, reported on the successful treatment of a basal cell carcinoma on the nose. Two years later, a physician in Boston, Francis Williams, reported on the treatment of a lip cancer. In the very early days, radiation therapy was performed using crude equipment that generated low-energy x-rays, depositing most of the dose within a few millimeters of the surface. This made it difficult to treat more...
deeply situated tumors. Large dose fractions were used that often produced a tissue slough similar to a form of cautery. We now have a much better understanding of the subtle changes that ionizing radiation induces in cellular DNA and other organelles, as well as the repair processes of tumors and normal tissues. Radiation therapy is currently delivered in more protracted fractionation schemas that take advantage of the differences between tumor and normal tissue radiobiology. Advances in technology continue to facilitate more sophisticated treatment approaches than ever before. Compact, high-energy linear accelerators are routinely used to produce megavoltage x-rays, and computerized treatment planning, coupled with sophisticated imaging, makes it possible to deliver higher doses of radiation to the tumor without causing unacceptable damage to adjacent normal tissues. The basic dilemma for radiation oncologists is shown in Fig. 2-1. The sigmoid curve on the left represents the probability of tumor control and the one on the right represents the probability of a normal tissue complication. If the curves are widely separated, then there is a high probability of achieving tumor control and a low probability of causing a significant complication. However, in many cases the two curves lie very close together, and considerable thought and effort must be spent to separate the curves, either by taking advantage of biologic differences between the tumor and the adjacent normal tissue or by physically localizing the radiation dose to the tumor.

Fig. 2-1  Dose response curves for tumors (solid line) and normal tissue side effects (dashed lines) as a function of radiation dose along the horizontal axis. The curves are not specific to any particular tumor system.
**Physical Aspects of Radiation Therapy**

*Megavoltage* (MV) characterizes the energy of an x-ray (photon) beam produced through a bremsstrahlung process by accelerating electrons to a particular energy in MeV (million electron volts) before they impact a tungsten target to produce x-rays. Therapy beams have 50 to 200 times the energy of diagnostic x-rays. If the tungsten target is retracted, the high-energy electrons can be used to treat patients. Although there are no differences in the biologic effects produced by photons and electrons, they have markedly different physical dose distributions, as shown in Fig. 2-2. Electrons deposit most of their dose on the surface and superficial tissues, and for practical purposes do not penetrate beyond 5 cm. They are ideally suited to treat superficial tumors such as skin cancers, subcutaneous tumor nodules, and lymph nodes in the neck. X-rays from photons, however, penetrate much more deeply. Their deposited dose decreases exponentially with depth. For example, an average 10 by 10 cm, 6 MV photon beam deposits its maximum dose at 1.5 cm, 85% of the dose at 5 cm, and 50% at 15 cm. Electrons are thus well suited to treat deep-seated tumors, although there is an exit dose delivered well beyond the tumor that contributes to toxicity.

![Fig. 2-2 Depth-dose curves for 10 by 10 cm² fields from a 6 MV linac photon beam (solid line) and 10 MeV electron beam (dashed line). Note the superficial depth of penetration of the electron beam.](image)

The planning process begins by placing the patient in the treatment position. He or she wears a custom-made immobilization mask. Cross-sectional images are obtained with a CT scanner. The tumor and its potential pathways of spread, as well as pertinent normal structures, are contoured by the clinician using the planning data set obtained from these images, which are sometimes augmented by fusing these scans with MRI and/or PET images. Thus the target volumes and critical structures are defined
in three dimensions. Multiple photon beams are configured to deliver the desired
dose to the tumor while the tissues in the path of each beam (entry and exit) receive
a dose that is kept within tolerance levels. Each beam can be individually conformed
to the three-dimensional shape and size of the tumor using either custom-made,
Wood’s metal (Cerrobend) blocks and compensators or, more commonly, multileaf
collimators. Geometric versatility in directing a beam is achieved by mounting the
linac treatment head on a gantry that can rotate 360 degrees around an isocenter.
The addition of a collimator and a treatment table capable of movement and rotation
allow the creation of planar and noncoplanar beam angles and sophisticated treat-
ment plans. In general, the degree of accuracy and precision expected of these units
is approximately 98%.

**BILOGIC PRINCIPLES OF RADIATION THERAPY**

The typical biologic target for radiation therapy is DNA. Cells that have had their
DNA irreparably damaged die during mitosis. This process is called *reproductive
or mitotic cell death* and is the most common mode of death following irradiation. Di-
viding cells are therefore more sensitive to the lethal effects of radiation therapy.
Cancer tumors have uncontrolled cell division and a decreased ability to repair DNA
damage and are thus differentially ablated during a course of radiation therapy.

**Dose**

*Dose* is the amount of energy absorbed by tissues. The standard unit of dose mea-
surement is a gray (Gy), which corresponds to 1 joule of energy per kilogram of tis-
sue. In the literature, dose is sometimes specified in centigray (cGy) or rads, where
100 rads correspond to 1 Gy.

When radiation therapy is used to treat head and neck squamous carcinomas, the
gross (macroscopic) tumor dose is in the range of 66 to 72 Gy, and the dose for sub-
clinical microscopic disease such as clinically uninvolved lymphatic and neural path-
ways is approximately 50 Gy. This dose is sufficient to control subclinical disease in
more than 90% of patients. After an R0 resection, the typical dose to the operative
(surgical) bed is 56 to 60 Gy. Over 100 years of historical experience and evidence
show that those doses are relatively safe to normal structures while producing ac-
ceptable cure rates.

Ideally, a dose would be customized to an individual tumor based on the histology,
clonogen population, and its specific characteristics and kinetics. Unfortunately, cur-
rent knowledge does not allow this kind of customization to occur.
Fractionation and Repair

Fractionation refers to dividing a planned dose into smaller, better-tolerated fractions. The importance of fractionation in radiation therapy cannot be overstated. Delivering a planned total dose of 60 Gy in a single treatment would be toxic to normal structures and ineffective in curing cancers. A conventional course of radiation therapy comprises 1.8 to 2 Gy per fraction per day, given 5 days per week (that is, 9 to 10 Gy per week). A typical postoperative radiation therapy course comprises 60 Gy in 30 fractions over 6 weeks. Fractionation allows normal cells to repair the radiation damage between fractions, provided an adequate time interval of at least 6 hours separates the fractions. For a given total dose, the biologic effects of radiation therapy on normal structures decrease with a reduction in fraction size. Normal tissues have a well-recognized variability in their fractionation sensitivity. Tissues that are in a state of constant turnover (such as the epidermis and mucosal epithelium) are less sensitive to changes in fraction size than tissues that are not (such as the spinal cord, brain, bone, and dermis).

Hypoxia and Reoxygenation

Head and neck squamous cancers often contain hypoxic tumor cells produced as tumors outgrow their blood supply. These hypoxic cells are approximately three times more resistant to standard x-rays than their well-oxygenated counterparts. However, during a fractionated course of radiation therapy, the tumors shrink and allow the cells in the hypoxic regions to reoxygenate, making them more sensitive to radiation.

Redistribution and Reassortment

Cells that are in the G2 (premitotic) or M (mitotic) phase of the cell division cycle are the most sensitive to irradiation, and, conversely, cells that are in the S (DNA synthesis) phase are the most resistant. Through a protracted course of fractionated treatment, the resistant tumor cells in the S phase redistribute through the cell cycle into the sensitive phases, increasing the probability of their being killed by the radiation.

Repopulation and Time

The biologic effects of a given total dose diminish when that dose is protracted and vice versa. Tumor cells repopulate during a course of treatment, and when a treatment program is prolonged, a higher dose is required to yield the same tumor control probability. For example, a dose of 70 Gy given over 7 weeks can cure more than 80% of squamous carcinomas that are smaller than 3 cm in diameter with acceptable skin and mucosal reactions. If the same dose of 70 Gy is given over 9 weeks, therapeutic efficacy decreases and perhaps only 50% of cancers are cured. Conversely, 70 Gy given over 6 weeks results in a higher cure rate with worse acute reactions. Therefore it is important to achieve an optimal balance among total dose, fractionation, and time.
MULTIDISCIPLINARY APPROACH TO TREATMENT

Because of the complexity of head and neck cancer, optimal treatment requires the interdisciplinary skills of several specialists, including those in the areas of head and neck surgery, radiation oncology, medical oncology, reconstructive surgery, dentistry, maxillofacial prosthodontia, diagnostic radiology, pathology, endocrinology, and other allied specialties. Recognition and appreciation of the relative strengths and weaknesses of each specialty are of the utmost importance in a multidisciplinary team approach.

The head and neck region is an amalgam of disparate anatomic sites with distinct embryologic, histologic, and functional characteristics that are in very close proximity, often without a clear physical distinction. These sites have unique and overlapping neurovascular supplies and lymphatic drainage. Tumors arising from this region have diverse natural histories and patterns and pathways of spread. The prognosis may differ even for identical histology. For example, squamous carcinomas arising from the larynx and hypopharynx have completely different biologic behaviors and natural histories. Although these two primary sites have an intimate anatomic relationship, hypopharyngeal cancers have a worse overall prognosis with a higher rate of distant metastases.10 The oncologic approach taken with a particular histologic type in one site may be entirely different from the approach taken for the same histologic type in a neighboring site. For example, the primary treatment for nasopharyngeal cancers is radiation therapy, and the primary treatment for most sinonasal squamous cell cancers is surgery.

Most head and neck tumors arise from the mucosal surfaces and are squamous cell in origin. Less common tumors of minor salivary gland origin, mucosal melanomas, and other rare and esoteric tumors also occur. Malignant tumors of the salivary glands, thyroid gland, and parathyroid glands; soft tissue tumors; and bone sarcomas, lymphomas, cancers of the skin, and adnexal tumors are also categorized as head and neck cancers. Most of the discussion in this chapter emphasizes the role of radiation therapy for head and neck mucosal squamous cell cancers (HNSCC) of the upper aerodigestive tract, but other selected tumors are also discussed.

The choice of primary treatment modality depends on tumor factors, including location, histology and stage; patient factors, including preferences and suitability; and treatment factors, including the expected cosmetic and functional deficits and available expertise. For example, early-stage cancer of the oral cavity is best treated by surgery, without any long-term sequelae of therapy. On the other hand, early-stage cancer of the glottic larynx is best treated by radiation therapy, which allows an excellent functional outcome for voice quality. Comparable tumor control and survival result for each modality.
It is best to avoid combined treatment with surgery and radiation therapy for an early-stage tumor, because either modality generally is sufficient as the sole therapy. Combined modality treatment is required for advanced-stage disease.

**Radiation Therapy for HNSCC**

HNSCCs are moderately sensitive to radiation therapy, and most head and neck cancer patients undergo radiation therapy at some stage of their disease process. Radiation therapy is used in the curative and palliative settings. In the curative setting, it is used as monotherapy for small cancers or in combination with surgery as postoperative treatment for large or high-risk cancers. During the past decade, concurrent chemoradiation therapy has become a popular alternative to definitive surgery for locally advanced cancers when organ preservation is a goal. In this setting, surgery is reserved for salvage of treatment failure.

Although results are site specific, conventional radiation therapy gives excellent results for early-stage tumors in general (T1 and favorable T2 primary tumors, N0-1), with approximately 85% to 90% cure rates and excellent functional outcomes. Unfavorable (infiltrative) T2 and favorable (exophytic) T3 tumors have intermediate outcomes, with control rates of 60% to 80%. Most T3 and T4 tumors have a poor outcome with radiation therapy alone, with control rates of 15% to 40%. Strategies to intensify noninvasive local treatment include altered fractionation and the addition of systemic therapy. Surgery, particularly selective neck dissection, is offered for patients with incomplete response.

**Altered Fractionation**

Altered fractionation for HNSCC refers to a fractionation schedule that significantly differs from the conventional, once-daily treatment of 1.8 to 2 Gy given 5 days a week (9 to 10 Gy per week). The two major treatments designed to intensify local effects of radiation therapy are hyperfractionation and accelerated fractionation. A plethora of data support the validity of both of these approaches for improving local control in moderately advanced primary tumors (that is, unfavorable [infiltrative] T2 and favorable [exophytic] T3 primary tumors with minimal nodal involvement).

However, these regimens also increase local toxicity, including acute mucositis, and long-term sequelae such as dysphagia, and patient selection is critical in ensuring safety and success.

**Hyperfractionation**

Hyperfractionation refers to the delivery of small doses per fraction, typically 1.15 to 1.2 Gy per fraction twice a day, with a minimum 6-hour interval between fractions. This allows greater repair of radiation damage by normal tissues; therefore, for a given total dose, hyperfractionation reduces the biologic effects on normal tissues.
This gain in tolerance by normal tissues allows dose escalation, and total doses of 80.5 to 81.6 Gy are typically delivered. Randomized trials have demonstrated improved local control compared with conventional radiation therapy, without any significant increase in permanent late effects of radiation therapy.\textsuperscript{11,12} In one study, the greatest benefit was seen in T3 tumors, with no benefit for node-positive and T2 tumors.\textsuperscript{12} The logistical challenge of treating patients twice a day has been a hindrance to the widespread adoption of this fractionation scheme.

**Accelerated Fractionation**

*Accelerated fractionation* refers to the delivery of more than 10 Gy per week, which shortens the overall treatment time. This minimizes tumor repopulation during a course of radiation therapy, and for a given total dose would theoretically result in greater tumor control. One way to accelerate a course of treatment is to increase the number of fractions delivered per week. Acceleration may be achieved, for example, by delivering six fractions a week instead of five (that is, 12 Gy instead of 10 Gy per week), resulting in a total dose of 70 Gy in 6 weeks instead of 7. This modest acceleration is within tolerance limits and has resulted in greater local disease control in a randomized study.\textsuperscript{13} The benefit resulted from improved local control in the primary site; there was no difference in control in the neck.

Another popular approach is the concomitant boost approach used at the M. D. Anderson Cancer Center, in which 72 Gy is given over 6 weeks, with treatments given twice daily for the last 12 treatments.\textsuperscript{11} It is important not to accelerate the treatment course so much that the total dose must be reduced.\textsuperscript{14-16}

In a landmark study by the Radiation Therapy Oncology Group (RTOG) 9003, four different fractionation regimens were examined in 1073 patients who had locally advanced head and neck cancer treated with radiation therapy alone.\textsuperscript{11} The regimens were (1) standard fractionation (SF) at 2 Gy per fraction, 5 days per week, to 70 Gy in 7 weeks; (2) hyperfractionation (HF) at 1.2 Gy per fraction, twice daily, 5 days per week, to 81.6 Gy in 7 weeks; (3) accelerated fractionation with split (AFS) at 1.6 Gy per fraction, twice daily, 5 days per week, to 67.2 Gy in 6 weeks, including a 2-week rest after 38.4 Gy; or (4) accelerated fractionation with concomitant boost (AFC) at 1.8 Gy per fraction, 5 days per week, and 1.5 Gy per fraction to a boost field as a second daily treatment for the last 12 treatment days to 72 Gy in 6 weeks. Patients treated with HF and AFC had significantly better 2-year locoregional control than those treated with SF or AFS (54.4\% and 54.5\% versus 46.0\% and 47.5\%, respectively). All three altered fractionation groups had significantly greater acute side effects than those treated with SF. This study also found that a break in treatment, as in the AFS schedule, negated any gain from acceleration. In practice, it is important to avoid intentional treatment breaks and make up for any unintentional missed days from holidays or other interruptions to complete the overall treatment time per prescription schedule.
Currently, with once-daily intensity-modulated radiation treatment (IMRT), most centers use a “dose painting” approach, in which some degree of acceleration is built into the treatment program. Smaller T1 and T2 tumors are treated with radiation therapy alone to 66 Gy in 30 fractions at 2.2 Gy per fraction over 6 weeks. Large T3 and T4 tumors are treated with concurrent chemoradiation therapy to a dose of 70 Gy in 33 fractions at 2.12 Gy per fraction to the macroscopic disease target with excellent results.\textsuperscript{17,18}

**Radiation Therapy Combined With Chemotherapy**

Historically, chemotherapy was used in a palliative setting. It is now recognized that HNSCC is a chemoresponsive disease with a 30% to 40% response rate in the metastatic and recurrent setting and a 70% to 90% response rate in the primary setting.\textsuperscript{19} The efficacy of chemotherapy combined with radiation therapy has been demonstrated in many studies.\textsuperscript{19-25} The main sequencing approaches are: induction or neoadjuvant chemotherapy (ICT), in which the chemotherapy course is completed before starting definitive radiation therapy; concurrent or synchronous chemoradiation therapy (CRT), in which chemotherapy and radiation therapy schedules overlap; and adjuvant chemotherapy (ACT), in which chemotherapy starts after radiation therapy is completed.

Initial studies used ICT, with the goal of organ preservation using the rationale of spatial cooperation and treatment of occult metastases before the start of radiation therapy. The landmark randomized trials, the Veterans Affairs larynx study\textsuperscript{20} and the European Organization for Research and Treatment of Cancer (EORTC) hypopharynx study,\textsuperscript{21} demonstrated that nonsurgical strategies using ICT followed by radiation therapy safely preserved the larynx without compromising overall survival. In the Veterans Affairs study, larynx preservation was achieved in 64% of the patients. These studies were not designed to study the possible therapeutic gain of ICT. Nonetheless, this approach has been widely embraced because of the impressive response rates and the excellent patient compliance. The main disadvantage of ICT is a delay in starting definitive radiation therapy treatment. A metaanalysis showed that ICT has not significantly improved local control or survival.\textsuperscript{22}

The rationale for CRT is radiosensitization, and a number of randomized studies show CRT to be superior to radiation therapy alone, albeit at the cost of acute normal tissue side effects with significantly increased mucosal and other toxicity.\textsuperscript{22-25}

The Intergroup 0099 randomized trial\textsuperscript{23} demonstrated a significant benefit in local control and survival in favor of CRT with three cycles of three-weekly cisplatin versus conventional radiation therapy in patients with advanced nasopharyngeal carcinoma. Only two thirds of patients completed all three cycles of concurrent chemotherapy, highlighting the toxicity of chemotherapy that is given concurrently with radiation therapy.
GORTEC 9401 was a multiinstitutional randomized trial initiated by the French Head and Neck Oncology and Radiotherapy Group that compared standard radiation therapy alone (70 Gy in 35 fractions) with CRT in patients with stage III or IV oropharyngeal carcinoma. The locoregional control and survival were improved by the addition of chemotherapy. Most patients in this study had locally advanced T3-T4 primary tumors.

A large metaanalysis based on updated individual patient data examined the effect of adding chemotherapy to radiation therapy to treat HNSCC. The addition of chemotherapy was associated with a pooled hazard ratio of death of 0.90 (95% CI 0.85-0.94, \( p < 0.0001 \)), corresponding to an absolute survival benefit of 4% at 5 years, in favor of chemotherapy. The benefit was mainly attributable to an absolute benefit of 8% from CRT, with no significant benefit associated with ICT or ACT.

RTOG 9111 randomized 515 patients with stage III or IV glottic or supraglottic larynx carcinoma to radiation therapy alone (RT), ICT + RT, and CRT. Five-year, locoregional control was significantly better with CRT (68.8%) compared with ICT + RT (54.9%, \( p = 0.0018 \)) or RT (51%, \( p = 0.0005 \)). Laryngeal preservation was also significantly better with CRT (83.6%) compared with ICT + RT (70.5%) or RT (65.7%).

Based on these data, CRT has become the standard of care in the curative treatment of unfavorable, locally advanced HNSCC (unfavorable T3, T4, N2-3) for suitably selected patients, and altered fractionation is used for intermediate-stage primary tumors with minimal or no nodal involvement.

The magnitude of absolute benefit is significant in these studies; however, the obvious concerns are acute toxicity and long-term sequelae. It is increasingly recognized that CRT is not warranted in all American Joint Committee on Cancer (AJCC) stage III and IV HNSCC patients. For example, T1N1 tumors have a generally favorable prognosis with radiation alone, and the additional morbidity from synchronous chemotherapy is difficult to justify outside of a formal clinical trial.

The potential benefit of ICT before CRT is unknown and is currently an area of active investigation. Two recently reported trials demonstrated a significant benefit to the addition of docetaxel integrated in sequential induction chemotherapy followed by radiation therapy or chemoradiation regimens. Favorable, disease-free survival outcomes were reported. However, these studies did not compare sequential chemoradiation regimens with the current standard of care of CRT.
RADIATION THERAPY COMBINED WITH SYSTEMIC TARGETED THERAPY

Overexpression of epidermal growth factor receptor (EGFR) has been consistently identified in patients with HNSCC. A monoclonal antibody to EGFR, cetuximab (C225) has activity in recurrent and metastatic HNSCC. A landmark randomized study examined the benefit of the addition of C225 combined with radiation therapy in patients with locally advanced HNSCC. Two hundred thirteen patients with primary tumors in the oropharynx, hypopharynx, or larynx were randomized to radiation therapy alone versus radiation therapy plus concurrent C225. There was a 10% absolute survival benefit (55% versus 45%) at 3 years with the addition of C225. With the exception of an acneiform rash and infusion reactions, the incidence of grade 3 or greater toxic effects, including mucositis, did not differ significantly between the two groups. Thus patients who are not candidates for standard CRT because of comorbidities may now receive treatment intensification with C225. The discovery of subtypes of HNSCC with human papillomavirus (HPV) origins that are less resistant to treatment with chemotherapy and radiation could provide an opportunity to improve the therapeutic ratio by reducing the morbidity in HPV-positive tumors with less intensive therapy in the future.

POSTOPERATIVE RADIATION THERAPY

Single-modality therapy with either surgery or radiation therapy yields suboptimal locoregional control with locally advanced HNSCC. Attempted salvage treatment for recurrences is seldom successful. The fatal consequence of an unsalvageable recurrence in the head and neck, as well as a painful death with open, fungating wounds and an extremely poor quality of life during terminal stages, warrants aggressive initial treatment. The combination of surgery and radiation therapy was proposed by MacComb and Fletcher in 1957. Data to support this approach were first published in 1970. Subsequently, a large number of studies from major institutions have identified prognostic factors associated with a high risk of locoregional failure: close or positive margins, extracapsular extension, perineural invasion, multiple nodes, and the location of the primary site, and some have shown the efficacy of postoperative radiation therapy (PORT).

Some of the most compelling data come from the Memorial Sloan Kettering Institute, which showed that a change of policy from treating with surgery alone to utilizing PORT was associated with a reduction of regional recurrences from 71% to 13% in patients with pathologically confirmed nodal metastases at multiple levels in the neck. Similarly, the Medical College of Virginia group reported a comparison of patients with advanced HNSCC managed with surgery with or without PORT. Local control rates at 3 years were improved with the addition of PORT in patients with adverse pathologic features: without PORT and with PORT, extracapsular extension was 31% and 66% (p = 0.03), positive margins were 41% and
49% ($p = 0.04$), and both extracapsular extension and positive margins were 0% and 68% ($p = 0.001$), respectively. Multivariate analysis demonstrated that the use of PORT and the presence of extracapsular extension significantly affected local control. A matched-pair analysis from the Mayo Clinic of the results of PORT following neck dissection showed a significant improvement in regional control rates and overall survival in patients who received PORT. This is remarkable considering that in an earlier report, surgeons from the same institution concluded that there was no established role for PORT after radical neck dissection.\textsuperscript{47}

However, not every patient may need PORT. A prospective study has identified a subset of low-risk patients without any adverse pathologic factors (clear surgical margins, no extracapsular spread or nerve invasion, pN1) who have an excellent prognosis with surgery alone, with a 5-year locoregional control rate of 83%.\textsuperscript{48}

**Dose and Volume**

In the postoperative setting, the historically recommended dose to the entire operative bed is 56 to 60 Gy using conventional fractionation of 1.8 to 2 Gy per fraction, with the entire tumor bed being treated.\textsuperscript{3,32} A prospective randomized study concluded that with daily fractions of 1.8 Gy, a minimum tumor dose of 57.6 Gy to the whole operative bed should be delivered with a boost of 63 Gy to sites of increased risk (for example, extracapsular tumor spread).\textsuperscript{37} Dose escalation above 63 Gy at 1.8 Gy per day does not appear to improve the therapeutic ratio. Using 2 Gy per fraction, the biologic equivalent of these doses is 56 Gy in 28 fractions to the operative bed and 60 Gy to high-risk regions.

Another prospective study from the same institution reported on 213 locally advanced HNSCC patients who were treated surgically and stratified based on adverse pathologic findings (extracapsular extension, close/positive margin status, nerve invasion, multiple positive nodes, size of largest node greater than 3 cm, and oral cavity site).\textsuperscript{48} Patients were grouped as follows:

- **Low risk:** No adverse pathologic factors
- **Intermediate risk:** One adverse pathologic factor other than extracapsular extension
- **High risk:** Extracapsular extension and/or two or more adverse pathologic factors

Low-risk patients received no further treatment and had a 5-year actuarial locoregional control rate of 83%. Intermediate-risk patients received 57.6 Gy in 6.5 weeks and had 5-year locoregional control and survival rates of 94% and 66%, respectively. The results are consistent and justify the use of a moderate radiation therapy dose for patients with an intermediate risk of recurrence. High-risk patients were randomized to receive conventionally fractionated treatment of either 63 Gy in 7 weeks or 63 Gy in 5 weeks with altered fractionation. There was a trend toward improved tumor control outcome with the accelerated treatment, although greater toxicity was noted.
These patients had 5-year actuarial locoregional control and survival rates of 68% and 42%, respectively, and 33% of them failed with distant metastases. Intensification of treatment is thus warranted in this high-risk group.

**Time Interval Between Surgery and Postoperative Radiation Therapy**

Tumor clonogens proliferate throughout a course of therapy, meaning that the combination of surgery and PORT should be considered as a treatment package that is best delivered in a timely and coordinated fashion.\(^9,49\) A prolonged interval (6 weeks or longer) between surgery and conventionally fractionated radiation therapy is associated with decreased locoregional control \((p = 0.02)\) and survival \((p = 0.01)\) for high-risk patients in a prospective study.\(^48\) High-risk patients who have a significant delay between surgery and PORT appear to benefit from accelerated treatment.\(^48\)

When dental extractions are required before beginning radiation therapy, teeth should be extracted in conjunction with tumor surgery to prevent an unnecessary delay in starting PORT. Protracted, split-course radiation therapy regimens are not justified, not even to avoid transient mucosal reactions, because the risk of recurrence is too high.

**Postoperative Chemoradiation Therapy**

Multiinstitutional trials for patients treated with ablative surgery followed by PORT show locoregional control, distant metastasis, and 5-year survival rates of 30%, 25%, and 40%, respectively.\(^50\) Optimal therapy remains a matter of debate, especially with regard to treatment intensity and sequencing. Two recently reported randomized trials examined the potential benefit of CRT added to PORT (postoperative CRT or POCRT) to improve the outcome for patients with high-risk resected HNSCC.\(^51,52\)

RTOG 9512 evaluated 459 patients and defined *high risk* as one or more of the following risk factors: two or more positive lymph nodes, extracapsular nodal extension, and microscopically positive margins.\(^51\) Patients were randomized to PORT versus POCRT. Two-year locoregional control, but not overall survival, improved significantly with the addition of three-weekly bolus cisplatin chemotherapy. Acute grade 3 or higher toxicity occurred in more patients in the combined therapy group.

EORTC 22931 randomized patients with resected, high-risk squamous cell carcinoma arising from the oral cavity, oropharynx, hypopharynx, or larynx to PORT or POCRT with bolus cisplatin.\(^52\) Eligibility included patients with pT3-T4, pN2-N3, T1-T2, or N0-N1 status with unfavorable pathologic findings (extranodal spread, positive resection margins, perineural involvement, or vascular tumor embolism), or oral cavity or oropharyngeal tumors with involved lymph nodes at level IV or V. The addition of chemotherapy significantly improved the 5-year overall survival (53% versus 40%) and locoregional relapse rate (18% versus 31%) at the cost of increased grade 3 or higher toxicity.
A combined analysis of these two randomized studies was performed by the principal investigators of the studies.\textsuperscript{53} The results suggest that microscopically positive resection margins and extracapsular spread of the tumor from neck nodes are the most significant prognostic factors for poor outcome, and patients with these risk factors benefited the most from the addition of chemotherapy. Cisplatin-based POST is now routinely recommended for patients with one or both of these risk factors who are medically fit to receive chemotherapy.

\section*{Normal Tissue Effects of Radiation Therapy}

Normal tissue effects of radiation therapy are typically categorized as either acute or late effects. \textit{Acute or early effects} occur during the course of radiation therapy and in the days to weeks following treatment. \textit{Late effects} occur 3 or more months after treatment. Factors influencing these effects include total radiation therapy dose, dose per fraction (fraction size), duration of the overall treatment course, volume of normal tissue irradiated, radiation modality, and other physical factors such as beam energy and the location of hot spots in the treatment plan. Other factors such as previous and subsequent surgical procedures, systemic therapy with radiosensitizing agents such as cisplatin, the adequacy of supportive care such as dental prophylaxis, age, medical comorbidities such as severe connective tissue disorders and diabetes, and smoking also play important roles in modulating the timing and severity of normal tissue effects.

\subsection*{Acute Effects}

The acute or early effects of radiation therapy on normal tissues in the head and neck generally occur in tissues that are in a state of constant turnover such as epidermis of skin, mucosal surfaces, and bone marrow. The timing of manifestation of acute effects is a function of the cellular turnaround time in the unperturbed state. For example, the epidermis of skin has a turnover time of 4 weeks, and the effects of irradiation on the epidermis are not seen during the first 2 to 3 weeks of therapy. At a cellular level, radiation therapy predominantly leads to mitotic (reproductive) cell death as a result of unrepaired DNA damage. When the dividing layer of cells is unable to replenish the losses from the natural cellular turnover, epithelial denudation occurs followed by an inflammatory response mediated by proinflammatory cytokines.

Acute effects follow a fairly consistent time course, although there is individual variability among patients. Some of the common clinical effects that occur during radiation therapy to the head and neck include radiation dermatitis, epilation, painful mucositis, dysphagia, odynophagia, xerostomia (dry mouth), the formation of thick and stringy secretions that are difficult to clear, altered taste, and fatigue. These acute effects often challenge patient compliance and require very aggressive management with a variety of agents, including moisturizing neutral creams, oral bicarbonate rinses, analgesics (topical, nonnarcotic, and narcotic), steroids, and antiemetic agents. Patients frequently require nutritional and hydration support through feeding tubes.
and/or repeated IV fluid infusions. For a given tissue and radiation therapy technique, the severity of acute effects is directly related to the total dose and volume irradiated, and inversely related to the overall treatment time. Very severe acute effects that may occur with intensified local treatment may not heal adequately and become consequential late effects.\textsuperscript{54}

Skin erythema typically becomes apparent around the third to fourth week and is progressive during the course of treatment. Treatment to a curative dose of 70 Gy may result in dry or moist desquamation and peeling toward the end of a treatment course. Acute skin effects of radiation typically resolve 6 to 12 weeks after treatment.

Oral cavity and pharyngeal mucositis appears around the second week and is the major dose-limiting toxicity during head and neck radiation therapy. It may manifest earlier with concurrent cytotoxic chemotherapy or altered fractionation.\textsuperscript{13,55} There are currently no established means of preventing or mitigating mucositis. It is progressive during treatment and may cause significant pain, odynophagia, or dysphagia requiring analgesics, and nutritional support through feeding tubes. Radiation mucositis resolves within 4 to 8 weeks after treatment.

Xerostomia with thick, highly viscous, and stringy oral secretions and the loss or alteration of taste commonly occur during treatment with significant doses to the parotid and submandibular glands and minor salivary glands of the oral cavity. These effects are usually accompanied by a secondary loss of appetite and occasional nausea. Together with pharyngeal mucositis and thick secretions, an exaggerated and hypersensitive gag reflex develops that further precludes adequate oral alimentation. These patients are at high risk for dehydration, nutritional compromise, and aspiration pneumonia. Partial to total recovery of taste and salivary function is possible over a few months to a year after treatment if the mean radiation therapy dose to the parotid gland does not exceed 26 Gy.\textsuperscript{56}

**Late Effects**

Late effects following radiation therapy are somewhat less predictable than early effects in their occurrence, timing, and severity. The late effects of radiation therapy on normal tissues in the head and neck generally occur in tissues that are not in a state of constant turnover. Specific examples of interest in the head and neck include salivary glands (xerostomia), dermis (hyperpigmentation, epilation, telangiectasia, and chronic ulceration), mandible (osteoradionecrosis), teeth (dental decay), larynx (cartilage necrosis and edema), pharynx and cervical esophagus (dysphagia and strictures), neural structures (spinal cord, brain stem [paralysis] and brain [necrosis]), visual structures (retina, optic tracts and chiasm [partial or total blindness]), lacrimal gland (xerophthalmia), lens (cataracts), cochlea (sensorineural hearing loss), endocrine organs (thyroid [hypothyroidism]), pituitary gland (hypopituitarism), other connective tissues (masticatory musculature [trismus] and soft tissues fibrosis), and neck lymphedema. Most late effects manifest within 3 years following treatment.
Cellular depletion, vascular endothelial and microvascular effects, changes in the extracellular matrix, cytokine effects, and fibroblast dysfunction have been implicated in causing late effects. For a given tissue and radiation therapy technique, the severity of late effects is a function of the total dose, dose per fraction, and volume irradiated. Unlike acute effects, they are less dependent on the overall treatment time.

The tolerance dose, TD 5/5, is a commonly described value for the dose expected to result in a 5% risk of a certain complication or endpoint to a particular organ or tissue at 5 years following treatment using a conventional radiation therapy technique. A classic paper by Emami et al described TD 5/5 values for common organs at risk.

Xerostomia is one of the most significant late effects of head and neck radiation therapy. It may be permanent, with a debilitating effect on quality of life in general. It predisposes to accelerated dental decay and speech, with chewing and swallowing difficulties caused by the missing lubricant effect of saliva. A number of strategies have been used with varying success to prevent or ameliorate late xerostomia, including pilocarpine, amifostine, and oral sialogogues. Amifostine has been shown to reduce the rates of xerostomia in clinical studies, but it has not been widely adopted because of the logistical inconvenience of having to administer it within an hour or so of each radiation treatment and its induced nausea. Sugar-free chewing gum and bottled water may be the most pragmatic and effective strategy. Advances in radiation therapy techniques, in particular IMRT, have allowed parotid function preservation in select patients, making the use of radioprotectors such as amifostine less attractive. A randomized study has demonstrated significant salivary preservation with acceptable treatment outcomes using IMRT.

Patients are predisposed to dental caries because of the combined effects of xerostomia, impaired oral hygiene secondary to mucositis, an altered oral environment, viscous saliva with low pH, reduced buffering capacity, altered salivary electrolyte concentrations, changed nonimmune and immune antibacterial systems with acid plaque formation, changes in oral microflora toward cariogenic bacteria, and dietary changes with frequent high-calorie intake. It is essential that patients undergo a pretreatment formal dental evaluation with extraction of all nonrestorable teeth within the high dose area (greater than 55 Gy). However, healthy teeth do not have to be extracted from high-dose regions.

A minimum healing period of 10 to 14 days between dental extractions and the start of radiation therapy is recommended. Postradiation dental extractions and invasive procedures in the high-dose region should be avoided if possible to minimize the risk of osteoradionecrosis. If extraction is unavoidable, careful and atraumatic extraction with minimum mucoperiosteal flap elevation, minor alveoloplasty, and primary closure are recommended. Antibiotic coverage and hyperbaric oxygen are frequently used. A detailed discussion of osteoradionecrosis is presented in Chapter 40.
IMPACT OF RADIATION THERAPY ON SURGICAL PROCEDURES

Multimodality treatment integrating radiation therapy and chemotherapy with surgical approaches has been shown to increase the potential adverse effects on normal tissues and wound healing. Reconstruction options have been improved dramatically by using local flaps; pedicled flaps, which derive their blood supply from areas outside the irradiated field; and free flap approaches using microsurgical techniques. These advances have increased the flap success rate.

Radiation therapy either before or after surgery has long been recognized as having significant acute and late effects on skin and soft tissue, which may affect surgical wound healing and flap success because of the effects of radiation therapy on vasculature. Animal experimental data are conflicting regarding the effect of radiation therapy on the patency of microsurgical anastomoses. Clinical data examining the impact of radiation therapy on wound healing and flap success are limited. These studies are difficult to interpret because of the poor detail in reporting the radiation therapy technique and inconsistent reporting of surgical outcomes. The definitions and descriptions of complications vary widely, and the effect of confounding factors is rarely considered. There is some controversy about the possibility of previous irradiation of a recipient site or irradiation of a free flap significantly affecting healing and complication rates. However, most recent data have not shown deleterious outcomes with microvascular free flap reconstructive techniques. Choi et al examined the impact of perioperative radiation therapy in a cohort of 100 patients undergoing microvascular free flap reconstruction of the mandible at the University of Washington and found no significant association with the rate of complications. This group included patients who had no previous radiation therapy (28), preoperative radiation therapy (37), or postoperative radiation therapy (35). The median follow-up after surgery was 11 months. There were no differences among the three groups in complications of any severity. No case of complete flap loss was observed. They concluded that radiation therapy can be safely administered after surgery to patients undergoing head and neck free flap reconstruction of the mandible.

The most critical time period for wound healing is the initial 24 to 48 hours after surgery. The risk is significantly decreased by 3 to 4 weeks following surgery, and after 4 weeks it is generally safe to begin postoperative radiation therapy unless delayed wound healing has occurred.

SPECIAL TECHNIQUES AND MODALITIES

Intensity-Modulated Radiation Treatment

IMRT is a very conformal, three-dimensional technique capable of precisely targeting tumors and is used routinely in the treatment of HNSCC. IMRT refers to the modulation of individual beam intensities so that the high-dose volume matches the tumor geometry in all three dimensions while delivering an appropriate dose to ar-
eas at risk for microscopic disease. Advances in computerized treatment planning use inverse planning algorithms along with hardware improvisations, and high-resolution multileaf collimators have brought this technique into routine use at most radiation therapy centers in the developed nations.

The major benefit of IMRT is the sparing of critical structures while delivering high doses to the tumors, as seen in Fig. 2-3. In selected patients, IMRT can successfully spare the salivary glands, mitigating the debilitating effects of xerostomia. IMRT can also spare other normal structures such as the cochlea, oral mucosa, temporomandibular joint, and mandible. It may also reduce the frequency of osteoradionecrosis. Although IMRT allows better conformality of the high-dose region to the tumor, it does so at the expense of increasing the low-dose volume of tissue. This low-dose spill into nontarget structures may result in unexpected incidental toxicity from IMRT.

As with any precision technique, it is possible to be highly precise and precisely inaccurate. The greatest risk with IMRT is to miss the tumor altogether. The margin for error is small because the dose gradient is very steep, and it is possible to miss the target as a result of inappropriate parotid sparing or by not recognizing the patterns of microscopic tumor spread. Setup inaccuracies and errors caused by patient or organ motion, deformation of tumors as they shrink through a course of radiation treatment, and misregistration of images can lead to unforeseen overlap of normal and tumor tissue.

**Fig. 2-3** Comparison of a conventional radiation therapy plan (A) with an IMRT plan (B). The red color wash shows the high-risk clinical target volume (CTV 66), and the green color wash shows the low-risk clinical target volume (CTV 54) for microscopic disease. CTV 66 is covered conformally by the red 98% isodose line in the IMRT plan. In the conventional plan, conformality is lacking—the 98% isodose line covers CTV 66 as well as CTV 54 and normal tissue, including the mandible and oral mucosa. The magenta isodose line in the conventional plan shows an undesirable 105% hot spot located on the mandible and in the posterior neck. There are no hot spots in the IMRT plan.
therapy, and patient weight loss become issues. To circumvent setup errors, image-guided radiation therapy (IGRT) that verifies the match between the treatment plan and final patient position and corrects for inaccuracies is currently being adopted at many centers. Adaptive radiation therapy refers to modifying the field configuration and delivered dose during a course of treatment to mitigate the problem of target deformation during therapy.

IMRT is very resource intensive, because clinicians have to carefully outline (contour) the targets to be treated and normal structures to be missed using CT scans obtained with the patient in the treatment position, immobilized by a mask. Image fusion with MRI scans and PET scans further improves the accuracy of contouring, as do training and knowledge of detailed cross-sectional anatomy. Other issues to consider with IMRT include a greater time required for treatment planning and quality assurance of a treatment plan, as well as an increase in treatment time per fraction from approximately 10 to 15 minutes for a conventional treatment to 20 to 30 minutes with IMRT. The longer a patient is on the treatment table, the more likely he or she will move, decreasing the reliability of the positioning during setup and treatment. Therefore IMRT might appear very beneficial and appealing in theory, but in practice there are multiple pitfalls to avoid.

Tomotherapy is a form of IMRT. It combines the principles of a diagnostic CT scanner with an MV photon–generating treatment head. An advantage of tomotherapy is the ability to generate daily MV images that can be aligned and correlated with the planning images. The necessary patient shifts are then made to ensure an acceptable match. This process of image-guided radiation therapy improves the accuracy of treatment, although MV images lack clarity and are not ideal.

The Gamma Knife is a device for performing stereotactic radiosurgery on intracranial and skull base tumors. It consists of approximately 200 $^{60}$Co sources aligned to focus at a single isocenter. Thus the beams are highly convergent, and the dose drops off quite rapidly away from the focal region. By using collimators of various sizes and moving the focal point through the target volume, very conformal dose distributions can be delivered. A rigid head frame is used to ensure reproducibility of a patient’s position throughout tumor imaging, treatment planning, and treatment delivery. Submillimeter precision is typically achieved with single-fraction treatments being the norm. This modality may be used as a boost treatment for skull base disease near a critical structure, after a course of fractionated radiation therapy. An example is given in the section titled Neutrons, Protons, and Heavy Ions. It is also useful in the palliative treatment of brain metastases and in recurrent, previously irradiated tumors in the skull base.

The Cyber Knife is a stereotactic radiosurgery system that incorporates a linear accelerator mounted on a fully articulated robotic arm gantry. The system is capable of rotational and translational movements with delivery of multiple beams from nearly 1300 different beam orientations. The geometric flexibility and mechanical accuracy allows delivery of highly conformal radiation doses to complex tumor volumes.
with very steep dose gradients, typically using single-fraction or multisession hypofractionated (using large doses per fraction) regimens. Two orthogonal x-ray imagers provide periodic image guidance during each treatment, allowing the robotic gantry to be dynamically brought into alignment to account for patient or target movement. Similar to the Gamma Knife, the system was initially introduced for the management of intracranial and skull base tumors but has recently been used successfully to treat a wide range of extracranial sites, including recurrent, previously irradiated head and neck tumors.\textsuperscript{77,78}

\textbf{Brachytherapy}

\textit{Brachytherapy} literally means treatment at a short distance. It refers to placing or implanting radioactive material in such a manner that the delivered dose is much larger in the tumor than in the surrounding normal tissue. In the treatment of head and neck tumors, the radioactive sources may be placed \textit{interstitially}, meaning that they physically penetrate the tissue as in the treatment of cancers of the tongue, floor-of-mouth, or faucial arch. For some locations such as the nasopharynx and buccal mucosa, the sources may be placed in the form of intracavitary tubes or molds. Martinez\textsuperscript{79} and Montemaggi et al\textsuperscript{80} present detailed discussions of the use of brachytherapy. Brachytherapy implants may be classified according the dose rate given to the tumor (that is, how rapidly the specified dose is delivered).

Low dose rate (LDR) implants deliver 0.4 to 2.0 Gy per hour. LDR implants are generally inserted as permanent seeds or temporary implants in an operating room while the patient is under general anesthesia. One of the first isotopes used for LDR implants was radium-226 in the form of rigid needles to treat tumors of the oral tongue, floor-of-mouth, and lips, as well as advanced neck disease. These needles were difficult to use, and the treating radiation oncologist and assisting nurse or technician frequently received a substantial dose during needle placement.

The use of remote afterloading techniques and isotopes emitting lower-energy gamma rays was a major advance. Today, iridium-192 is the isotope most commonly used in head and neck LDR implants. Using metal trocars, plastic catheters are placed through the region of interest, and then radiopaque dummy sources are inserted into the catheters as a surrogate for the radioactive seeds that are ultimately placed. Orthogonal radiographic imaging or treatment planning CT scans and state of the art three-dimensional treatment planning is performed using these dummy sources, giving no exposure to clinical personnel. The iridium sources are inserted remotely into the catheters after the implant geometry has been finalized and remain in place until the desired dose has been delivered over a period of days while the patient stays in a shielded room. If brachytherapy implants are used as the sole treatment, such as for small and T1 tumors of the tongue, then approximately 50 to 60 Gy is given over 5 to 6 days. More frequently, brachytherapy is used as a boost after about 50 Gy has been delivered using an external beam; in this case, 15 to 20 Gy is typically given.
High dose rate (HDR) implants deliver a radiation dose at a rate greater than 12 Gy per hour. These implants utilize a computer-controlled, remote afterloader to position a high-intensity iridium-192 source within a set of preplaced, plastic catheters. The single, high-intensity source is located at the end of a flexible, steel guide cable. The catheter is placed in a manner similar to that described previously. Either orthogonal radiographic films or CT images are used to localize the catheters and source positions using dummy radiopaque seeds. The radiation oncologist specifies the dose to be delivered at various points throughout the implant, and then a computer program using inverse planning iteratively calculates the dwell time of the source at various points within the field of catheters placed throughout the tumor or resection cavity. The patient is brought to a shielded room once or twice a day and the catheters are connected to the remote afterloader. The source is then transported under computer control from a shielded safe into the catheters, where it dwells at specified locations for specified periods of time. Typically 3 to 4 Gy is given to a specified isodose line around the tumor in each session, which takes place within 5 to 10 minutes. The radiobiology of an HDR implant is akin to that of large doses per fraction external beam therapy. The fine control over the radiation source placement generally results in a more optimal physical dose distribution than that achieved with LDR implants. There are also fewer logistical and radiation protection issues with HDR implants, and patients typically do not require admission during the course of a treatment.

Conceptually, brachytherapy used as monotherapy is analogous to a wide, local surgical excision of the primary site without addressing the potential pathways of spread. Brachytherapy used as a boost is preferred for larger or deeply infiltrating tumors, with external beam radiation therapy addressing the microscopic disease. As with any highly specialized technique, it is best practiced in the few high-volume centers with expertise. It is contraindicated for tumors abutting bone because of the high risk of osteoradionecrosis.

**Neutrons, Protons, and Heavy Ions**

**Neutrons**

Neutrons are uncharged and have dose distributions similar to those of conventional photon beams (Fig. 2-4). However, they are a form of high linear energy transfer (LET) radiation therapy, which is more likely to cause double stranded breaks in the cellular DNA—a type of radiation damage that is less readily repaired by cells. Battersmann et al[^81] determined the relative biological effectiveness (RBE) of fast neutrons relative to $^{60}$Co gamma radiation for various human tumors metastatic to the lung and found that the highest value of 8.0 corresponded to adenoid cystic carcinomas of salivary gland origin. For squamous carcinomas, the RBE was in the range of 3 to 3.5, which is in the same range as the RBE for late effects in most normal tissues. The greater the RBE, the more likely the clinical benefit of neutron radiation therapy. Multiple randomized trials have compared neutron radiation therapy against
standard radiation therapy for various forms of HNSCC. The results have indicated no significant advantage for squamous cell cancers; therefore this modality is rarely used in their treatment. The results for salivary gland tumors stand in sharp contrast; the only randomized clinical trial was stopped early on ethical grounds, because the neutron-treated patients were faring substantially better than the group treated with conventional radiation therapy. A final report showed improved local control at 10 years of 56% versus 17% \((p = 0.009)\) but no improvement in long-term survival because of the competing risk of death from distant metastases. More recent, single-institution studies corroborate this finding. Douglas et al reported on major salivary gland tumors and found the local control rate at 9 years was 78% for tumors 4 cm or smaller in greatest diameter compared with 40% for tumors 4 cm or larger. In the case of adenoid cystic carcinoma with extension to the skull base, it was necessary to reduce the neutron dose to the upper portion of the tumor to avoid damage to CNS structures, which resulted in a lower local control rate of 39% at 40 months. The use of a Gamma Knife stereotactic radiosurgery boost has improved this rate to 82%, although further follow-up is necessary to more completely evaluate the efficacy and late toxicity of this modified form of treatment.

**Protons**

Protons are heavy charged particles that deposit little energy along their initial path. Their energy loss is localized at the end of their range in a Bragg peak (Fig. 2-5). For practical purposes, protons have biologic properties similar to those of standard megavoltage photon radiation therapy. Proton doses are generally specified in terms of cobalt gray equivalent or CGE, which equals the physical dose multiplied by a scaling factor of 1.1. Proton radiation therapy centers are expensive to set up and use either cyclotrons or synchrotrons to accelerate protons up to approximately 250 MeV and then direct the beam into one of several treatment rooms. These rooms

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**Fig. 2-4** Depth-dose curves for 10 by 10 cm² fields from a 6 MV linac (dashed line) and the therapy beam from the University of Washington fast neutron radiation therapy facility (solid line).
may have either fixed ports or isocentric gantries with the same degrees of freedom as modern linear accelerator equipment. Proton radiation therapy has been used extensively for skull base tumors lying close to highly critical structures such as optic nerves, the optic chiasm, or brain stem. Representative local control rates range from 59% to 88% for chordomas and from 92% to 100% for chondrosarcomas.\textsuperscript{88-91} Twenty-nine patients with advanced oropharyngeal tumors have been treated at Loma Linda University Medical Center using a combination of photons and proton radiation therapy.\textsuperscript{92} The 5-year, actuarial survival was 65%, and the locoregional control rate was 88% at the primary site and 96% in the cervical neck nodes.

**Fig. 2-5** Depth-dose curves for a 170 MeV proton beam (dashed line) and a 330 MeV per amu carbon ion beam (solid line). Note the greatly enhanced energy deposition at the Bragg peak, which occurs at the end of the particle range for these heavy charged particles.

### Heavy Ions

Carbon and other heavy ions are a high-LET form of radiation therapy that combines the dose localization benefits of proton radiation therapy (see Fig. 2–5) with the biologic properties of fast neutrons. Accelerating heavy ions to clinically useful energies requires larger cyclotrons or synchrotrons than those used in proton radiation therapy, and the higher magnetic fields required to bend the “stiffer” beam indicate that gantries are considerably larger as well. The cost of a heavy ion facility is approximately 1.5 to 2 times greater than the cost of a proton facility having the same number of gantries and treatment rooms. A phase I/II dose escalation study was performed at the HIMAC facility in Chiba, Japan, for patients with advanced head and neck tumors.\textsuperscript{93} There were 34 evaluable patients with a spectrum of tumor histologies. The overall 5-year local control rate was 75% with acceptable treatment-related toxicity. The authors note improved outcomes in patients with nonsquamous histologies such as melanoma and salivary gland tumors, which are the same subsets of tumors for which fast neutrons also show improved outcome relative to standard radiation therapy.
CRITICAL POINTS

Must Know

- Radiation therapy should be considered part of the treatment protocol for most head and neck cancers.
- Radiation therapy can be delivered preoperatively or postoperatively.

Should Know

- Radiation doses can be precisely targeted using techniques such as IMRT.
- Toxicity is described in terms of acute effects and late effects.
- Multimodality treatment combining radiation therapy and chemotherapy with surgery significantly increases the risk of complications.

Synopsis

- Radiation therapy is a consideration for treating most head and neck cancers.
- Modern techniques allow precise targeting of tumors to minimize side effects.
- The combination of radiation therapy with other treatment modalities can significantly improve tumor control.

References


6. Nordsmark M, Bentzen SM, Rudat V, et al. Prognostic value of tumor oxygenation in 397 head and neck tumors after primary radiation therapy: an international multi-center study. Radiother Oncol 77:18-24, 2005. This study analyzes the relationship between pretreatment measurements of tumor oxygen tension and survival in advanced head and neck cancer. The prognostic model shows that 5-year survival is almost constant when the fraction of PO2 values are 2.5 mm Hg (in the range of 0% to 20%), whereas the 5-year survival approaches 0% in the most hypoxic tumors. This study provides evidence that tumor hypoxia is associated with a poor prognosis in patients with advanced head and neck cancer.


When analysis of radiation therapy results for nearly 500 patients with oropharyngeal cancer showed evidence for rapid tumor regrowth during extensions of treatment from about 5 weeks to about 8 weeks, the authors searched the literature for similar cases of accelerated tumor regrowth in head and neck cancer patients treated with radiation therapy. The values presented here are average values for a large number of patients: it is necessary, not only to verify the results of these retrospective analyses in prospective studies, but also to develop methods to predict the time of onset and rate of accelerated tumor clonogen repopulation in individual patients.


EORTC protocol 22971 compared once daily fractionation (CF) to pure hyperfractionation (HF). The superiority of HF was demonstrated in patients staged T3N0, T3N1 but not in T2. The Cox model confirmed that the treatment regimen was an independent significant prognostic factor for locoregional control. This improvement of locoregional control was responsible for a trend to an improved survival. There was no difference in late normal tissue damage between the two treatment modalities.


The aim of this metaanalysis was to assess whether hyperfractionated radiation therapy could improve survival. Randomized trials comparing conventional radiation therapy with hyperfractionated or accelerated radiation therapy, or both, in patients with nonmetastatic HNSCC were identified, and updated individual patient data were obtained. It was found that altered fractionated radiation therapy improves survival in patients with head and neck squamous cell carcinoma. Comparison of the different types of altered radiation therapy suggests that hyperfractionation has the greatest benefit.


Continuous, hyperfractionated, accelerated radiation therapy (CHART) was tested in a multicenter, randomized, controlled clinical trial. Similar local control was achieved by CHART when compared against conventional radiation therapy, despite the reduction in total dose from 66 to 54 Gy—supporting the importance of repopulation as a cause of radiation failure. Reduced late morbidity is a factor that, together with patient preference, should be considered when deciding which radiation therapy program to employ for curative treatment of head and neck cancer.


CHAPTER 3

Principles of Chemotherapy

Merrill S. Kies

HIGHLIGHTS

• Chemotherapy as a single modality has no established role as a curative treatment option.
• Chemotherapy is frequently used in the treatment of head and neck cancer, either as a component of primary treatment or for recurrent disease.
• In general, patients with early stage disease should receive conventional therapy with surgery, radiation therapy, or both.
• Patients with late stage disease may be considered for chemotherapy treatment in conjunction with other modalities.
• Patients with metastatic disease should receive chemotherapy with palliative intent if performance status is favorable.

Head and neck surgeons encounter many patients who will receive chemotherapy as a component of primary treatment or for recurrent or metastatic disease. Often these patients have locally advanced squamous cell cancers for which there may or may not be a potentially curative approach, with surgery or radiation therapy. Chemotherapy may be administered concomitantly with radiation therapy; in sequence with radiation or surgery (known as induction therapy); or as a single modality treatment for patients with recurrent or advanced disease not amenable to a curative local treatment strategy. Biologic agents that target specific molecular pathways are under investigation. The epidermal growth factor receptor (EGFR) and related intracellular activities have been increasingly studied and established as vulnerable targets. The focus of this chapter is systemic treatment approaches.
SQUAMOUS CELL CARCINOMA

Before 1970, chemotherapy had a limited role in the management of squamous cell cancers of the head and neck, in part because of a paucity of available drugs with documented antitumor activity. The folic acid analog methotrexate was commonly used and recognized as a cytotoxic agent. It provided expected tumor responses in about one third of patients treated. However, these responses were typically partial and short lived, usually 3 to 4 months; thus treatment goals were palliative. In older literature, the assessment criteria used to define response were neither uniform nor strict. The reported response rates tended to be unreliable, representing an accumulation of observations that could reflect any degree of tumor regression. In contrast, during the past two decades, a more rigid system has been applied to the testing of potentially useful drugs. There are now clearly defined parameters for the objective evaluation of response and survival time, and statistical guidelines for the design of clinical research trials to establish efficacy or to show improvement compared with standard therapies.

The identification of the metal compound cisplatin eventually led to recognition of it as a highly active agent for the treatment of squamous cell carcinoma of the head and neck (SCCHN). Presently, combination chemotherapy regimens are most often platin based and used as a component of primary therapy for patients with stage III or IV disease and for palliation in patients with locally recurrent or metastatic cancers. Several highly effective chemotherapy regimens have been identified and incorporated into combined modality approaches for treating newly diagnosed patients. The ultimate goal is to improve survival time with squamous cell cancers of the head and neck. It has become clear that induction chemotherapy may induce rapid tumor regression in most patients, without substantially increasing the morbidity from subsequent surgery or radiation. This approach is still being studied. A proportion of responding patients have no histologic evidence of residual tumor in resected specimens. This increases the possibility of altering the standard surgical approach for some primary tumors to preserve organ function. In addition to investigating the potential activity of chemotherapy administered before definitive local therapy, chemotherapy used concomitantly with radiation as a means to sensitize cancers to radiation therapy has become a standard of care for many patients with intermediate and advanced oropharyngeal and laryngeal cancers with no distant metastases (M0), as an alternative approach to surgery.

A new class of drugs (that is, molecularly targeted agents) has recently become available for treating cancer. These compounds have a distinct mechanism of action, blocking specific molecular pathways central to the carcinogenic process. As a result, molecularly targeted drugs exhibit antiproliferative, proapoptotic, antiangiogenic, and chemotherapy– and radiation therapy–sensitizing properties, which contribute to their overall antineoplastic effects. Adverse events associated with these drugs are very distinct from the classic side effects observed with cytotoxic agents and are largely determined by the target pathway inhibited. It has recently been demonstrated that cetuximab (a biologic agent that targets EGFR), given concomitantly with radiation therapy, improves the survival of patients with head and neck cancer,
with no increased risk of severe radiation-induced side effects. This is proof of principle that biologic agents are valid therapeutic options for this disease. Moreover, this discovery begins an exciting era for research and clinical management of head and neck cancers.

**Combined Modality Therapy**

Chemotherapy as a single modality has no established role as a curative treatment option. However, the addition of chemotherapy given concomitantly with radiation therapy has been shown to improve local disease control and overall survival as definitive treatment with anatomic organ preservation or after surgical resection. For locally advanced disease, chemotherapy given before definitive radiation or chemoradiation (induction) may also improve survival, especially with the use of combination chemotherapy consisting of a taxane, cisplatin, and infusional 5-fluorouracil (TPF).

Powerful local treatment strategies with surgery and radiation therapy may lead to a curative outcome for a high percentage of patients with early-stage SCCHN, but for a more modest percentage of patients with stage III or IV disease, even if there are no distant metastases (M0). Moreover, results of treatment for recurrent or metastatic disease with chemotherapy are far from satisfactory. These results have led to an emphasis on primary treatment strategies, because the potential to eradicate the disease and maintain function is far greater. The following three general approaches have been established:

1. Chemoradiation for organ preservation in which chemotherapy is given simultaneously with radiation to enhance its effect as a definitive, potentially curative treatment
2. Chemoradiation as adjuvant therapy in which chemotherapy and radiation therapy are simultaneously given after surgery for high-risk patients to increase local control and to decrease the metastatic disease burden, thus improving survival
3. Induction chemotherapy, also known as neoadjuvant therapy, in which chemotherapy is given before surgery or radiation

**Concomitant Chemoradiation Therapy**

Many squamous cell cancers of the head and neck are diagnosed at a late stage. Stages III and IV disease may necessitate extensive or radical surgery that can alter function. Depending on the precise site and stage, radical surgery may affect speech, swallowing function, and cosmesis. In the 1990s, a role for induction chemotherapy and radiation as a combined modality treatment to enhance organ preservation was explored in the Department of Veterans Affairs Laryngeal Cancer Study. For early-stage cancers of the larynx, definitive radiation therapy or conservation laryngeal surgery produces excellent tumor control with preservation of speech and swallowing function, and remains the standard of care. But for patients with more advanced disease, combining radiation therapy with chemotherapy has provided a powerful nonsurgical alternative, administered with the goals of disease eradication and organ preservation.
Induction chemotherapy with cisplatin-based regimens is highly active, with clinical partial and complete responses observed in 80% to 90% of previously untreated patients with SCCHN. It had been postulated that a substantial response to initial treatment with chemotherapy would lead to an improvement of therapeutic efficacy for surgery or radiation therapy. If this were true, radiation therapy might become an acceptable alternative to laryngectomy with prospects for tumor control and organ function. These considerations led to the Department of Veterans Affairs Laryngeal Cancer Study, in which 332 patients with stage III or IV squamous cell carcinoma of the larynx were randomized to receive either induction chemotherapy consisting of cisplatin and fluorouracil followed by radiation therapy or surgery and postoperative radiation therapy. Patients who had no tumor response to chemotherapy or those who had locally persistent or recurrent cancer underwent salvage laryngectomy. Two-year survival for both treatment groups was 68%, and 41% of patients randomly assigned to the experimental arm were alive with a functional larynx at 2 years. Thus the efficacy of chemotherapy followed by radiation therapy (with surgical salvage) was similar to that of surgery followed by radiation therapy and established organ preservation as a realistic goal of nonsurgical treatment administered with curative intent. Lefebvre et al later reported data from a European trial involving patients with cancers of the hypopharynx. In this randomized study comparing induction chemotherapy followed by radiation in complete responders with surgical resection and postoperative radiation therapy, overall survival was considered to be equivalent, again demonstrating that larynx preservation could be achieved in some patients without jeopardizing survival.

Pontreau et al presented data from GORTEC 2000-01 comparing induction chemotherapy using cisplatin and fluorouracil with docetaxel (TPF) or without docetaxel in patients with hypopharyngeal and laryngeal cancer requiring laryngectomy. Patients achieving a substantial tumor response proceeded to definitive radiation therapy with organ preservation. In 220 patients, preliminary results have shown a superior overall response rate of 83% with TPF versus 61% for cisplatin and fluorouracil. Larynx preservation was also superior, occurring in 70% of patients in the TPF arm versus 58% for cisplatin and fluorouracil. Neutropenia was greater in the experimental arm (57% versus 35%). Overall, TPF demonstrated a significantly superior tumor response rate, was tolerated with acceptable toxicity, and appeared to be associated with improved larynx preservation.

In the Veterans Affairs study, trends were observed in patterns of tumor relapse, with 20% of patients in the chemotherapy arm having locoregional recurrence versus 7% in the surgery arm. Distant disease recurrence was more likely in the surgical arm, affecting 17% of patients versus 11% in the chemotherapy/radiation therapy arm. Salvage laryngectomy was required more often in patients with glottic cancers than in those with supraglottic primary sites (43% versus 31%), in patients with fixed vocal cords than in those with mobile vocal cords (45% versus 29%), and in patients with gross invasion of thyroid cartilage than in patients without (41% versus 35%). Notably, salvage laryngectomy was required in 56% of patients with T4 cancers compared with 29% of patients with smaller primary tumors ($p = 0.001$).
The Veterans Affairs larynx study has prompted further investigations of chemotherapy and radiation therapy in the treatment of patients with intermediate-stage laryngeal cancer using the sequential administration of induction chemotherapy, consisting of cisplatin and fluorouracil, followed by radiation therapy as the control arm. This regimen was compared with concomitant cisplatin and radiation therapy, and radiation therapy administered as a single treatment modality. For all groups, totaling 547 patients, surgical salvage was reserved for patients with persistent or locally recurrent disease. Eligible patients had stage III or IV disease but with T1 and most T4 patients excluded. Preservation of the larynx was greatest in patients receiving concomitant chemoradiation therapy, with statistical significance obtained, compared with patients receiving radiation therapy as a single modality. Survival was not affected by treatment assignment. Acute mucocutaneous toxic effects of treatment were greatest in the patients who received radiation therapy with concomitant cisplatin. Forastiere et al more recently provided an updated, 5-year analysis of Radiation Therapy Oncology Group (RTOG) 91-11 data (Table 3-1). Most notably, laryngeal preservation was greatest in patients randomized to concomitant radiation therapy with cisplatin (84% versus 66% with radiation therapy alone, \( p = 0.0002 \)). Laryngectomy-free survival was similar, comparing the cisplatin and fluorouracil induction arm with the concomitant chemoradiation arm. Moreover, overall survival was 59% in the induction program versus 55% in the concomitant chemoradiation arm, which is not a statistically significant difference. Disease-free survival was similar between the sequential and the concomitant chemoradiation strategies.

<table>
<thead>
<tr>
<th>Table 3-1 RTOG 91-11 5-year Update</th>
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<tbody>
<tr>
<td>Radiation Therapy Compliance</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Cisplatin/fluorouracil \rightarrow radiation therapy</td>
</tr>
<tr>
<td>Radiation therapy + cisplatin</td>
</tr>
<tr>
<td>Radiation therapy alone</td>
</tr>
</tbody>
</table>

RTOG, Radiation Therapy Oncology Group.

These trials indicate that for patients with intermediate-stage squamous cell carcinoma of the larynx, a combined treatment program with the objectives of tumor eradication and laryngeal preservation is feasible. It should be emphasized that patients with destructive T4 primary laryngeal cancers were not included in the more recent RTOG 91-11 trial. These patients may require total laryngectomy for optimal tumor control and preservation of functional swallow. Treatment planning should be multidisciplinary for accuracy in staging and the most effective decision-
making. Moreover, to optimize long-term function, patients should also be followed by qualified speech pathologists, further emphasizing the value of multispecialty care in managing complex cancers of the head and neck.

Within the past decade, concomitant chemoradiation therapy has become the standard-of-care treatment option for patients with locally advanced squamous cell carcinomas of the larynx, oropharynx, and hypopharynx (Table 3-2). The theoretic rationale and mechanism for the interaction between cytotoxic drugs and radiation that results in additive or synergistic enhancement have been reviewed in detail, and is based on several mechanisms. These include (1) inhibition of DNA repair, (2) redistribution of cells in sensitive phases of the cell cycle, and (3) promoting oxygenation of anoxic tissues. The net effect is to improve cellular cytotoxicity. The benefits of adding chemotherapy delivered during radiation are notably demonstrated in recently published metaanalyses. Concomitant administration of chemotherapy and radiation was reported to achieve improved local control and an 8% survival advantage at 5 years over radiation therapy administered as a single modality. This approach to improved tumor control appears to be associated with increased acute and chronic toxicities, inanition, esophageal stenosis, gastrostomy tube dependence, and recurrent infection related to aspiration.

### Table 3-2  Randomized Trials Comparing Radiation Therapy With Concomitant Chemoradiation Therapy

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Number of Patients</th>
<th>Chemotherapy</th>
<th>Radiation (Gy)</th>
<th>Survival Benefit</th>
<th>Locoregional Control Benefits</th>
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<tbody>
<tr>
<td>Jeremic et al</td>
<td>1997</td>
<td>159</td>
<td>P</td>
<td>70</td>
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<tr>
<td>Al-Sarraf et al</td>
<td>1998</td>
<td>147</td>
<td>P</td>
<td>70</td>
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<td>Yes</td>
</tr>
<tr>
<td>Jeremic et al</td>
<td>2000</td>
<td>130</td>
<td>P</td>
<td>77</td>
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<td>Yes</td>
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<tr>
<td>Adelstein et al</td>
<td>2003</td>
<td>295</td>
<td>P</td>
<td>70</td>
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<td>Adelstein et al</td>
<td>1997</td>
<td>100</td>
<td>PF</td>
<td>66-72</td>
<td>Yes‡</td>
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<tr>
<td>Wendt et al</td>
<td>1998</td>
<td>270</td>
<td>PFL</td>
<td>70.2†(split)</td>
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<tr>
<td>Brizel et al</td>
<td>1998</td>
<td>116</td>
<td>PF</td>
<td>70-75</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Calais et al</td>
<td>1999</td>
<td>226</td>
<td>CpF</td>
<td>70</td>
<td>Yes</td>
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<tr>
<td>Staar et al</td>
<td>2001</td>
<td>240</td>
<td>CpF</td>
<td>69.9†</td>
<td>Yes§</td>
<td>Yes§</td>
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<tr>
<td>Budach et al</td>
<td>2005</td>
<td>384</td>
<td>MF</td>
<td>70.6-77.6†</td>
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<td>Yes</td>
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<tr>
<td>Bensadoun et al</td>
<td>2006</td>
<td>163</td>
<td>PF</td>
<td>75.6-80.4</td>
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</tbody>
</table>

* Disease-free survival.
† Altered fractionation radiation.
‡ Relapse-free survival.
§ Oropharynx cancer subset.

Cp, Carboplatin; F, fluorouracil; L, leucovorin; M, mitomycin; P, cisplatin.
Choice of Chemotherapy Regimen

Concomitant Chemoradiation Therapy

The choice of the best chemotherapy regimen to be used in conjunction with radiation has not been well addressed in randomized trials, but cisplatin 100 mg/m² administered on days 1, 22, and 43 of a daily radiation treatment plan is widely accepted as an academic standard. Single agents used to treat patients with head and neck cancer have been combined with radiation. Multiagent chemotherapy given concomitantly with radiation therapy has also been evaluated in several studies. Data from selected randomized trials of combined therapy are shown in Table 3-2. In general, to date, there is no convincing evidence to suggest that multiagent chemotherapy is superior to single-agent chemotherapy when given concomitantly with radiation therapy. Additionally, most reported trials of concomitant chemotherapy (single-agent or multiagent) and radiation therapy have described enhanced acute treatment-induced toxicity, primarily mucosal, which has often resulted in dose reductions and interruptions of the radiation therapy treatment schedule. This may have marked deleterious effects on overall outcomes. Thus in combining these two treatment modalities, especially when multiagent chemotherapy regimens are used, it is essential that toxicity not prevent the administration of radiation. Single-agent cisplatin has evolved as a reliable adjunct to radiation therapy, commonly used in the United States in chemoradiation programs for head and neck cancers of any site (see Table 3-2). This combined regimen has become established in part because of favorable results observed in the Intergroup trial for nasopharyngeal carcinomas. In this study, patients received either radiation therapy alone or cisplatin (100 mg/m² on days 1, 22, and 43) during radiation therapy, followed by adjuvant chemotherapy with cisplatin and 5-fluorouracil (three cycles). An analysis of 147 randomized patients revealed significant differences in 3-year survival time (78% versus 47%) and progression-free survival time (69% versus 24%) favoring the chemotherapy group.

Recently, biologic agents have been studied to assess independent activity, as well as in combination with chemotherapy and radiation therapy. EGFR-targeted agents are the class of drugs in the most advanced stages of clinical development. Fig. 3-1 shows signaling pathways that may be targets for new drugs in development. In an important study, Bonner et al conducted a prospectively randomized phase III trial in 424 treatment-naïve stage III and IV patients with squamous cell carcinoma of the oropharynx, hypopharynx, and larynx. Patients were randomized to radiation therapy as a single modality versus radiation therapy with cetuximab administered on a weekly schedule of 250 mg/m² following an initial loading dose of 400 mg/m². The experimental regimen was generally well tolerated. Three percent of patients receiving the targeted agent developed serious hypersensitivity reactions, but severe-grade, in-field mucocutaneous toxicity notably was not increased in the combined modality treatment arm. Moreover, locoregional tumor control (median 24.4 months versus 14.9 months) and overall survival (hazard ratio for death 0.74, \( p = 0.03 \)) were improved. In a retrospective subset analysis, the survival advantage was most favor-
able for patients with oropharyngeal primary cancers. This is a landmark study—the first to demonstrate a survival advantage for targeted therapy in patients with SCCHN.

Thus we see that organ preservation strategies are feasible for treating patients with SCCHN. For appropriately selected patients, combined-modality treatment confers similar, if not greater, survival with surgical approaches, while avoiding extensive resections and maintaining anatomic organ preservation. However, the level of long-term organ function and quality of life are concerns for patients receiving chemoradiation therapy. In particular, treatment-related fibrosis with compromising effects on swallowing and cervical mobility may be problematic after concomitant chemora-

Fig. 3-1 Biologic agents have been studied to assess independent activity, as well as in combination with chemotherapy and radiation therapy. EGFR-targeted agents are the class of drugs in the most advanced stages of clinical development. Major signaling pathways that may be targets for new drugs in development are shown here.
diation, and attempts are underway to better define long-term functional outcomes. For patients with stage III or IV M0 oropharyngeal and hypopharyngeal squamous cell cancers, concomitant chemotherapy and radiation therapy has proved superior to radiation therapy alone, and is considered a standard of care for the treatment of locally advanced disease that is not considered amenable to surgical resection. Single-agent cisplatin administered every 3 weeks, with radiation therapy administered once daily, is the most widely accepted regimen. Biologic agents such as cetuximab are currently being studied for the treatment of this disease as well. Their exact role has not yet been well defined, but the combination of cetuximab and radiation therapy may be a suitable treatment alternative for older patients with intermediate-stage head and neck cancers, or for patients who are not good medical candidates for chemotherapy. Oral cavity and locally advanced laryngeal cancers are more often treated with surgical resection, which is the optimal definitive local therapy.

Concurrent Chemoradiation as Adjuvant Therapy

Adjuvant chemotherapy after definitive surgery is a treatment strategy used for many types of cancer, with the goal of eradicating micrometastatic disease and ultimately improving long-term survival. In head and neck cancer, adjuvant chemotherapy as a single modality treatment is still not widely accepted, because previous trials have shown difficulty completing the treatment plan, and there has not been demonstrated efficacy. In the Head and Neck Intergroup study, a large multiinstitutional trial was conducted to test whether the addition of chemotherapy to surgery and radiation therapy prolonged survival time or altered the pattern of recurrence. Eligible patients had stage III or IV squamous cell carcinoma of the oral cavity, oropharynx, or larynx, or stage II, III, or IV squamous cell carcinoma of the hypopharynx with negative pathologic margins of resection. Patients were randomized to immediate postoperative radiation therapy or three cycles of cisplatin plus 5-fluorouracil chemotherapy followed by radiation therapy. An analysis of the 503 patients in the study has shown no significant difference in disease-free survival time, overall survival time, and local and regional control. However, there was a significantly lower rate of distant metastases as a site of failure ($p = 0.016$) at any time for patients treated with adjuvant chemotherapy. Perhaps more important was the finding that a high-risk subset of patients (those with extracapsular extension, carcinoma in situ, or close surgical margins) appeared to benefit from adjuvant chemotherapy, with increased survival time and local control that approached statistical confidence compared with those receiving radiation alone.

Two trials testing induction chemotherapy added maintenance chemotherapy to one treatment group and observed differences in outcome. The Head and Neck Contracts program trial of one course of cisplatin and bleomycin induction chemotherapy before surgery and radiation included 6 months of maintenance chemotherapy in one of the three treatment arms. There was a significant decrease in the distant metastatic rate observed for those patients. Ervin et al. randomly assigned patients showing a response to cisplatin, bleomycin, and methotrexate induction chemotherapy to receive three additional cycles or observation after definitive surgery and ra-
Radiation therapy. The 3-year disease-free survival rate for patients receiving maintenance chemotherapy was 88% compared with 57% for control subjects \((p = 0.03)\). In a phase II pilot study, Johnson et al.\(^{29}\) treated 42 patients with extracapsular spread of tumor in cervical lymph node metastases with 6 months of methotrexate and 5-fluorouracil after resection and radiation therapy. The 2-year disease-free survival rate was 66%, which was improved from an expected control rate of 38% based on historical experience.

Considered together, the results of these trials indicate that adjuvant chemotherapy can affect micrometastatic disease and decrease the rate of distant recurrence. The data also suggest that disease-free survival time may be improved. The major impediment to successfully conducting adjuvant or maintenance chemotherapy trials in patients with head and neck cancer is patient noncompliance and physician fatigue. The morbidity of the primary treatment, combined with the medical and social situations of many patients, makes classical adjuvant chemotherapy difficult or sometimes not feasible. In addition, there appears to be no role for adjuvant chemotherapy in low-risk patients, although high-risk patients may benefit. However, these aspects remain to be further clarified in definitive randomized phase III trials.

More recently, prospective studies conducted in the United States\(^{30}\) and Europe\(^{31}\) testing the value of concomitant cisplatin and radiation therapy for high-risk postoperative patients have demonstrated improved local tumor control and overall survival in patients with resected tumor margin involvement and/or nodal extracapsular spread.\(^{32}\) Although the study entry criteria were slightly different for these two studies, patients were randomized to radiation therapy alone or combined treatment. Acute mucocutaneous side effects were heightened in the combined modality arm but chronic toxicity was not reported to be elevated. There was an overall 42% reduction in the risk of local disease recurrence that appeared to account for the benefit. Thus, for surgical patients with the selection factors indicated previously, postoperative concomitant drug and radiation therapy is now considered a standard of care.

**Induction Chemotherapy**

Theoretically, treatment with chemotherapy before surgery or radiation—known as induction chemotherapy—has several advantages. Initial treatment with chemotherapy is feasible. Patients are not debilitated secondary to surgery or radiation therapy. Clearly the drug activity is optimal in previously untreated patients, probably because there is no previous disruption of normal vascularity. Effective systemic therapy induces primary and nodal disease response in a high percentage of patients and, further, there may be a systemic effect with a reduced risk of distant disease recurrence.\(^{33}\)

With the introduction of cisplatin into clinical trials in the mid-1970s, combination therapy was developed with cisplatin and other agents (bleomycin, vinblastine, vincristine, or methotrexate) to form two-drug regimens with similar results.\(^{34}\) An alter-
The results of randomized controlled trials of induction chemotherapy before surgery, radiation therapy, or both have been published. The Head and Neck Contracts program, \textsuperscript{27} the Southwest Oncology Group (SWOG) trial, \textsuperscript{43} and the Veterans Affairs Laryngeal Cancer Study Group trial\textsuperscript{3} were large multiinstitutional randomized studies. The patients had advanced, resectable head and neck cancer, and the treatment arms were well balanced to TN stage and primary site. The Head and Neck Contracts program randomly assigned patients to receive one of three treatments:

1. Surgery followed by radiation
2. Induction chemotherapy with one cycle of cisplatin plus bleomycin followed by surgery and radiation
3. Induction chemotherapy, surgery, radiation, and maintenance chemotherapy with cisplatin for 6 months

The 5-year survival rates for the three regimens were 35\%, 37\%, and 45\%, respectively; the differences were not statistically significant. However, the time to development of distant metastases and the frequency of distant metastases as a site of first recurrence were significantly less in patients in the maintenance chemotherapy arm compared with the other two groups. On analysis of subgroups, there was also a sig-
significant difference in disease-free survival time for patients receiving maintenance chemotherapy for oral cavity primary tumors and for N1 or N2 disease. In retrospect, it is not surprising that this trial did not show improvement in overall survival time, because only one cycle of cisplatin and bleomycin was administered before surgery, resulting in a modest response rate of 37%.

In the SWOG trial, patients were randomly assigned to receive either three cycles of cisplatin, bleomycin, methotrexate, and vincristine before surgery and radiation therapy, or standard treatment with surgery and radiation therapy. The median survival time was 30 months for patients in the standard treatment arm compared with 18 months for the induction chemotherapy arm. The distant metastatic rate was 49% with standard treatment and 28% with induction chemotherapy. Although differences in survival time and pattern of recurrence are striking, statistical significance was not reached. This trial fell short of its accrual goals and had a high rate of noncompliance, with only 56% of patients assigned to induction chemotherapy completing the treatment per protocol.

Domenge et al have reported a phase III trial in which 318 patients with locally advanced oropharyngeal squamous cell cancers were randomly assigned to receive induction chemotherapy with cisplatin and 5-fluorouracil followed by locoregional treatment or locoregional therapy alone. Overall survival was better in the chemotherapy group (median 5.1 versus 3.3 years; \( p = 0.03 \)).

The Veterans Affairs Laryngeal Cancer Study Group completed a randomized trial in patients with resectable stage III and IV squamous cell cancer of the larynx. Patients were randomly assigned to receive standard therapy with total laryngectomy and postoperative radiation therapy or to receive a maximum of three cycles of cisplatin and 5-fluorouracil chemotherapy followed by radiation therapy. Surgery was reserved for patients requiring salvage from persistent or recurrent disease. If patients did not have at least a partial response at the primary site after two cycles of chemotherapy, they underwent immediate surgery. The complete and partial response rate after two cycles of chemotherapy was 85%. The pathologically confirmed complete response rate at the primary site was 64%. At a median follow-up period of 33 months, there was no significant difference in survival time. However, the patterns of relapse differed: recurrence at the primary site was 2% with surgery versus 12% with chemotherapy (\( p = 0.0005 \)); regional node recurrence rates were similar (\( p = 0.305 \)); distant metastases were 17% with surgery versus 11% with chemotherapy (\( p = 0.016 \)); and the rate of second primary malignancies was 6% with surgery versus 2% with chemotherapy (\( p = 0.029 \)). After 3 years of follow-up, 66% of surviving patients in the induction chemotherapy treatment group had a preserved, functional larynx. Similar results were reported by the European Organization for Research and Treatment of Cancer (EORTC) comparing cisplatin and 5-fluorouracil induction chemotherapy followed by radiation therapy to laryngopharyngectomy and radiation in patients with locally advanced cancer of the hy-
popharynx. No survival time differences were observed, and 28% of the chemotherapy patients were alive with a functional larynx. The larynx preservation rate was 42% at 3 years, considering only deaths from local disease as failure.4

In a follow-up to the Veterans Affairs study, the Head and Neck Intergroup conducted a prospective three-arm study comparing induction chemotherapy with cisplatin and 5-fluorouracil followed by radiation therapy, radiation therapy alone, and radiation therapy with concomitant cisplatin.6,7 For entry, patients had stage III/IV disease, but T1 and advanced T4 lesions conferred ineligibility. Tumors infiltrating more than 1 cm into the tongue base or the demonstration of thyroid cartilage destruction were not allowed in the study. Of the 547 patients in the study, 65% had stage III disease. Two thirds of the patients had supraglottic primary sites. No unexpected toxicity was observed. With no difference in overall survival, the concomitant treatment arm resulted in superior larynx preservation of 88% compared with 74% resulting from sequential chemotherapy and radiation, and 69% with radiation therapy alone. Notably, patients with destructive T4 primary tumors were excluded from this study. Long-term outcomes providing data on quality of life and function are needed.

Two trials showed an improvement in survival time for chemotherapy-treated patients after subset analysis. In a large Italian study, Paccagnella et al46 observed an improvement in local control, metastatic rate, and survival time for inoperable patients. In a follow-up study to the Head and Neck Contracts program, Jacobs et al47 reported an improvement in survival time for the subgroup with oral cavity primary cancer and limited nodal disease. Regarding patterns of failure, multiple trials showed a decrease in the rate of distant metastasis.4,33,43,46,47

These trials have helped to clarify many issues. First, the overall response rates range from 60% to 90%, with clinical complete response rates of 20% to 50%. Survival time is improved in patients with a complete response compared with nonresponders, and pathologic complete response (confirmed by biopsy or resection, with no residual tumor) can be seen in about 30% of patients with a complete response. Second, a response to chemotherapy may be used to predict a response to radiation therapy. Patients who fail to respond to chemotherapy do not respond well to radiation therapy. Third, neoadjuvant chemotherapy increases neither surgical nor radiation therapy complication rates. Fourth, the most critical prognostic factors for response are TN stage and type of chemotherapy. Biologic behavior appears to differ per site. Fifth, although no benefit in overall survival time has yet been shown, a significant reduction in the rate of distant metastases has been observed. Finally, organ preservation and improved quality of life can result with induction chemotherapy. For patients with advanced laryngeal cancer who would require a total laryngectomy, the available data indicate that laryngeal function can be preserved in two thirds of patients without jeopardizing survival time.
There has been increased interest in the study of induction chemotherapy from the development of potentially more effective three-drug combinations (Fig. 3-2). This represents an attempt to improve the cisplatin and infusional fluorouracil regimen. Hitt et al. compared cisplatin and fluorouracil with a three-drug combination of paclitaxel, cisplatin, and a modified dose of fluorouracil (PCF). Responses were significantly better in the experimental program (33% complete response versus 14%), without an overall increase in acute toxicity. Indeed, mucositis seemed lessened with the modified fluorouracil dose. Grades 2 to 4 mucositis affected 16% of patients who received PCF compared with 53% of patients treated with cisplatin and fluorouracil. Significant peripheral neuropathy occurred in 8% of patients who received PCF. Following induction chemotherapy, patients received concomitant chemoradiation with cisplatin (100 mg/m²) administered on days 1, 22, and 43. Patients who received the three-drug combination showed a trend to longer overall survival (p = 0.06); however, the subset of patients whose disease was defined as unresectable had a more clear benefit (p = 0.004).

More recent studies have generated considerable excitement. A 358-patient phase III EORTC study compared cisplatin and fluorouracil with docetaxel, cisplatin, and 5-fluorouracil (TPF). After induction chemotherapy, all patients received radiation therapy administered as a single modality. With a median follow-up of 32 months, TPF produced superior tumor responses, with a significant progression-free survival advantage with a hazard ratio of 0.72 and an overall survival hazard ratio of 73. Also, more toxic deaths (5.5% versus 2.3%) were observed in the cisplatin

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**Table 3-2** Selected induction taxane trials. *cbdca*, Carboplatin; *CR*, complete response; *CT*, chemotherapy; *HR*, hazard ratio; *OS*, overall survival; *PF*, cisplatin and fluorouracil; *PFS*, progression-free survival; *PPF*, paclitaxel, cisplatin, and fluorouracil; *R*, randomized; *RT*, radiation therapy; *SCC*, squamous cell carcinoma; *TPF*, docetaxel, cisplatin, and fluorouracil.
and fluorouracil arm. In the TAX 324 phase III trial, patients were randomly assigned to receive either induction chemotherapy with docetaxel (75 mg/m²), cisplatin (100 mg/m²), and continuously infused fluorouracil (1000 mg/m²/d) for 4 days, or the standard cisplatin and fluorouracil schedule. Three treatment cycles were administered before patients underwent an examination under anesthesia followed by chemoradiation with weekly carboplatin area under the curve 1.5. Following this, a fraction of patients underwent surgery for residual disease, or if there was advanced node involvement, at diagnosis. There appeared to be a significant disease-free and overall survival advantage for patients receiving TPF. With a hazard ratio of 0.70, 62% of patients who received TPF were alive at 36 months compared with 48% of patients who received standard cisplatin and fluorouracil. The analysis of the site of treatment failure is also of note. There was an unexpected, but statistically significant difference with respect to locoregional disease control favoring the TPF group, as well as a more modest reduction in the distant metastasis rate with the addition of the third drug (Table 3-3).

### Table 3-3  TAX 324: Analysis of Failure

<table>
<thead>
<tr>
<th></th>
<th>TPF (n = 255)</th>
<th>PF (n = 246)</th>
<th>N = 501</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failures/treated</td>
<td>88 (35%)</td>
<td>110 (45%)</td>
<td>198 (40%)</td>
</tr>
<tr>
<td>LRF*</td>
<td>77 (30%)</td>
<td>93 (38%)</td>
<td>170 (34%)</td>
</tr>
<tr>
<td>Primary</td>
<td>43 (17%)</td>
<td>49 (20%)</td>
<td>92 (19%)</td>
</tr>
<tr>
<td>Neck</td>
<td>22 (9%)</td>
<td>33 (13%)</td>
<td>55 (11%)</td>
</tr>
<tr>
<td>Both</td>
<td>12 (5%)</td>
<td>11 (4%)</td>
<td>23 (5%)</td>
</tr>
<tr>
<td>Distant metastases†</td>
<td>14 (5%)</td>
<td>21 (9%)</td>
<td>35 (7%)</td>
</tr>
<tr>
<td>Distant only</td>
<td>11 (4%)</td>
<td>17 (7%)</td>
<td>28 (6%)</td>
</tr>
<tr>
<td>Distant and LRF</td>
<td>3 (1%)</td>
<td>4 (2%)</td>
<td>7 (1%)</td>
</tr>
<tr>
<td>Second primaries</td>
<td>9 (4%)</td>
<td>10 (4%)</td>
<td>16 (3%)</td>
</tr>
</tbody>
</table>

*Hazard ratio 0.73 (0.54-0.99), p = 0.04.
†Hazard ratio 0.60 (0.30-1.18), p = 0.14.
LRF, Locoregional failure; F, fluorouracil; P, cisplatin; T, docetaxel.

Previous experience with induction chemotherapy has not led to a consensus regarding overall benefit. There is a potential for added chemotherapy toxicity and a delay or compromise in definitive local therapy. However, the data from recent trials are promising, and we strongly support ongoing randomized studies designed to more precisely define the value of induction chemotherapy in patients with locally advanced disease who are to proceed to concomitant chemoradiation. Two such trials are currently accruing patients in North America, both testing docetaxel, cisplatin, and fluorouracil followed by concomitant chemoradiation therapy. Survival is
the primary endpoint. These studies are summarized in Table 3-4. We anticipate that future phase I and II studies will investigate innovative and novel systemic therapy programs with integration of molecularly targeted agents. We can look forward to a day when individual patient characteristics, tumor site and stage, and tumor biologic markers will prompt individualized therapy based on validated selection factors.

### Table 3-4 Randomized Induction Chemotherapy Trials in SCCHN

<table>
<thead>
<tr>
<th>Group</th>
<th>Stages</th>
<th>Sites</th>
<th>Induction Regimen</th>
<th>Concurrent Regimen</th>
<th>Survival Endpoint</th>
<th>Targeted Improvement</th>
<th>Accrual Goal (number of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Chicago</td>
<td>N 2-3</td>
<td>All</td>
<td>DPF × 2</td>
<td>DFHX</td>
<td>3 years</td>
<td>50%-65%</td>
<td>400</td>
</tr>
<tr>
<td>Dana-Farber Cancer Institute</td>
<td>III-IV</td>
<td>All</td>
<td>DPF × 3</td>
<td>Various</td>
<td>3 years</td>
<td>55%-70%</td>
<td>300</td>
</tr>
</tbody>
</table>

*D, Docetaxel; F, fluorouracil; H, hydroxyurea; P, cisplatin; X, hyperfractionated radiation administered on alternate weeks.*

Induction chemotherapy is highly active, with tumor responses observed in a high percentage of patients. TPF is the current model for further testing. The induction strategy has been shown to reduce the risk of distant metastases but also represents a vehicle for the evaluation of other clinical molecular endpoints. The development of increasingly effective induction chemotherapy may eventually affect the efficacy of radiation therapy, with an improvement in local disease control. We await the results of ongoing randomized trials before we accept induction chemotherapy as a standard treatment, and to better identify the subgroups of patients who may be most likely to benefit from this approach.

### Systemic Chemotherapy for Recurrent or Metastatic Disease

Systemic management of recurrent head and neck cancer is a major concern, because 30% to 50% of patients diagnosed will eventually die with recurrent local and regional disease within 5 years. Distant metastases may be clinically present in about one third of patients with recurrent disease, but occult disease determined at autopsy may be present in up to 60%. The primary goal of conventional chemotherapy used for palliation should be to prolong survival time. Patients with locally advanced or disseminated recurrent SCCHN have a median survival time of 6 to 9 months, and 20% survive 1 year. Patients achieving a substantial response to chemotherapy have improved symptom control and overall survival.

Active chemotherapeutic agents for SCCHN include the platinum compounds (cisplatin and carboplatin), taxanes (docetaxel and paclitaxel), 5FU, and methotrexate. Response rates with two drug combinations range from 20% to 40%, but with the
duration of response tending to be brief (usually 3 to 4 months) and with no clearly significant improved overall survival compared with single agents.52

**Targeted Therapy**

The histologic prognostic factors for head and neck cancer are the presence of locoregional metastasis, vascular or lymphatic invasion, positive surgical margins, and extracapsular spread of tumor cells from involved lymph nodes into soft tissues of the neck. There is a major effort to identify molecular signatures and to better understand mechanisms of tumor progression,53 because this may facilitate the identification of more precise biomarkers and vulnerable therapeutic targets.

Metastatic progression of tumor cells is a multistep and complicated process.54 Each step appears to involve interdependent molecular interactions among tumor cells and between tumor cells and the surrounding microenvironment. Multilayered systems are under study with genomic and proteomic techniques. Moreover, the fairly recent recognition of human papillomavirus (HPV) as an etiologic factor confers a potentially favorable prognostic factor for an estimated 50% to 60% of patients with oropharynx cancers.53 See Fig. 3-1 for potential molecular targets. DNA microarray and other techniques posit multiple potential factors affecting metastatic potential55–57: keratins, cell-surface proteases, mesenchymal cell markers, cell-matrix adhesion molecules, chemokines, and modulating elements for the extracellular matrix and epithelial-to-mesenchymal transition.56 Chemokine (C-X-C motif) receptor (CXCR4) and its ligand, stromal cell–derived factor (SDF-1), may combine to direct primary tumor cells to metastatic sites.57 This activity may be crucial in the evolution of metastatic patterns and relate to enhanced secretion of angiogenic factors, such as vascular endothelial growth factors (VEGFs), and surface receptor concentration. Fig. 3-353 provides a model of genetic instability and tumor progression in SCCHN.

![Fig. 3-3 Model of genetic instability and tumor progression in SCCHN.](image-url)
Antiangiogenic compounds target VEGF, platelet-derived growth factor (PDGF), fibroblast growth factor (FGF), transforming growth factors alpha and beta (TGF-alpha and TGF-beta), and interleukin-8, along with the receptors of these proteins. Phase I and II trials have been launched to examine VEGF inhibitors, either as single agents or in combination with chemotherapeutic agents, for SCCHN. We have observed tumor responses in 25% of patients receiving cetuximab and bevacizumab in a phase II inter-SPORE project with no significant hemorrhagic toxicity as yet.

EGFR is overexpressed in SCCHN. The development of monoclonal antibodies and small-molecule tyrosine kinase inhibitors has led to inhibition of EGFR signaling and associated molecular networks. EGFR consists of four family members, of which EGFR (HER1) and HER2 are the best characterized. Ligands for EGFR are epidermal growth factor (EGF), TGF-alpha, amphiregulin, epieregulin, betacellulin, and heparin-binding EGF-like growth factor (HB-EGF). HER2 has no known natural ligands. After binding EGFR, dimerization obtains and activates subsequent phosphorylation of tyrosine kinases, downstream signaling mediators, and ultimately cellular proliferation. Nuclear translocation of EGFR and other growth factor receptors is important for signaling in rapidly growing cells, and the activity is largely abrogated by treatment with cetuximab, which also strongly inhibits phosphorylation of EGFR. EGFR and the ligands EGF and TGF-alpha are overexpressed in SCCHN and linked to a poor prognosis after treatment. For these reasons, EGFR is a target for experimental therapeutics.

Chimeric and humanized IgG antibodies target the extracellular domain of EGFR epitopes and have been shown to prevent EGFR signaling. Antibodies have been shown to have single-agent antitumor activity. Small-molecule EGFR tyrosine kinase inhibitors, such as gefitinib and erlotinib, bind within the intracellular domain to inhibit kinase activity, thus modulating transcription, cell-cycle progression, cell survival, and motility, all of which facilitate invasiveness and metastasis. In early clinical trials, these agents have been shown to have independent activity, with response rates from 5% to 15%, depending on the dose and schedule.

Most recently, there have been efforts to identify targeting agents that exploit tumor cell vulnerabilities. Cetuximab is a chimeric monoclonal antibody directed against the EGFR and has been found to be an active agent in SCCHN when used as a single compound or in combination with cisplatin or radiation therapy. In an important phase III trial, 117 patients with metastatic or recurrent SCCHN were randomized to receive cisplatin as a single agent or in combination with cetuximab. The addition of cetuximab improved the overall response rate from 10% to 26% (\( p = 0.03 \)) and median survival from 2.7 to 4.2 months. These data suggested more benefit associated with the combination than with single-agent cisplatin.

In a landmark prospective phase III trial, Vermorken et al randomly assigned 442 eligible patients with untreated recurrent or metastatic squamous cell carcinoma to receive a platin/fluorouracil regimen with or without cetuximab. Significant pro-
longation of overall survival from 7.4 months to 10.1 months was seen in the group of patients receiving cetuximab ($p = 0.04$). The addition of cetuximab prolonged median progression-free survival from 3.3 to 5.6 months ($p <0.001$) and increased the response rate from 20% to 36%. There was no crossover treatment. This study marks the potential for targeted systemic drug therapy to have an impact on survival, and to be a component of treatment for patients with metastatic disease.

**CONCLUSION**

Tumors of various histologic types occur in the head and neck. Excluding thyroid malignancies, approximately 80% are squamous cell carcinomas. Data evaluating the impact of chemotherapy on survival time, particularly for combined modality treatments, are limited to this common histologic type for which patient numbers are available for randomized comparative trials. Phase I, II, and III studies in patients with locally recurrent or metastatic disease have shown that chemotherapy can produce response rates of 30% to 40%, and combination chemotherapy is more effective than single agents. However, responses historically have tended to be brief (2 to 4 months) and may not be associated with longer survival time. The addition of cetuximab to cytotoxic chemotherapy may augment efficacy. Nonetheless, chemotherapy for these patients is palliative. Exceptions to this are patients with tumors of the nasopharynx who have higher response rates, and a small proportion of long-term, disease-free survivors. Prognostic factors have been identified that should be used by physicians to select patients most likely to benefit from palliative treatment.

In newly diagnosed patients with locally advanced disease, high response rates have been achieved with induction chemotherapy, which remains under study. An important role for chemotherapy may be to preserve organ anatomy and function at selected sites. Multicenter randomized trials have been conducted that show preservation of the larynx in a large percentage of patients receiving either sequential or concomitant chemotherapy and radiation. Chemotherapy administered concurrently with radiation therapy has improved local control and survival over radiation therapy as a single modality in select series of patients with SCCHN who were not considered candidates for surgery. The increase in toxicity associated with chemoradiation therapy should be carefully considered when selecting patients for combined treatment. The concomitant administration of cetuximab and radiation therapy shows promise for advancing nonsurgical therapy without an apparent increase in severe-grade toxicity.

Patients with early-stage disease (that is, stage I or II) should receive conventional therapy with surgery, radiation therapy, or both. Patients with stage III or IV disease can be separated into two groups: those for whom surgical resection is indicated and those for whom it is not. Patients with disease that is not to be resected should often be treated with chemotherapy and radiation or entered into a combined chemoradiation treatment protocol. Those with stage III disease may also benefit from combination treatment as part of a clinical trial. The optimal treatment strategy, either concomitant chemoradiation therapy or possibly sequential induction chemotherapy
followed by radiation therapy (with or without drug-sensitizing treatment), depends on the site and disease stage, and ongoing trials. Patients with metastatic disease should receive chemotherapy with palliative intent if performance status is favorable. Patients with resectable disease can be further divided into subgroups by site. Those with advanced primary oral cavity tumors are best served by surgery followed by radiation therapy, whereas patients with oropharyngeal, hypopharyngeal, or laryngeal tumors are often treated with radiation, with or without chemotherapy, depending on the precise site and stage. Many patients with hypopharyngeal cancers and T4 cancers of the larynx should be considered for possible laryngectomy. Chemoprevention will continue to be an important area of research in the coming decade. Multiple new strategies are to be considered for further testing.

The management of head and neck cancer is multidisciplinary. The identification of effective targeted and chemotherapeutic agents and their integration into the initial curative therapy of head and neck cancer has the potential to improve survival time and preserve organ function. The impact of HPV on the natural history of oropharyngeal cancers and the response to treatment are under study. Through well-designed and well-executed clinical trials, coupled with basic research of the biology of upper aerodigestive tract tumors, further advances in the management and prevention of these cancers can be achieved.

**CRITICAL POINTS**

**Must Know**
- Chemotherapy alone has no curative role for treating head and neck cancer.
- Chemotherapy as an adjuvant treatment may help improve local disease control or treat metastatic disease.

**Should Know**
- Chemotherapy can be used as an induction treatment, as a concomitant treatment, or as an adjuvant treatment.
- Biologic agents that target specific molecular pathways are currently under investigation.

**Synopsis**
- Chemotherapy has an adjuvant role in the treatment of head and neck cancers.
- Chemotherapy either alone or in combination with radiation therapy may improve local disease control, but these combinations significantly increase toxic side effects.
- The development of agents that target molecular pathways will likely lead to increased use of chemotherapeutic agents to treat head and neck cancers.
References


   This study compared radiation therapy alone against radiation therapy plus cetuximab for treating locoregionally advanced squamous-cell carcinoma of the head and neck. The authors conclude that treatment with concomitant high-dose radiation therapy plus cetuximab improves locoregional control and reduces mortality without increasing the common toxic effects associated with radiation therapy to the head and neck.


   Patients in this study were randomly assigned to receive either three cycles of chemotherapy (cisplatin and fluorouracil) and radiation therapy or surgery and radiation therapy. Preliminary results suggest a new role for chemotherapy in patients with advanced laryngeal cancer and indicate that a treatment strategy involving induction chemotherapy and definitive radiation therapy can be effective in preserving the larynx without compromising overall survival.


   For this study, patients with locally advanced cancer of the larynx were randomly assigned to one of three groups. After 2 years, the proportion of patients who had an intact larynx after radiation therapy with concurrent cisplatin (88 percent) differed significantly from the proportions in the groups given induction chemotherapy followed by radiation therapy (75 percent) or radiation therapy alone (70 percent). The rate of locoregional control was also significantly better with radiation therapy and concurrent cisplatin. However, overall survival rates were similar in all three groups. The authors conclude that, for patients with laryngeal cancer, radiation therapy with concurrent administration of cisplatin is superior to induction chemotherapy followed by radiation therapy or radiation therapy alone for laryngeal preservation and locoregional control.


   The authors discuss the concomitant use of chemotherapy and radiation, which has proven to be more consistently successful than radiation therapy alone, and it produces both locoregional control and survival benefits. Large group studies have established high-dose single-agent cisplatin and concurrent radiation therapy as the standard of care for select patients. This same treatment regimen also has been demonstrated to be the most effective multimodality strategy for larynx preservation.


The authors use the example of head and neck cancer to show how concurrent chemoradiation therapy is used to treat a cancer where locoregional control is central for treatment success. Although single-agent cisplatin-based chemoradiation therapy is still widely used as a standard therapy, the authors suggest that multiagent-based chemoradiation therapy and EGFR-inhibitor-based treatments offer distinct advantages. They provide guidance, based on clinical trial evidence, on how to choose appropriate treatment platforms for patients.


Head and neck cancer is the sixth most common cancer worldwide. Squamous cell carcinoma, by far the most common head and neck malignancy, has an annual incidence rate of 17 per 100,000 in the United States and accounts for more than 10,000 deaths each year.\(^1\) Although nonsurgical therapies such as radiation and chemoradiation have emerged as attractive methods of functional organ preservation, the surgical management of head and neck cancer remains vital, driven and
supported by advances in microsurgical reconstruction. Surgery, with or without adjuvant therapy, is the primary modality for treating oral cavity cancers, nasal and paranasal sinus neoplasms, and skull base malignancies. Surgery is also frequently used as salvage therapy in oropharyngeal, laryngeal, and hypopharyngeal cancers. Comprehensive surgical management involves addressing the primary site and the cervical lymph nodes at risk.

The goal of surgical management for head and neck cancers is to completely extirpate the cancer while attempting to reduce morbidity. Minimizing treatment-related morbidity is especially pertinent in head and neck cancer management, because treatments can interfere with speech, swallowing, cosmesis, and quality of life. Free tissue transfer has been a significant advance in the surgical management of these patients, allowing reconstruction of form and function.

For most head and neck subsites, the exact treatment modality and surgical approach depends on the size of the primary tumor, the proximity to vital structures, the involvement of cervical lymph nodes, and the presence of distant metastases.

**Approaches to the Oral Cavity and Mandible**

- Transoral approach
- Combined transoral/transcervical approach (lingual release)
- Degloving approaches
- Transmandibular approach (mandibulotomy)

Surgery remains the primary therapeutic modality for tumors of the oral cavity. Reconstructive techniques are often required to restore form and function, including maintenance of the airway, mastication, swallowing, and speech. Oral cavity is a general term that encompasses the buccal mucosa, the floor of the mouth, the hard palate, the retromolar trigone, the anterior two thirds of the tongue, and the upper and lower gingiva (alveolar processes) when tumor location is considered. The choice of surgical approach depends on the tumor size, subsite, depth of invasion, proximity to the maxilla or mandible, and the need for concomitant neck dissection and reconstruction. In general, the best approach is one that provides excellent exposure for tumor resection with adequate margins and allows the reconstruction method of choice while minimizing functional impairment.

**Transoral Approach**

The transoral approach is reserved for limited lesions of the oral cavity that do not significantly invade or erode bone and are not obscured from view by being in a significantly posterior or inferior position. The most appropriate lesions are small, early primaries (T1 and limited T2) of the buccal mucosa, floor of the mouth, anterior tongue, hard palate, or gingiva2 (Fig. 4-1). This approach can be combined with ip-
silateral or bilateral neck dissections when appropriate. Care must be taken when a neck dissection accompanies a floor-of-the-mouth resection, because occult orocervical fistula formation is common. Lesions of the buccal mucosa or floor of the mouth that overlie salivary duct papillae must also be noted. Excision in these areas should be accompanied by sialodochoplasty, unless the gland in question is to be excised.

**Fig. 4-1**  Transoral resection of an oral squamous cell carcinoma of the tongue. A, Preoperatively, the mobile tongue was easily grasped with a silk suture to facilitate resection. B, The resected tumor. C, The wounds were left open to close by secondary intention. Alternatively, they could have been closed primarily.

**Combined Transoral/Transcervical Approach**

(Lingual Release)

The combined transoral/transcervical approach involves releasing the contents of the oral cavity from their mandibular attachments, facilitating relocation beneath the mandible and into the neck. The lingual release allows removal of larger tumors (T1 to T3) of the oral tongue and/or floor of the mouth that are not completely accessible through a transoral approach while avoiding facial incisions and preserving
lower lip sensation. The approach requires a transcervical exposure of the inferior border of the mandible. Subsequently, an incision is created in the floor of the mouth, beginning at the inferior extent of one anterior tonsillar pillar (palatoglossal fold) and extending in a circumferential fashion to the opposite pillar. The incision can be created along the lingual gingiva, staying close to the mandibular arch, and can even include periosteum if the lesion extends significantly toward the lingual surface of the mandible. Once the oral contents are brought into the neck, direct visualization and bimanual palpation allow resection of lesions with adequate margins (Fig. 4-2). Structures at risk of injury with this approach include the lingual arteries and nerves and the hypoglossal nerves. Although lip sensation is typically preserved, floor-of-the-mouth and tongue hypesthesia often result.

Degloving Approaches

Degloving approaches are best suited for tumors that approximate or directly invade bone. In the oral cavity, this approach is most often used to gain exposure to the mandible for marginal or segmental mandibulectomy, although extended cheek flaps and midfacial degloving approaches can provide excellent exposure for tumors of the hard palate, retromolar trigone, and buccal mucosa. For mandibular exposure, the degloving approach begins with a standard transcervical approach. The incision begins at the ipsilateral mastoid tip and is brought to the midline in a curvilinear fashion. At the midline, the incision can be extended superiorly in the vertical plane, up to and including the vermilion of the lower lip if necessary to improve exposure (lip-splitting technique). When exposure of the entire mandible is required, the in-
cision is extended across the midline to the contralateral mastoid, an approach referred to as a *visor flap*. The superior neck flap is raised in the standard subplatysmal plane. The marginal mandibular nerve is identified and protected, and the flap is reflected over the inferior border of the mandible. Once the masseter muscle is exposed, the incision is carried down to the periosteum, and the periosteum and masseter are reflected off the mandible. In cases with extension through the mandible, the skin flap is reflected off the tumor to provide an adequate lateral margin. Occasionally, skin sacrifice is necessary. Segmental mandibular resection can then be accomplished with this approach. Once the osteotomies are created, the segment of bone in continuity with the oral cavity contents can be lowered into the neck to facilitate exposure for the oral mucosal cuts (Fig. 4-3). The main drawback to the degloving approaches is the division of one or both mental nerves.

**Fig. 4-3** The degloving technique for oral cavity tumor resection. A, The lesion was in the floor of the mouth and extended anteriorly to invade the mandible. The tumor required segmental mandibular resection. B, The patient’s lower lip was split in the midline to facilitate and improve exposure. C, The tumor extended from the anterior root of the tongue to the lingual aspect of the mandible.
Transmandibular Approach (Mandibulotomy)

The mandibulotomy approach, which involves a midline or paramedian mandibulotomy and mandibular swing, facilitates excision of extensive lesions of the tongue or floor of the mouth. This approach is particularly valuable in providing exposure for resection of tumors of the posterior tongue involving the tongue base, which cannot easily be accessed through the previously discussed approaches.\(^4\) Although the mandibulotomy approach is most commonly used in conjunction with a lip-splitting incision, it can also be performed with a degloving approach. The standard cervical incision is carried superiorly in the midline vertical plane through the vermilion border of the lower lip. Often, a Z-plasty is created in the submental area to prevent scar contracture in the area of maximal tension. A midline or paramedian mandibulotomy can be performed, depending on the dentition and/or tumor location. Regardless of the approach chosen, the mandibulotomy should be created between the mental foramina to preserve function. The paramedian or midline mandibulotomy avoids injury to the mental nerve and prevents ischemic necrosis, a complication related to lateral sacrifice of the inferior alveolar artery in the inferior alveolar canal. Before making the mandibular osteotomy, a mandibular reconstruction plate is bent to fit the mandible at the planned site. Placement of the osteotomy between two teeth can devitalize the surrounding teeth, particularly with the midline mandibulotomy. Therefore, in the dentate mandible, dental extraction at the osteotomy site should be considered. Once the osteotomy is performed, the mandible is swung laterally on the side of the lesion. The mucosal cuts can be made around the tumor under direct visualization (Fig. 4-4). When possible, an adequate cuff of mucosa should be preserved along the gingiva on the lingual surface of the mandible to facilitate closure.

![Fig. 4-4](image)

**Fig. 4-4**  The mandibulotomy approach. The mandible and lower lip were divided and swung laterally to expose the left lateral tongue. The left hemitongue was resected. Before creating the osteotomy, a mandibular reconstruction plate was contoured to ensure postoperative occlusion.
APPROACHES TO THE MAXILLA AND MIDFACE

- Internal incisions
  - Transoral/transvestibular approach
  - Midfacial degloving approach
  - Transnasal endoscopic approaches
- External incisions
  - Lateral rhinotomy incision
- Maxillectomy
  - Medial maxillectomy
  - Infrastructure maxillectomy/alveolectomy
  - Anterolateral maxillectomy
  - Subtotal maxillectomy
  - Total maxillectomy with orbital preservation (suprastructure maxillectomy)
  - Total maxillectomy with orbital exenteration

Approaches to tumors of the midface also depend on the tumor size, pathology, and location. Tumors diagnosed in the maxilla are often large and associated with significant bony erosion and extension outside the bony confines of the nose and paranasal sinuses. The proximity of these lesions to the skull base and orbit also represent special functional considerations for surgical planning. The frequent use of radiation (either adjuvant or neoadjuvant) and chemotherapy are important considerations that affect the choice of reconstructive modality. Because bony resection of the maxilla accompanies all tumor resections, the chosen surgical approach must be appropriate for the amount of bone to be resected. Surgical approaches to tumors of the midface and skull base are often described by the incision used and extent of maxillectomy required to gain access and achieve complete tumor removal.

The more extended procedures for midface tumors overlap significantly with approaches to the cranial base. There is no uniform approach to maxillary surgery for resection of benign or malignant tumors. Spiro et al\(^5\) proposed a classification system to standardize reporting of patients following maxillectomy. In general, a limited maxillectomy involves resection of one wall, a subtotal maxillectomy involves two walls, and a total maxillectomy involves all walls of the maxilla. This classification scheme, however, has not been widely used, and many other schemes with minor variations have been proposed.

A number of incisions have been used to facilitate the variety of surgical procedures encompassed by the term maxillectomy. The incision should allow adequate exposure for complete resection while preserving function and cosmesis. The incisions used for a maxillectomy can be simplified by dividing them into internal and external incisions.
Internal Incisions

Transoral/Transvestibular Approach

The transoral/transvestibular approach is commonly used for most unilateral lesions located inferiorly in the maxillary sinus with bony extension through the hard palate. The approach requires significant lip and cheek retraction, combined with a gingivobuccal incision along the mucosa lateral and anterior to the maxilla. The extent of the incision is determined by the tumor size and location. The soft tissues of the cheek can be elevated superiorly, exposing the maxilla laterally and anteriorly to facilitate en bloc tumor extirpation through the mouth.

Midfacial Degloving Approach

The midface degloving approach, described by Casson et al., has been applied to almost all forms of maxillectomy. This approach involves extended sublabial and gingivobuccal incisions, a nasoseptal transfixion incision, and intercartilaginous and piriform aperture incisions. It allows the soft tissue of the midface to be separated from the maxilla and therefore provides excellent bilateral maxillary exposure (Fig. 4-5). The major advantage of this approach is that it avoids any facial incisions; however, it is technically more difficult than the various external transfacial approaches. The circumferential vestibular incision may cause vestibular stenosis and result in a significant functional complication.

Transnasal Endoscopic Approaches

Transnasal endoscopic procedures are rapidly replacing the more classic open approaches for select nasal and sinonasal neoplasms. They allow access to the nasal cavity, maxillary sinus, and anterior skull base. Endoscopic approaches avoid facial incisions and may be combined with either an anterior maxillotomy approach (Caldwell-Luc) or midface degloving approach to provide better access and exposure.

Fig. 4-5  The midface degloving approach. The gingivobuccal, transfixion, intercartilaginous, and piriform aperture incisions provide access to the maxillas bilaterally. The right maxillary antrum was opened laterally, providing exposure to the entire sinus.
External Incisions

Lateral Rhinotomy Incision

The lateral rhinotomy incision is the most basic of the external approaches to the maxilla. All other external incisions are simply extensions of the lateral rhinotomy, which makes use of the basic cosmetic subunits of the nose and face. It involves an incision that is carried around the nasal ala on the ipsilateral side, and superiorly along the nasofacial angle to a point midway between the medial canthus and the dorsum of the nose. This approach provides acceptable exposure for limited resections of the nasal cavity or medial maxilla; however, more comprehensive maxillectomies require greater exposure, which can be accomplished in one of three ways:

- The incision can be extended inferiorly through the lip along the lateral philtrum to allow elevation of a cheek flap, referred to as the Weber-Ferguson incision. Special consideration must be given to the infraorbital nerve at its exit point through the infraorbital foramen. For tumors with significant anterior extension through the face of the maxilla, skin resection is best accomplished with this approach.
- The incision can be extended superiorly to the medial end of the eyebrow (Lynch incision) with division of the medial canthal ligament and nasolacrimal duct. This approach facilitates resection of lesions that abut or invade the orbit from the medial direction (Fig. 4-6).
- The incision can be extended laterally below the lower eyelid and/or above the upper eyelid. This approach should be considered for lesions requiring a total maxillectomy and lesions with orbital invasion that require concomitant orbital exenteration.

Fig. 4-6  The lateral rhinotomy incision with Lynch and Weber-Ferguson extensions. This incision is particularly useful for lesions involving the maxilla, sinuses, orbit, and central skull base.
Maxillectomy
Maxillectomies are classified according to the number of sinus walls to be resected.

Medial Maxillectomy
A medial maxillectomy is classically used to manage lesions of the lateral nasal wall, most commonly inverting papillomas. The medial maxillectomy involves resection of the medial wall of the maxilla with the inferior and middle turbinate, portions of the ethmoid sinuses, and sometimes the lacrimal bones. The goal of medial maxillectomy is removal of the lateral nasal wall from the floor to the ethmoid roof and from the piriform aperture to the plane defined by the most posterior aspect of the maxilla. Although medial maxillectomy is often performed through a lateral rhinotomy approach, a midface degloving or an endoscopic approach may also be used to increase surgical exposure and avoid facial incisions.

Infrastructure Maxillectomy/Alveolectomy
The infrastructure maxillectomy/alveolectomy is used for diseases originating in the oral cavity or those of odontogenic origin. The infrastructure maxillectomy is designed to resect the involved alveolar segment and/or hard palate. Smaller lesions are usually approached transorally through a transvestibular incision, and more extensive pathologies generally require either an extended lateral rhinotomy or a midface degloving approach.

Anterolateral Maxillectomy
The anterolateral maxillectomy is the least common of the limited maxillectomies. This procedure is most often used to manage pathology arising from the facial skin, the parotid gland, or the gingivobuccal sulcus that secondarily invades the face of the maxilla. Surgical access to the anterolateral maxilla is generally accomplished through facial incisions designed to manage the primary location of the tumor. Excellent exposure can be accomplished through either an extended lateral rhinotomy approach with a lip-split or a midface degloving approach, both of which accommodate skin excision when necessary.

Subtotal Maxillectomy
A subtotal maxillectomy involves near complete resection of the maxilla, leaving only the orbital floor (Fig. 4-7). It is generally used for neoplasms arising in the maxillary sinus that do not invade the orbit. Midface degloving or extended lateral rhinotomy approaches are used and provide excellent exposure.
Total Maxillectomy With Orbital Preservation
(Suprastructure Maxillectomy)

When the tumor involves the bony orbital floor, a total maxillectomy is required to provide complete tumor resection (Fig. 4-8). Most surgeons agree that orbital sparing is ideally suited for patients whose periorbita has not been invaded by tumor. With the increasing use of adjuvant cancer therapies and the realization that aggressive orbital exenteration seldom results in a significant survival advantage, a more conservative approach utilizing the orbital-sparing suprastructure maxillectomy is usually recommended. A total maxillectomy is most commonly accomplished using an extended lateral rhinotomy or Weber-Ferguson approach.9
Total Maxillectomy With Orbital Exenteration

A total maxillectomy with orbital exenteration is warranted for patients with obvious gross tumor extension into the orbit (Fig. 4-9). Procedures including orbital exenteration are generally subdivided into two subgroups: those requiring eyelid resection and those that spare the eyelid. An extended lateral rhinotomy is commonly used, combined with a supraorbital extension and either upper and lower lid incisions or transconjunctival incisions, depending on the surgical plan for the eyelids.

Fig. 4-9

Approaches to the Cranial Base

- Anterior skull base approaches
  - Transcranial approach
  - Subcranial approach
  - Combination procedures for skull base resection
  - Transnasal endoscopic approaches
- Lateral skull base approaches
  - Infratemporal fossa approaches
  - Transtemporal approaches

Surgical access to the cranial base can be gained through a wide variety of procedures and approaches, many combining craniotomy, craniofacial, transfacial, and transnasal endoscopic techniques. The exact approach chosen depends on the tumor location, dimensions, extent of the skull base and vital structure involvement,
and inferolateral extension into the paranasal sinuses and infratemporal and pterygopalatine fossae. In most cases, the involvement of a neurosurgeon is essential. Similar to approaches to the oral cavity and midface, approaches to the skull base must include access to the tumor that allows complete removal while minimizing functional and cosmetic morbidity. Dural resection is frequently required with skull base surgery; therefore the approach must factor in dural reconstruction, which is a crucial element to prevent postoperative complications such as meningitis, cerebrospinal fluid leak, and pneumocephalus. The numerous approaches to the skull base and their complexities preclude in-depth discussion in this chapter. Therefore the main approaches are highlighted with their indications.

**Approaches to the Anterior Skull Base**

**Transcranial Approach**

The transcranial approach makes use of a traditional frontal craniotomy and affords access to superiorly based sinonasal and skull base pathology entirely from above. This “craniotomy alone” technique involves a bicoronal scalp incision, a frontal craniotomy, and retraction of one or both frontal lobes (Fig. 4-10). Access can be gained to lesions high in the ethmoid complex that do not extend below the middle meatus, as well as frontal or olfactory cleft lesions with extension into the ethmoids. Entry into the sinuses can be gained laterally through the orbit in cases with ethmoid extension. The transcranial technique also allows excellent exposure for pathology with significant intracranial extension, without facial incisions. However, this approach can involve substantial brain retraction and routinely requires sacrifice of the olfactory nerves. It is inappropriate for lesions with inferior or lateral extension into the nasal cavity or maxillary sinuses.

**Fig. 4-10** The transcranial approach. A bicoronal incision and bifrontal craniotomy were created. The anterior skin flap was retracted to reveal orbital contents. Lesions of the central skull base may be accessed with posterosuperior retraction of the frontal lobes.
Subcranial Approach
The subcranial approach has gained significant popularity over the past 15 years for its ability to preserve function and provide wide exposure (Fig. 4-11). The standard bicoronal scalp incision is used. This approach involves an osteotomy/craniotomy through the orbital rims, glabella, and part of the nasal bones so that pathology of the central skull base can be approached straight on rather than from above. This approach obviates the need for significant frontal lobe retraction, avoids the use of facial incisions, and allows resection of lesions that extend into the nasal cavity and those with intradural extension.\textsuperscript{10,11}
Combination Procedures for Skull Base Resection

The midfacial degloving approach discussed previously can be combined with either the transcranial or subcranial approach to allow access to inferior, lateral, and bilateral lesions of the skull base, craniofacial skeleton, paranasal sinuses, and nasopharynx. This approach, when combined with the approaches already discussed, allows complete craniofacial resection without the use of external facial incisions. An extended maxillotomy, also carried out through the midfacial degloving approach, involves osteotomies through the hard palate, lateral nasal wall, and maxilla, allowing complete mobilization of the maxilla/hard palate unit inferiorly or laterally. This approach can be combined with a craniotomy for comprehensive central skull base access.

For lesions with significant lateral extension, extension through the posterior maxillary wall, or orbital invasion, the transcranial or subcranial approaches can be combined with the external facial incisions discussed previously for excellent midface exposure. A lateral rhinotomy or extended lateral rhinotomy incision, combined with a transcranial or subcranial approach, allows resection of central skull base lesions that extend into the pterygopalatine fossa, pterygoid plates, or orbit.

Transnasal Endoscopic Approaches

Skull base lesions can also be resected through a variety of transnasal endoscopically assisted and purely endoscopic techniques. With endoscopically assisted approaches, endoscopes are used through the nose to assist with transcranial or subcranial approaches and avoid facial incisions. Transnasal endoscopic approaches have also been used alone to remove nasal and paranasal sinus tumors that extend into the skull base. However, long-term outcome analysis using this approach for benign and malignant skull base tumors is yet to be reported and should be performed in select cases at centers with extensive experience.12,13

Approaches to the Lateral Skull Base

Although many lesions of the lateral cranial base can be treated using previously discussed approaches (that is, maxillectomy approaches), the resection of lesions of the temporal bone requires detailed knowledge of the anatomy of the mastoid, facial nerve, and internal carotid artery. These procedures are often performed in concert with an otologic surgeon.
Infratemporal Fossa Approaches

The infratemporal fossa approaches can be divided into the preauricular and postauricular groups (Fig. 4-12). These approaches are designed to offer wide exposure to the jugular foramen and jugular bulb, internal carotid artery, clivus, pterygopalatine fossa, nasopharynx, and petrous apex. The postauricular approaches were described and popularized by Fisch and Mattox and are broken down into three basic types: A, B, and C. All of these approaches involve a standard postauricular incision, with cervical and anterosuperior temporal extensions as needed to facilitate tumor and vascular structure exposure, and dissection and mobilization of the facial nerve. They all also require a radical mastoidectomy with closure of the external auditory canal. The type A approach allows posterolateral access to the jugular bulb, petrous carotid artery, and the posterior portions of the infratemporal fossa. The facial nerve is widely dissected, and a long segment is mobilized and transposed anteriorly. The type B approach allows access to the superior portions of the infratemporal fossa, the clivus, and the petrous apex, and does not require transposition of the facial nerve. Instead, the temporalis muscle is reflected inferiorly, the bone of the middle cranial fossa floor is thinned, and the mandibular condyle may be resected to improve access. The type C approach is essentially an anterior extension of the type B procedure. The pterygoid plates are removed, and access to the sphenoid sinus, cavernous sinus, parasellar areas, and lateral nasopharynx is gained.

Fig. 4-12
The preauricular approaches to the infratemporal fossa differ from the Fisch procedures in that a preauricular skin incision is used, and the trajectory of approach is purely lateral. In addition, resection of the mandibular condyle is usually required with preauricular approaches. These approaches expose areas similar to those of the Fisch type B and C approaches, but do not require transection of the external auditory canal or radical mastoidectomy, so middle ear function is often preserved. The preauricular incision may be extended superiorly to accommodate a frontotemporal craniotomy in cases of intracranial tumor extension.

**Transtemporal Approaches**

For lesions confined to the temporal bone and external auditory canal, the transtemporal approaches are used (Fig. 4-13). The most limited procedure is a sleeve resection of the external auditory canal, which is performed for lesions involving the cartilaginous ear canal. It involves full-thickness removal of the cartilaginous canal, with circumferential removal of the skin of the bony ear canal. The bony canal is preserved and resurfaced with a split-thickness skin graft. The lateral temporal bone resection is used for lesions requiring resection of the bony external auditory canal, with the medial margin being the tympanic anulus. The skin incision involves either a small cylindrical component internally to encompass the tragus and concha, together with an extended postauricular incision, or it can involve total auricular resection in a wide fashion, with extension inferiorly into the neck. The ear canal is sewn closed.
The cervical portion of the incision allows parotidectomy, neck dissection, and mandibular resection, if these components are necessary. A subtotal temporal bone resection allows complete removal of lesions involving the middle ear up to the medial edge of the mesotympanum. The total temporal bone resection sacrifices the petrous carotid artery. The skin incision required is typically a large C-shaped postauricular incision, with wide inferior extension for cervical exposure. A neck dissection can be performed if necessary.\textsuperscript{16}

**SURGICAL APPROACHES TO THE NECK (NECK DISSECTION)**

Head and neck cancer has a propensity to metastasize to the regional lymph nodes. The risk of nodal metastases depends on the tumor site, histology, and stage. Nodal metastases remain one of the most important prognostic factors in head and neck cancer.\textsuperscript{17} Surgical removal of cervical lymph nodes and management of nodal metastases is referred to as a neck dissection. In general, a neck dissection is performed when surgery is used to treat the primary tumor and nodal metastases are clinically (or radiographically) evident at presentation (therapeutic neck dissection) or patients are at high risk of clinically occult microscopic disease (prophylactic or elective neck dissection). A prophylactic neck dissection is usually recommended either when the risk of micrometastasis is higher than 20% in a clinically negative neck. Neck dissections are also performed when patients have large metastatic nodes that were treated with radiation (with or without chemotherapy) along with the primary tumor, and there is either a clinical or radiographically incomplete response to treatment (persistent disease), or with recurrence.

**Neck Dissection by Type**

A common nomenclature system for neck dissections has been adopted that takes into account the lymph node groups (levels) that are removed and, secondarily, the anatomic structures that are either preserved or resected (Table 4-1). The extent of neck dissection is determined by the extent of the disease. In general, there are three main anatomic types of neck dissections.
A radical neck dissection (RND) involves removing all the lymph nodes from one side of the neck, along with the sternocleidomastoid muscle, the internal jugular vein, and the spinal accessory nerve. An extended radical neck dissection involves removing additional structures than would normally be removed with an RND such as the deep muscles of the neck or carotid artery. A modified radical neck dissection (MRND) involves removing all the lymph nodes on one side of the neck, but one or more of the nonlymphatic structures are spared. Most frequently, the main goal of an MRND is preservation of the spinal accessory nerve. A selective neck dissection (SND) involves removal of some lymph node groups from one side of the neck, with preservation of all nonlymphatic structures.

### Table 4-1 Neck Dissection Level Terminology

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<tr>
<th>Level of Neck Dissection</th>
<th>Anatomic Description</th>
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| I                        | Submandibular and submental triangles  
                          | Anatomic borders: lower border of the mandible and the bellies of the digastric muscle; hyoid bone and the midline |
| II                       | Upper jugular nodes  
                          | Anatomic borders: skull base to the bifurcation of the common carotid artery at the level of the hyoid bone; lateral border of the sternohyoid muscle to the posterior border of the sternocleidomastoid |
| III                      | Middle jugular  
                          | Anatomic borders: from the inferior border of level II to the cricothyroid membrane; lateral border of sternohyoid muscle to the posterior border of the sternocleidomastoid |
| IV                       | Lower jugular  
                          | Anatomic borders: from the inferior border of level III to the clavicle; lateral border of the sternohyoid muscle to the posterior border of sternocleidomastoid |
| V                        | Posterior triangle  
                          | Anatomic borders: anterior border of the trapezius posteriorly; posterior border of the sternocleidomastoid anteriorly; clavicle inferiorly |
| VI                       | Anterior compartment  
                          | Anatomic borders: hyoid bone superiorly; suprasternal notch inferiorly; medial border of the carotid sheath laterally |
The lymphatic drainage patterns of head and neck cancers have been well described and are relatively consistent.\textsuperscript{18} A classification system of cervical lymph nodes has been developed based on these observations (Fig. 4-14). The most accurate way to describe the type of neck dissection performed is with an explanation of the levels of lymph nodes removed and the structures either preserved or sacrificed (see Table 4-1). The nodes most at risk of metastases from primary tumors of the oral cavity and oropharynx are generally levels I through IV; with laryngeal and hypopharyngeal tumors, levels II through IV are most at risk. Nodal metastases from cutaneous malignancies depend on the location of the lesion. Levels II through V and the superficial and deep suboccipital nodes are at risk with lesions of the posterior scalp or the postauricular or suboccipital regions (usually melanoma and other cutaneous malignancies). For cutaneous malignancies arising on the anterior scalp or preauricular or temporal regions, selective neck dissection is recommended with excision of the parotid and facial nodes, levels IIA, IIB, III, VA, and the external jugular nodes. For cutaneous malignancies arising on the anterior and lateral face, selective neck dissection is recommended with excision of parotid and facial nodes, levels IA, IB, II, and III. Central compartment neck dissection (levels II though IV, VI, and VII) may be performed for thyroid cancer.\textsuperscript{18}

![Fig. 4-14 The nodal regions of the neck.](image-url)
Indications for Different Types of Neck Dissections

Selective neck dissections are classically performed in patients who have no clinical or radiographic evidence of nodal metastasis but who have a potential risk of micrometastases. Modified radical neck dissections are performed when patients present with nodal metastases that do not involve the accessory nerve. Radical neck dissections are performed in patients with very extensive nodal disease or in patients whose neck disease is intimately associated with the accessory nerve. The goal of any neck dissection is to remove the lymph nodes with cancer and/or those at risk for cancer, with minimal morbidity. The most notable sequelae in patients who have had neck dissections are related to manipulation or resection of the accessory nerve; therefore every reasonable attempt is made to preserve it. Even if the nerve is preserved, dysfunction and morbidity still arise from its surgical manipulation.

Technical Tips for Neck Dissection

- Position the patient’s head slightly upward with the neck extended.
- Raise skin flaps in the subplatysmal plane; beware of the great auricular nerve on the anterior surface of sternocleidomastoid muscle.
- Identify the marginal mandibular nerve, and dissect clear of the facial vessels and submandibular gland.
- Level I: Skeletonize the anterior digastric muscle. Define the mylohyoid muscle and retract it superomedially for submandibular triangle dissection. Identify and preserve the lingual nerve.
- Level II: Dissect the anterior border of sternocleidomastoid muscle, and identify the accessory nerve. Dissect out the accessory nerve only if level IIB nodes are to be removed. Define the posterior digastric, and retract it superiorly to facilitate level IIA dissection from the internal jugular vein.
- Level III: Identify the omohyoid muscle. Complete level III dissection from the deep layer of the deep cervical fascia, preserving the cervical nerve roots.
- Level IV: If level IV nodes are to be removed, resect the omohyoid but beware of dissecting too inferiorly because of the proximity to lymphatic vessels.
- Level V: Identify the accessory nerve on the posterior border of sternocleidomastoid, and identify the border of the trapezius. This maneuver generally requires dissection of the posterior border of sternocleidomastoid muscle.
- Raise the neck dissection specimen from posterior to anterior. Keep the dissection in the fascial plane above the phrenic nerve. Dissect along the internal jugular vein and the carotid artery, and preserve the vagus nerve. Once the dissection is carried anterior to the carotid sheath, identify the hypoglossal nerve.
CONCLUSION

Surgical approaches to the head and neck require an extensive and intricate knowledge of head and neck anatomy and immense versatility in technical skill. The approaches to the oral cavity, mandible, midface, cranial base, and neck highlight soft tissue, vascular, and bony surgical techniques, with a trend toward minimal access and endoscopic procedures. These procedures, especially when performed with microvascular reconstruction, can provide excellent oncologic control and symptom relief with preservation of form, function, and cosmesis.

CRITICAL POINTS

Must Know
- Head and neck procedures are numerous.
- The various approaches require anatomic knowledge and versatility in surgical skill.
- Cervical nodal disease must be considered when planning a surgical approach to the head and neck.
- The surgical approach to head and neck pathology often depends on the reconstructive method chosen.
- The nodal levels of the neck must be understood.

Should Know
- There may be an indication for prophylactic neck dissection in certain situations.
- Previous surgery or radiation may affect vessel selection.

Synopsis
- There are numerous surgical approaches to the head and neck.
- The surgical approach to use is dictated by the disease process being treated as well as the reconstructive modality.

References


Rates of head and neck cancer are traditionally linked to public health issues. The objective of this article is to describe the epidemiology of head and neck cancer in the United States. A total of 75,000 cases of head and neck cancer were diagnosed in 2001, and the incidence is rising. Mortality decreased to some degree with all sites except the thyroid, where it was stable. Many head and neck cancers have changing incidence and mortality rates contrary to expected changes, given the trends in public health issues.

A variety of surgical approaches for treating primary oral cavity tumors are presented to explain the technique and rationale behind each treatment choice. The size, location, proximity to bone, lymph node status, histology, and prior treatment considerations are used to determine the most appropriate surgical approach for primary oral cavity tumors. Oncologic outcomes and physical function show the best results from surgical treatment of many primary oral cavity tumors, but necessitate careful selection of surgical approach. Each surgical approach must be selected based on relevant tumor, patient, and physician factors.


The authors reviewed a 10-year experience with 403 maxillectomies performed between 1984 and 1993 and determined that a limited maxillectomy (LM) was performed in 230 patients. The tumor site and extent defined five different approaches in this cohort. Subtotal maxillectomy (SM) or total maxillectomy (TM) was performed in 135 and 38 patients, respectively, almost 90% of whom had a cheek flap approach. The classification of maxillectomy as LM, SM, or TM is useful and feasible. To define an LM, the portion of the maxilla removed (that is, palate, anterior wall, and/or medial wall) must be specified. For any maxillectomy, the access used should be listed, and the surgeon should indicate whether the maxillectomy has been extended to include adjacent structures.


Assessment of Reconstructive Outcomes

Prabhat K. Bhama, Ernest A. Weymuller, Jr.

HIGHLIGHTS

- Patients undergoing head and neck cancer treatments have more psychosocial impairment and significantly higher rates of suicide than the general cancer population.
- A patient's quality of life (QOL) can be broadly measured using general and specific assessment tools.
- Understanding current QOL findings is essential for determining which approach to use to quantify the subjective concept of QOL.
- Psychometric validation should be used to assess subjective outcomes before implementing QOL instruments.

Given the current therapeutic options for head and neck cancer, it is impossible to avoid treatment-related side effects. Unlike most other cancers, the impact of the surgical management of head and neck cancer treatment is immediately noticeable in social settings because of facial disfigurement, altered speech, and the inability to swallow. Patients with pathologic conditions of the head and neck have particularly difficult psychosocial consequences as a result of their treatment. Patients treated for head and neck cancer are more impaired with respect to their QOL,¹ are frequently depressed,²⁻⁵ and have significantly higher suicide rates than those with other cancers and the general population.⁶ Thoughtful avoidance of functional impairment may optimize their QOL and possibly interrupt the chain of events leading to
depression and suicide. A clear understanding of the preoperative, perioperative, and postoperative factors influencing structural, functional, and QOL outcomes associated with head and neck microsurgical reconstruction can help surgeons develop more effective treatment regimens for patients with head and neck tissue defects.

This chapter focuses on functional and QOL outcome assessment. The other critical outcome measures of survival and locoregional control are not discussed. Functional and QOL outcomes are interrelated, but research has demonstrated that they do not always track together. The QOL is affected by many factors other than function, and a functionally disabled patient may often report an excellent QOL. Alternatively, a person with excellent function may report a poor QOL.

Depending on the intent of a study, a patient’s QOL may be measured using a variety of instruments, ranging from a broad format to a narrow focus (general QOL, cancer-specific QOL, head and neck cancer–specific QOL, or organ-specific QOL). Functional assessment is usually targeted to a particular system (for example, a barium swallow study and evaluation of speech articulation).

This chapter presents the following information:
1. Established tenets of general QOL investigations
2. Established tenets of head and neck QOL investigations
3. The results of an international consensus conference on QOL measurement for patients with head and neck cancer
4. The psychometric evaluation of a QOL instrument
5. A review of research results by QOL and functional domain (for example, swallowing and pain)
6. A review of research regarding site-specific microvascular reconstruction
7. Designing a reconstructive outcomes study

**GENERAL QUALITY OF LIFE AND OUTCOMES**

**Defining Quality of Life**

As a subjective concept, QOL defies a universally accepted definition. The definition offered by the World Health Organization is an example of the generally accepted description of quality of life:

[Quality of life is] an individual’s perception of his/her position in life, in the context of the culture and value systems in which he/she lives, and in relation to his/her goals, expectations, standards, and concerns. It is a broad-ranging concept, incorporating in a complex way the person’s physical health, psychological state, level of independence, social relationships, personal beliefs, and relationship to salient features of the environment.
Typically, three levels of inquiry are recognized:
1. General (global) QOL, which is based on multifactorial assessment
2. Health-related QOL, which assesses the impact of general health
3. Disease-specific QOL, which focuses on the impact of a specific illness

Basic Quality of Life Tenets
Evaluating a person’s QOL is challenging, because it involves the quantification of a subjective concept. When studying the effects of reconstruction on a patient’s QOL, it is helpful to be aware of some of the common trends and findings in QOL research. Box 5-1 includes a list of generally accepted doctrines regarding QOL evaluation, and Box 5-2 presents important findings in head and neck cancer–specific QOL literature.

Box 5-1  Generally Accepted Tenets in QOL Research

1. QOL investigation should be based on patient-oriented inquiry. Because health-related QOL reflects the value that a patient places on his or her health status and function, accurate assessment of QOL requires a direct response from the patient. Assessment by others (for example, the physician or a family member) has been shown to be inaccurate.

2. A patient’s QOL varies over time and is influenced by a wide range of life experiences, and studies must take into account that QOL is a dynamic process. Most authors advise that the best way to evaluate treatment-related QOL is sequentially, with assessments before and after treatment.

3. Cultural differences influence QOL responses and must be accounted for. A QOL investigation must use instruments that are validated in the language appropriate to the study population. Existing QOL instruments cannot simply be translated to a new language. The process of validation in a new language requires translation, back translation, and validation in the new setting. Moreover, comparing patients in New Zealand and Canada, Morton demonstrated that even among people who speak the same language, sociocultural differences must be considered. Sociodemographic variables can also play a role in the QOL.

4. Some patients may sacrifice elements of their QOL to achieve cancer survival if given the choice. However, even this seemingly fundamental precept may vary according to a person’s culture and religion.

5. Life satisfaction affects a patient’s QOL responses. The human tendency toward seeking life satisfaction affects QOL responses in the long run. Acute treatment-related toxicity drives QOL down, and in most instances QOL tends to return to baseline values over time.

Continued
Box 5-1  Generally Accepted Tenets in QOL Research—cont’d

6. Cancer patients in particular tend to draw on a broad set of emotional resources to sustain life satisfaction and tend to report a good QOL, even in the face of treatment-related functional impairments. If these emotional resources fail, depression may result.19

7. Functional status and QOL are not necessarily related. A consistent finding in QOL research is that a patient’s functional status and overall QOL are not predictably related.20-23 Moreover, the functional status and perceived QOL are associated with depression.24

8. The more general (global) the QOL instrument, the less sensitive it is to treatment-related effects.20,23,25-28 Therefore to detect side effects pertinent to specific treatments, it is essential to use QOL instruments that are specific to the disease process being studied.

Box 5-2  Common Findings in Head and Neck–Specific QOL Research

1. Swallowing, pain,18 and comorbid illness appear to be the determining factors in the QOL after treatment of the head and neck.28

2. Pain is a common concern at the time of diagnosis in patients with head and neck cancer.29

3. Neck dissection is associated with shoulder and arm pain, and the more extensive the dissection, the greater the likelihood of shoulder disability.29

4. A more advanced presenting stage is associated with a lower QOL before and after treatment.23,30,31

5. Depression is common in patients with head and neck cancer and is generally undertreated.2-5

6. Most single-institutional studies in head and neck QOL are hampered by inadequate numbers for achieving statistical or clinical significance.24

7. Collaborative, multiinstitutional studies are needed to test existing opinions regarding head and neck QOL.32
Measuring Quality of Life

Many instruments are available for assessing the QOL of patients with head and neck cancer. In 2002 the International Conference on Quality of Life in Head and Neck Cancer was held to seek national and international agreement on methods for measuring and reporting QOL of patients with head and neck cancer. This conference included participants from many disciplines: otolaryngology, general surgery, maxillofacial surgery, medical oncology, radiation oncology, speech pathology, head and neck nursing, psychology, psychometrics, and clinical epidemiology. Deficiencies in the majority of QOL studies for patients with head and neck cancer were identified at the conference, and criteria for improved experimental design and reporting of QOL data were defined.

The continual introduction of new scales for QOL measurement offers little opportunity to develop widespread familiarity with any one scale. Consequently, a major goal of the conference was to highlight a small number of instruments used to gauge QOL to improve communication and the understanding of results. A limited list of recommended instruments was identified based on the following criteria:

1. The instrument must be psychometrically robust with demonstrated validity, reliability, and responsiveness.
2. It must be translated into multiple languages.
3. It must be in widespread use.

Box 5-3 lists the instruments selected at the conference that fit these criteria. The widespread use of these key instruments may help standardize QOL assessment, thereby improving opportunities for multiinstitutional research.

**Box 5-3  Selected High-Quality Questionnaires for QOL Measurement**

<table>
<thead>
<tr>
<th>Performance Status</th>
<th>Head and Neck Cancer–Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karnofsky</td>
<td>EORTC Head and Neck</td>
</tr>
<tr>
<td>ECOG</td>
<td>FACT Head and Neck</td>
</tr>
<tr>
<td>Global Generic</td>
<td>UW-QOL</td>
</tr>
<tr>
<td>SF-36</td>
<td>Head and Neck Functional Status</td>
</tr>
<tr>
<td>General Cancer</td>
<td>Performance Status Scale for Head and Neck Cancer Patients (PSS-HN)</td>
</tr>
<tr>
<td>EORTC-C30</td>
<td></td>
</tr>
<tr>
<td>FACT-G</td>
<td></td>
</tr>
</tbody>
</table>

ECOG, Eastern Cooperative Toxicity Group; EORTC, European Organization for Research and Treatment of Cancer; FACT, Functional Assessment of Cancer Therapy; SF-36, Short Form with 36 questions; UW-QOL, University of Washington–Quality of Life.
Many instruments are available for assessing QOL. These instruments have various dimensions and measure different domains, incorporating functional, physical, psychological, and social aspects of life.

**Psychometric Evaluation of a Quality of Life Instrument**

It is essential to validate QOL instruments before implementation through a process called *psychometric validation*. A full discussion of the psychometric evaluation of QOL instruments is beyond the scope of this chapter, but a brief explanation follows.

The psychometric evaluation of a QOL instrument involves validating a survey used to assess subjective outcomes (for example, symptomatology and QOL). This produces a numeric score from a nonobjective construct. The validation of such an instrument requires the confirmation of validity, reliability, and responsiveness.

*Validity* is the degree to which the scale measures what it is claimed to measure. It can be further divided into several categories. The most important of these is typically *construct validity*, which addresses the question: Does the scale behave the way the investigator hypothesizes? *Reliability* tests the error, both random and systematic, that is inherent in any measurement. *Test-test reliability* assesses whether repeated administrations at short intervals yield similar results. *Internal consistency* is also a subset of reliability, and measures the correlation, if any, of questions in the instrument with one another. Finally, *responsiveness* is a key factor in longitudinal studies and measures the instrument’s sensitivity to clinical change—in other words, if there is a clinical improvement or worsening, can it be detected using this scale?

**Specific Quality of Life Information**


Most head and neck–specific QOL instruments gather information based on a patient’s selection of choices within various domains. Among the domains are swallowing, chewing, pain, anxiety, speech, and appearance.
For example, the University of Washington–Quality of Life (UW-QOL) instrument poses the following options for the domains *pain* and *swallowing*:

- **Pain**
  - I have no pain.
  - I have mild pain, not needing medication.
  - I have moderate pain that requires regular medication (for example, paracetamol).
  - I have severe pain controlled only by prescription medicine (for example, morphine).
  - I have severe pain, not controlled by medication.

- **Swallowing**
  - I can swallow as well as ever.
  - I cannot swallow certain solid foods.
  - I can only swallow liquid foods.
  - I cannot swallow, because it “goes down the wrong way” and chokes me.

### Domain-Specific Research Results

#### Swallowing

Of all the domains, interference with swallowing function has been shown to have the most profound impact on global QOL.\(^{37,38}\) Surgical intervention for the treatment of head and neck cancer often results in dysphagia as a result of impaired function during the oral preparatory phase, the oral phase, and the pharyngeal phase of swallowing.\(^{39}\) Prognostic indicators for good swallowing and good speech at 1 year after surgical treatment for oral and oropharyngeal cancer include the use of primary surgical closure/laser surgery as opposed to flap reconstruction. The addition of radiation therapy has a negative effect in this setting.\(^{40}\)

The current consensus favors nonsurgical management of cancer involving the base of the tongue. Surgical treatment of advanced lesions of the tongue base results in a poor functional outcome, prompting practitioners to offer brachytherapy with radiation therapy or combined chemoradiation.

Primary radiation therapy for cancers of the base of the tongue results in a better performance status after treatment (as tested on a subjective scale) compared with primary surgical therapy.\(^{41}\) Primary radiation therapy for these cancers has also been shown to maintain patients’ pretreatment functional status, QOL, and employment potential.\(^{42,43}\)

Similar survival rates have been achieved with chemoradiation and surgical salvage compared with surgery and postoperative radiation therapy for the treatment of advanced head and neck cancer.\(^{44}\) To investigate the effects of various treatment modalities on swallowing function, Gillespie et al\(^{45}\) conducted a cross-sectional survey of 40 patients with stage III or IV squamous cell carcinoma of the oropharynx, hypopharynx, or larynx at least 12 months after treatment (chemoradiation with or without
neck dissection, or surgery and adjuvant radiation therapy). The authors found that patients who underwent chemoradiation therapy had better swallowing outcomes than patients who underwent surgery and radiation therapy. Additionally, patients who were without oral intake for 2 weeks or more had more severe chronic swallowing dysfunction.

The functional benefit of nonsurgical treatment for tumors of the base of the tongue has influenced current therapy; however, it has not been determined whether loco-regional control and survival have equally benefitted. Prospective studies are warranted to compare conventional surgical approaches with organ preservation techniques and their effect on QOL and survival.

**Oral Function**

Worsened masticatory ability in posttreatment head and neck cancer patients has been associated with a decreased QOL. A study of patients undergoing treatment for oral cancer in Brazil showed that chewing was the most common problem at the baseline assessment and during the follow-up. Moreover, a study of 54 patients who underwent free fibula flap reconstruction for mandibular defects in Germany showed that approximately two thirds of the subjects noted difficulties with mastication.

Virtually all head and neck cancer patients have side effects during and after radiation therapy. Among these, oral mucositis is the most debilitating, dose-limiting, and dose-delaying acute toxicity, and it can result in severe pain. Patients with oral mucositis require opioid analgesics. Hyposalivation, oral discomfort, the risk of dental caries, mucosal sensitivity, and negative effects on oral intake and taste are common following treatment. Dry mouth is a key chronic complication of cancer therapy and advanced disease.

Clearly, consideration of oral function is imperative when assessing the QOL in head and neck cancer patients. The European Organization for Research and Treatment of Cancer (EORTC) QOL questionnaire supplemented with an oral addendum measures QOL and oral function after hematopoietic cell transplantation, and it has been used in patients with head and neck cancer.

**Dental Status**

Dental problems are well-documented sequelae of surgery and/or radiation therapy for head and neck cancers. A decreased number of teeth or dental functional units has been associated with diminished self-perception of oral health status and a decreased health-related QOL. Additionally, in the absence of rehabilitation, there is a persistent decline of QOL related to dental condition. It has been demonstrated that patients who become edentulous after treatment, those without occlusion, and those with higher decayed/missing/filled scores or decreased oral-opening measurements reported a worsened QOL. Prosthodontic implants and a postoperative rehabilitation program have a positive effect on patients’ health-related QOL.
Speech

Surprisingly, communication impairment was not ranked as the most important QOL domain in one study. Communication scores for patients with laryngeal cancer are shown to be lower than those for patients with oral cavity or oropharyngeal cancer; however, overall “bother” scores are more favorable in laryngeal cancer patients compared with other head and neck cancer patients.

It is important to use diagnosis-specific questionnaires when assessing the QOL in laryngeal cancer patients. Compared with chemoradiation therapy, surgical therapy with adjuvant radiation therapy yields similar QOL results. With regard to QOL domains, laryngectomy patients place significant value on the physical consequences of surgery and interference with social activities and tend to minimize the effect of the change in voice quality.

Pain

Pain is a common symptom at the time of diagnosis in patients with head and neck cancer. Surgical extirpation may alleviate pain, but it usually increases after treatment and subsequently improves. Surgery on the neck is associated with shoulder and arm pain.

Based on recent studies, neck dissection has a negative impact on patients’ QOL and health status. Moreover, more extensive neck dissections are associated with an increased incidence of shoulder-related disability. Fortunately, over the second half of the twentieth century, neck dissection evolved from solely radical neck dissection to include more conservative procedures.

The presence of shoulder and neck pain after neck dissection is a common cause of postoperative morbidity in patients with head and neck cancer. It is postulated that mechanical overload on the shoulder caused by changes in scapular position and the absence of stabilization after trapezius denervation lead to shoulder pain. However, even with spinal accessory nerve preservation, patients can have shoulder pain.

Recently investigators have assessed the benefit of preserving cervical sensory nerves. Roh et al conducted a retrospective cohort study of 53 patients who underwent selective or modified radical neck dissection. These patients were placed into two groups, based on their cervical sensory root branch status. One group included patients with preserved cervical sensory roots, and the other group consisted of patients in whom these roots were removed. The patients were evaluated using questionnaires on depression and QOL, along with comparisons of sensory and motor functions of the neck and shoulder. The results of the study suggest that preserving the cervical sensory root branch during neck dissection reduces postoperative pain and permanent sensory deficits. Additionally, the study found that dissection of level V nodal tissue (the posterior triangle of the neck) is associated with neck and shoulder pain.
Wittekindt et al demonstrated that subcutaneous botulinum toxin A injections may reduce chronic neuropathic pain after neck dissection. It is theorized that the cause of myofascial trigger points is excessive release of acetylcholine at motor endplates, and that botulinum toxin A achieves analgesia by preventing acetylcholine release at the neuromuscular junction.

Other Patient Factors

Age
The effect of age on the QOL of head and neck cancer patients is not clear, although it has been shown by comparing age-matched reference data that younger patients tend to be more sensitive to change than elderly patients with regard to mobility, pain/discomfort, and anxiety/depression.

Adjuvant Radiation Therapy
The use of neoadjuvant chemoradiation therapy for the treatment of advanced oral cavity carcinoma is an effective treatment, although acute toxicities result in impairment of QOL. Likewise, adjuvant radiation therapy following mandibular resection for head and neck cancer has been shown to adversely affect health-related QOL but to increase cancer cure rates.

However, a large retrospective multicenter study demonstrated that radiation therapy has no significant impact on the general QOL in patients with oral cancer, but irradiated patients did have a significantly higher rate of xerostomia, more difficulty in swallowing, and less comprehensible speech compared with their nonirradiated cohorts.

Examples of Microsurgical Reconstruction–Specific Outcomes

Overview
Microsurgical reconstruction of the head and neck has excellent technical success rates. In fact, in cases of resection necessitated by malignancy or trauma, free tissue transfer is the most reliable and efficient means of reconstruction. A retrospective study of 241 cases of free tissue transfer for head and neck reconstruction reported a postoperative (30 days) mortality rate of 2.1% and a flap survival rate of 95%. The authors of this study reported a median length of stay of 11 days. This study also showed that administering more than 7 L of crystalloid solution during surgery to patients at least 55 years old was associated with major medical complications. Moreover, they noted that cigarette smoking, the need for more than one operating surgeon, and patient weight loss of more than 10% before surgery were related to major flap complications.
Soft Tissue Reconstruction

The mode of soft tissue reconstruction (that is, local flaps, microvascular free flaps, or myocutaneous grafts) after ablative surgery for oral cancer has been shown to have a statistically significant effect on QOL. Schliephake and Jamil\(^8\) concluded that pliable free tissue flaps have the best outcome with respect to QOL. However, primary reconstruction of small soft tissue defects in the oral cavity and oropharynx yields better postoperative functional outcomes compared with flap reconstruction.\(^84\)

Maxillofacial Reconstruction

Although tissue deficits following resection of neoplastic disease are often an indication for free tissue transfer reconstruction, traumatic injury to the head and neck can also result in complex defects, necessitating reconstruction with free flaps. Free tissue transfers in these patients can minimize the infection risk during healing, and good functional outcomes after free tissue transfer reconstruction are possible as a result of preserved tissue elasticity. Futran et al\(^8\) reported successful functional and aesthetic outcomes after free tissue transfer reconstruction for trauma-induced maxillofacial defects.

In another publication, Futran and Mendez\(^8\) concluded that patients who undergo reconstruction of maxillary and midface defects after neoplasia resection should be evaluated for the restoration of midface contours, swallowing function, phonation, and chewing. The authors also pointed out the important concept that a combination of free tissue transfer, local flaps, and maxillofacial prostheses may be used to achieve more favorable outcomes than would traditionally be possible with a single reconstructive technique.

Skull Base Reconstruction

Reconstruction of the skull base using skin graft dural closure has been reported to result in a high incidence of leakage of cerebrospinal fluid.\(^8\) In some institutions, the use of pedicled flaps to repair cranial base defects has been replaced by free tissue transfer reconstruction.\(^8\)

Chang and Robb\(^8\) at the University of Texas M. D. Anderson Cancer Center performed 77 skull base resections necessitating reconstruction from January 1993 to September 1999. Twenty-five patients underwent reconstruction using local flaps, and 52 underwent free tissue transfer reconstruction. The authors reported no significant association between the reconstructive method and the incidence of complications. They concluded that free flap reconstruction is a viable option for large cranial base defects.
Mandibular Reconstruction

Mandibular defects present several unique challenges to reconstructive surgeons. The mandible plays a key role in mastication, not only as a mobile unit, but also as housing for dentition. Moreover, the restoration of anatomy is paramount in cases of mandibular defects, because it has a profound impact on facial appearance. As discussed previously, oral and dental function and the ability to swallow can have significant effects on a patient’s QOL. Thus reconstructive surgeons must consider QOL outcomes when treating patients with oromandibular defects.

Fibular free flap reconstruction for cancer of the oral cavity results in favorable outcomes with respect to function, aesthetics, and QOL. Compared with no mandibular reconstruction, segmental mandibulectomy with free flap iliac crest reconstruction for cancer of the oral cavity yields better results for multiple domains, including physical well-being, social and family relationships, chewing, and swallowing. Also, segmental mandibulectomy with reconstruction using composite free tissue transfer results in similar postoperative QOL scores when compared with rim resection.

Primary Versus Secondary Mandibular Reconstruction

Andrade et al recently conducted a retrospective study of 149 patients who underwent mandibular reconstruction to clarify outcomes of primary versus secondary reconstruction. The authors focused on two outcomes: length of hospital stay and complication rates. They noted a similar length of stay between the two treatment groups and that secondary mandibular reconstruction does not necessarily correlate with a higher complication rate compared with primary reconstruction.

Tongue Reconstruction

Surgical treatment for neoplasia of the base of the tongue results in a poor functional outcome compared with nonsurgical treatment. To understand more about speech and swallowing outcomes in these patients, Rieger et al studied 32 patients who underwent resection of at least 50% of the base of the tongue. A radial forearm free flap was used to reconstruct all of the defects, followed by conventional radiation therapy. Interestingly, the authors concluded that the degree of soft palate resection and lingual and hypoglossal nerve involvement did not influence speech outcomes. Rather, the amount of tongue base initially resected had an effect on speech outcomes. However, it was noted that favorable speech outcomes are feasible following large tongue base resections. With regard to swallowing, the authors reported some interesting findings pertinent to the length of time spent eating. Specifically, they noted that treatment may result in increased meal durations, making it more difficult...
for patients to finish their meal within an allotted time. The authors also noted a 6.9% incidence of aspiration, and a 4.2% incidence of silent aspiration. Foods of thicker consistencies were managed more easily by the patients in the study.96

Another recent study of 16 patients who underwent partial glossectomy and lateral-cervical lymph node dissection for squamous cell carcinoma in Italy reported the outcomes of sensate-free forearm flap reconstruction. Nine of these patients had reconstruction with a nonsensate flap, and the remaining seven patients had reconstructions using sensate flaps. In the sensate flap group, a microsurgical anastomosis was performed between the lateral antebrachial cutaneous nerve and the residual lingual nerve. The authors reported better outcomes with respect to cutaneous sensitivity in the sensate flap group. Additionally, these patients had better outcomes for the recovery of oral function.97 Although the sample size was relatively small, according to this study, flap reconstruction of partial glossectomy defects with sensate-free forearm flaps yields more favorable results than reconstruction using nonsensate-free forearm flaps.

Pharyngolaryngoesophageal Reconstruction

Several options are available for the reconstruction of pharyngolaryngoesophageal defects. Although reconstruction has traditionally been performed with adjacent pedicled or rotation flaps, free flaps are now in common use. Jejunal, radial forearm, and anterolateral thigh (ALT) flaps are among the more common flaps used for reconstruction of pharyngolaryngoesophageal defects. Gastrooomental flaps have also been used. Each of these methods has its own advantages and disadvantages.

Jejunal Free Flap

Jejunal free flaps have unique donor site morbidity because of the laparotomy required to harvest enteric tissue. Some of the donor site complications that can occur from jejunal free flaps are ileus,98 ventral hernia, and small bowel obstruction. The postoperative recovery may also be slower, and the voice may develop a wet quality with occasional spasms.99-102

However, a study at the University of Washington showed that the laparoscopic harvest of jejunal free flaps may result in better outcomes compared with harvest through a laparotomy. Wadsworth et al103 reviewed records of 12 patients who underwent a laparoscopic harvest of a jejunal free flap and reported an average operative time of 2.4 hours for the abdominal portion of the procedure. The warm ischemia time was less than 4 minutes, and enteral feedings began on the first postoperative day. No donor site morbidity was identified in this study, and no major complications occurred with the flap.103 Therefore, at centers with such capabilities, the laparoscopic harvest of jejunal free flaps for pharyngoesophageal reconstruction would be more desirable compared with the open technique.
**Anterolateral Thigh Free Flap**

In a study at M. D. Anderson Cancer Center of 41 patients with laryngopharyngectomy defects, encouraging results were obtained after reconstruction with an ALT free flap. With regard to swallowing outcomes, 6% of the patients were partially dependent on tube feeding, and the rest achieved full oral intake (88% of these patients tolerated a regular diet, whereas 6% could only have a pureed diet as a result of strictures). Compared with jejunal free flaps, swallowing outcomes (as reported by the study) following ALT free flap procedures are superior.\(^{104}\) Speech outcomes were also found to be superior compared with a jejunal free flap. Additionally, tracheoesophageal voice quality is likely to be better using fasciocutaneous flap reconstruction versus jejunal free flap reconstruction.\(^{105}\)

Another study showed superior swallowing and speech functions with ALT free flap reconstruction compared with jejunal free flap reconstruction.\(^{98}\) Similar rates of pharyngoesophageal fistula and anastomotic stricture were also noted. This study also found that the postoperative recovery time and length of hospital stay were shorter for patients who underwent ALT flap surgery. Correspondingly, hospital costs were appreciably lower in this group of patients.

In a retrospective study, Murray et al\(^ {106}\) studied 14 patients who underwent circumferential pharyngoesophageal reconstruction with an ALT free tissue transfer wrapped around a salivary bypass tube. The authors reported no perioperative deaths, flap failures, or fistulas. However, they did note some early minor complications, including hematoma, infection, suture abscess, and donor site seroma. Migration of the salivary tube was also reported in two cases, and two patients developed strictures. Seven of the patients were eventually placed on an unrestricted, full oral diet. Eight of the patients were fitted with a Blom-Singer valve (InHealth Technologies, Carpinteria, CA) or a Provox2 voice prosthesis (Atos Medical AB, Hörby, Sweden) and were able to speak effectively.\(^ {106}\)

**Radial Forearm Free Flap**

As a fasciocutaneous flap, radial forearm free flap reconstruction can also result in better speech compared with jejunal free tissue transfers. However, the fistula rate may be higher after radial forearm free flap reconstruction,\(^ {107}\) and forearm donor sites can require a large amount of skin grafting to the area.\(^ {108,109}\) This can exacerbate postoperative discomfort, because donor areas for split-thickness skin grafting are often a source of significant pain. Furthermore, fistula rates comparable to other reconstructive methods have been reported, and hypopharyngeal stenosis can also be an issue following radial forearm free flap reconstruction, necessitating mechanical dilatation. Superior swallowing outcomes have been reported compared with jejunal free flap transfer,\(^ {109}\) although some studies have shown similar swallowing outcomes compared with jejunal flap reconstruction.\(^ {105}\)
FUTURE DIRECTIONS

Active Clinical Use of Quality of Life Information

Valid and responsive head and neck–specific QOL instruments are now available. The next generation of tools that assess QOL will include real-time intervention in patient care. A pretreatment QOL evaluation could be used to identify depression and to initiate intervention to improve the probability that a patient will complete the proposed course of therapy.2–5 A QOL evaluation during treatment could identify major changes in functional status and precipitate earlier intervention (for example, swallowing, pain, shoulder function, and mastication). For patient follow-up (monitoring) in after-treatment, it is likely that the use of QOL instruments will help to highlight areas of concern to the patient that might not otherwise be apparent to caregivers.18,110

Focusing on each domain score in head and neck–specific QOL instruments offers an opportunity to identify areas for rehabilitation (pain, dry mouth/altered saliva, speech, swallowing, chewing, and depression). QOL instruments offer a cost-effective method for sustaining contact with patients, especially those who have the greatest problem with follow-up. As noted by Bjordal et al,25 we tend to lose contact with the patients who need us most. Infirmitiy, geographic distance, and comorbidity are some of the factors that confound follow-up.

Moreover, because some data suggest that symptom changes may be useful markers of recurrence, it is possible that home-based, sequential QOL inquiry could be an effective form of screening for recurrence.110 The benefit of using QOL instruments for follow-up must be evaluated in a prospective fashion.20 Current practice uses expensive and time-consuming follow-up techniques (patients visit the specialist or specialists and undergo imaging studies). A prospective comparison of these methods with patient-reported information might reveal less-costly options for follow-up.

Potential Areas for Quality of Life Research

Palliative Care

Improving a patient’s QOL is the direct goal of palliative care, and continuing investigation is required because the head and neck literature contains little information to guide practitioners with respect to palliative care. Timon and Reilly111 described the time course of palliative care, and Goodwin30 provided an excellent analysis of surgical salvage treatment. Terrell et al28 described the clinical predictors of posttreatment QOL, but otherwise there is a paucity of information regarding the effect of palliative interventions (for example, pain regimens, the benefit of tracheotomy and percutaneous endoscopic gastrostomy tubes, and palliative radiation or chemotherapy) on a patient’s QOL.
Administration Methods for Alternative Quality of Life Instruments

Computer-based technologies could allow more cost-effective and user-friendly assessments of the QOL in cancer patients. For instance, touch-screen technology was compared with paper methods for administering the UW-QOLv4 and was preferred by the vast majority of patients in this study. This allows rapid access to large volumes of data, easy sharing and transfer of data between care providers, and an efficient analysis of data.

Designing a Reconstructive Outcome Study

The ideal reconstructive outcome study would include the following:

- Preoperative functional and subjective tests
- A record of anatomic subunits of the tumor’s extent (see examples below)
- A record of anatomic subunits of the tumor resection (see examples below)
- A description of the repair
- Postoperative (1 year) functional and subjective tests repeated

Functional and Subjective Tests

The functional outcome of head and neck reconstruction can and should be assessed using objective and subjective measures. A good objective outcome does not guarantee a good subjective outcome. Numerous functional and subjective QOL instruments are available. A prospective study of reconstructive outcomes should begin with a review of the various instruments to determine which one (or set) contains domains that address the issues relevant to the study (for example, swallowing, chewing, and speech).

Anatomic Quantification of the Lesion and Repair and Functional Assessment

Urken et al described a classification scheme for composite defects of the oral cavity and applied it to 71 cases of oromandibular reconstruction. Bone, soft tissue, and neurologic defects were addressed using this classification scheme.

Nicoletti et al performed a unique study of 196 patients who were treated for oral cancer with resection and various reconstructive techniques, followed by adjuvant radiation therapy. Their aim was to perform a subjective assessment of chewing, swallowing, and speech in these subjects. The lesions were diagrammed anatomically, based on size and site, and the patients were divided into 12 groups derived from the results of the surgical mapping. The functional assessment of chewing, swallowing, and speech was also performed using the Functional Intraoral Glasgow Scale. The results of the functional assessment were correlated to the anatomic regions that were mapped out earlier in the study. The authors presented a unique method of analysis for head and neck tumor resection and reconstruction, with the anatomic quantification of the lesion and repair correlated with the functional as-
Assessment. According to the authors, this study serves as a benchmark index for head and neck reconstruction outcomes research. Some important conclusions were also derived from this study. It was found that chewing and swallowing outcomes depended on the size of the resection, but not on the modality of reconstruction. Moreover, radiation therapy was found to be a negative prognostic factor for chewing and swallowing function. Figs. 5-1 and 5-2 demonstrate the concept well.

**Fig. 5-1** Floor of mouth unilateral small (FMUS) resections include the lateral floor of the mouth and the anterior two thirds of the lateral border of the tongue, with or without resection of the mandible rim. Floor of mouth unilateral medium (FMUM) resections include the lateral floor of the mouth up to the mylohyoid muscle plane plus wider excision of the entire lateral border of the tongue, with or without resection of the mandible rim. Floor of mouth unilateral large (FMUL) resections are large, full-thickness excisions of the lateral floor of the mouth plus the lateral border of the tongue, with or without segmental mandible resection.
Fig. 5-2  Extensive excisions (shaded blue) include resections of the retromolar trigone, one side of the floor of the mouth beyond the anterior midline, and up to half of the tongue.
The correlation of detailed surgical mapping based on anatomic subunit analysis with QOL and functional results can help to further define outcomes following head and neck reconstruction.

**CRITICAL POINTS**

**Must Know**
- Patients treated for head and neck cancer are frequently depressed, more impaired with respect to QOL, and have significantly higher suicide rates than those with other cancers and the general population.
- Functional and QOL outcomes are interrelated, but research has demonstrated that the two outcomes do not always track together. A patient’s QOL is affected by many factors other than function, and a functionally disabled patient may at times report an excellent QOL. The opposite is also true.
- QOL investigations should be based on patient-oriented inquiry.
- Cultural differences influence QOL responses and must be accounted for.
- Cancer patients in particular tend to draw on a broad set of emotional resources to sustain satisfaction with life and tend to report a good QOL even in the face of treatment-related functional impairments.
- Swallowing, pain, and comorbidity appear to be the determining factors in a head and neck cancer patient’s QOL.

**Should Know**
- A thorough understanding of preoperative, perioperative, and postoperative factors that affect QOL outcomes for head and neck reconstruction aid in the development of optimal and individualized treatment regimens.
- Sequential QOL inquiry that is based in the home could be a more cost-effective approach than the current practice of patient follow-up, which includes numerous visits to specialists and undergoing imaging studies.

**Synopsis**
- Assessing outcomes after microsurgical reconstruction of the head and neck involves recognizing several concepts.
- The oncologic outcome is the most important factor that should guide treatment. Restoration of anatomy and function are also important.
- Considering the significant side effects and cost of head and neck cancer treatment, it is essential to consider the impact that free tissue transfer has on each patient’s QOL.
References


   This study compared a provider-delivered smoking cessation intervention with a usual-care advice control condition. Participants completed a battery of self-report measures after diagnosis and before treatment and additional quality-of-life instruments at 1 and 12 months after initial smoking cessation advice. Results reinforce the need for rehabilitation management through the integration of psychologic and behavioral interventions in medical follow-up.


   Two studies of psychosocial interventions in head and neck cancer patients at different stages of their disease were performed. The first study concerned long-term group psychological therapy for patients with newly diagnosed head and neck cancer. Quality of life was measured longitudinally for 1 year and compared with that of a control group. The second study comprised a short-term psychoeducational program 1 year after treatment for head and neck cancer. Quality-of-life assessments were made repeatedly from diagnosis until 1 month after the intervention. These pilot studies suggest that head and neck cancer patients can benefit from different psychosocial interventions.


   The purpose of this study was to characterize suicide rates among patients with cancer in the United States and identify patient and disease characteristics associated with higher suicide rates. The study found that patients with cancer in the United States have nearly twice the incidence of suicide of the general population, and suicide rates vary among patients with cancers of different anatomic sites.


   Quality of life is a difficult concept to define and measure. A hypothesis is proposed that suggests that quality of life is a measure of the difference between the hopes and expectations of an individual’s current experiences. Quality of life can only be described by the individual and must take into account many aspects of life. The hypothesis is developed in a diagrammatic way, and several methods of testing the hypothesis are suggested.


   Measurement of health-related quality of life (HQL) is becoming more common in oncology, particularly in clinical trials. This report reviews the progress and assesses whether anything has been learned from these studies. Six lessons that have emerged from measurement of HQL in oncology are (1) HQL is a multidimensional construct and should be measured with multi-
dimensional instruments, (2) observers are poor judges of how patients feel about their HQL, (3) it is possible to achieve high rates of compliance in the collection of self-report HQL data, (4) aggressive therapy may result in improved HQL, (5) symptoms are associated with quantifiable disruptions in HQL, and (6) pretreatment HQL may be predictive of on-treatment HQL and of survival.

There are certain principles that can guide surgeons in the choice of the most appropriate reconstruction for any given patient. The operative term is “most appropriate,” not “best.” The best reconstruction may be a very complex and technically challenging surgical tour de force; however, that may not be the most appropriate. Multiple factors determine the level of suitability in head and neck reconstruction; these can be described as reconstructive principles.

**PATIENT AGE**

Research has shown that age is not important in terms of flap survival, but it is important in terms of comorbidities and consequent medical complications.\(^1\) Patient age alone should not influence our choice; however, the number and extent of the pa-
tient’s comorbidities is an important factor in the surgeon’s decision-making. Many head and neck patients are elderly, and often the best option for these patients is to optimize their medical condition, treat their comorbidities, and proceed with surgery.

**DISEASE CHARACTERISTICS**

It is obvious that the characteristics of the disease will determine the modalities of treatment—surgery, chemotherapy, radiation therapy, or, as is frequently the case, a combination of all of these modalities. Disease specifics also help the physician determine the choice of reconstruction. A patient with aggressive disease and a poor prognosis will not be well served by a complex multistaged reconstruction. Rather, for that individual, it is imperative to complete the safest and simplest reconstruction to maximize quality of life and time out of the hospital with his or her family. For example, a patient with a lateral mandibulectomy defect may be best served by a combination of reconstruction plate and flap, pedicled or free. However, for some patients the choice of a more radical surgical approach may achieve the goal of shortened hospital stay and more quality time out of the hospital. A patient with facial nerve involvement from an aggressive parotid tumor will probably be better served by a static sling procedure for his or her facial paralysis than a free functioning gracilis transfer (see Chapter 27). Conversely, complex and staged reconstruction may well be the most appropriate treatment for a patient with benign disease, where the ultimate goal is the very best reconstruction and not simply trying to keep the patient alive and well for as long as possible.

The planned treatment for the patient’s disease is another determinant of the most appropriate reconstructive choice. In dealing with malignant processes, the primary goal is disease control. Anything that potentially compromises that goal is unacceptable. For that reason, we generally stay away from complex staged reconstructions in patients requiring adjuvant treatment, particularly because timing may be important to provide optimal cancer control. If the reconstruction delays the delivery of care, then the reconstruction may compromise the patient’s ultimate disease outcome. It is much better, if necessary, to temporize and perform a temporary reconstruction that will serve the patient during adjuvant treatment, then complete the reconstruction at a later time. Fortunately, the general acceptance of microvascular reconstruction in head and neck surgery has allowed surgeons the luxury of completing complex reconstructions in a single stage with a very good expectation that, barring exceptional circumstances, the wound will have healed by the time the patient is ready for postoperative chemotherapy or radiation therapy.
Characteristics of the Defect

It is essential to analyze the characteristics of the defect when choosing a reconstructive modality that will work for the patient. Head and neck reconstruction presents unique challenges to the reconstructive surgeon, because this region is so visible that deformities of any kind are difficult to hide. Additionally, the demands on our reconstructive skills are greater in the head and neck than elsewhere in the body, where cosmesis may be less vital and function less specialized. The head and neck area includes both static and dynamic structures, which further complicates the procedure and healing process. Furthermore, the area contains organs of special function, such as the orbital contents, eyelids, nose, ears, and lips, which must also be considered. For all of these reasons, head and neck reconstruction demands versatility and some degree of ingenuity so that form as well as function can be restored to the maximum extent possible.

One of the most important principles in head and neck reconstruction is that local flaps work best because of the concept of replacing like with like. This is very important for the aesthetics of the reconstructive outcome, but it is equally important from a functional viewpoint precisely because of the specialized nature of some of the tissues being used. For example, mucosa works best to replace mucosa because it provides thin, pliable, moist tissue that can fulfill the function for which it is designed. Although skin paddles work as a replacement for mucosal defects, there is often a problem with dryness, lack of pliability, bulk, and sometimes, hair growth. As an alternative, many have advocated using muscle and allowing it to remucosalize when reconstructing intraoral and intranasal defects.4

Requirements for Reconstruction

There are certain situations in which a reconstruction will be required to provide specific elements. For example, flaps around the lips and eyelids will need to maintain some element of function, and the flaps chosen for these reconstructions will likely be different from the flaps chosen to simply cover a scalp defect. Some flaps may be required to act as a conduit, such as in pharyngoesophageal reconstructions. There are certain defects in which a particular type of reconstruction is required; the best example of this is the central mandibular defect. An osseous or osseocutaneous flap is mandatory in this situation, because the reconstruction failure rate is 35% if only a plate is used to reconstruct this particular defect.3 Color and texture
match is a particular issue in facial reconstruction. There are differences among different ethnic groups in terms of skin color variation between multiple potential donor sites.\(^5\) In patients who have a significant color mismatch, a very good solution is to deepithelialize the flap skin paddle and apply a very thin split-thickness skin graft harvested from the scalp\(^6,7\) (Fig. 6-1).

Fig. 6-1  A, This patient is seen following excision of a squamous cell carcinoma of the forehead, reconstructed with a scapular flap. Note the significant color mismatch. B, Parietal scalp shaved and prepared for a split-thickness skin graft harvest. C, Final outcome showing significantly improved color match.
RELIABILITY OF THE RECONSTRUCTION

Although we always try to ensure that our reconstruction is reliable, there are certain situations and certain defects that require the safest and most reliable reconstruction possible, because the consequences of failure are dire. Of course, surgery is just one modality of treatment for the patient’s disease. It is important that the surgical wound be healed before radiation therapy or chemotherapy is initiated; failure of the reconstruction may inordinately delay treatment and could conceivably affect disease outcome.

Another scenario in which reliability is critical is in cranial base reconstruction. Free flap reconstruction significantly changed the morbidity of cranial base resection because it provided well-vascularized tissue that was used to obliterate dead space and separate the cranial contents from the aerodigestive tract. The consequences of failure in this situation include CSF leak, meningitis and brain abscess—all potentially fatal complications. For this reason, the reconstruction modality chosen must be the most reliable possible, and the flap used must be dependable and safe. The emphasis is on safety rather than on elegance. This is not the sort of situation in which to try a new or unfamiliar flap unless there is a very good reason to do so.

CRITICAL POINTS

**Must Know**
- Age is not a reason to deny a patient reconstruction.
- Choose the most appropriate reconstruction, which may not necessarily be the “best.”
- Be aware that the patient may need adjuvant treatment that cannot be started until wounds are healed.
- When the consequences of failure are dire, make sure to perform the safest possible reconstruction, even if it is not the most elegant.

**Should Know**
- Use bone in central mandibular defects.
- Consider whether the defect demands a particular type of reconstruction.
- Consider resurfacing color mismatches with scalp grafts.

**Synopsis**
- Although choosing the most appropriate modality for head and neck reconstruction depends on a wide range of factors, such as the age of the patient, disease characteristics, and other specificities, there is some consensus on reconstructive principles that can assist in a surgeon’s decision-making.
References


   Many patients requiring head and neck free flaps are elderly, with concomitant medical problems and are therefore potentially at higher risk of adverse outcomes. In addition, they frequently have a history of heavy alcohol and cigarette consumption, which can compound the risks. The authors suggest that free flap surgery is a safe technique in elderly patients with surgical complications comparable to a younger patient population. As a result of concomitant medical problems, however, postoperative medical complications are more frequent in the older age groups, with a resultant increase in length of hospital stay.


   The purpose of this study was to define the role of reconstruction plates as bone replacement in oromandibular reconstruction. Vascularized autogenous bone proved to be more successful than metallic plates used alone in terms both of reconstruction survival and of minimizing days of life lost. The overall success rate of mandibular plate reconstruction was 78.9%, but analysis by defect type revealed a failure rate of 35% when the defects were anterior and only 5% when they were lateral.


   This review was conducted to assess the value of palliative microvascular reconstruction. The iliac crest osteocutaneous flap was found to be ideal for reconstructing large bony and soft tissue defects. A number of complications were observed, but most patients developed normal or easily intelligible speech, and most had their tracheostomies closed and sustained themselves on an oral soft diet. Although the prognosis with full-thickness oral carcinoma is grim, palliative surgery in these cases is well justified. The goals are to shorten the duration of hospitalization, reduce morbidity, and improve the remaining quality of life. Microvascular tissue transfer offers a means to achieve these goals in a single, reliable procedure.


   The purpose of this study was to determine the optimal color match for free tissue donor sites transferred to defects of the cheek and neck in a multicultural population. Sixty-four healthy volunteers underwent noninvasive skin color measurement of the cheek and neck, as well as of a standard set of potential free tissue donor sites using a chromometer. Wide variations exist between individuals of different ethnic backgrounds regarding the optimal donor sites for the best color match. In Caucasians, south Asians and southeast Asians, upper extremity sites, including the forearm and lateral arm flaps, provided the best color match. In blacks, there was much variation in color across the commonly used donor sites, and a larger panel of flaps can provide an appropriate color match in this group.


The purposes of preoperative evaluation are to plan the best anesthetic procedure based on the patient’s physiologic limitations and to minimize risk to the patient by recognizing and optimizing comorbid conditions.

Patients are evaluated and treated as if they will have difficult endotracheal intubation and problems in airway management.

If airway management has a potential to be complicated, it is best to avoid intravenous induction in favor of awake direct fiberoptic laryngoscopy or inhalational induction to maintain spontaneous ventilation.

It may be helpful to use a mild hypotensive technique to limit blood loss.

The patient should remain intubated postoperatively if there is a chance of postoperative edema of structures that could obstruct the airway.

Head and neck cancers compose 6% of all cancers. Oncologic management of advanced upper aerodigestive tract malignancies consists primarily of surgery and adjuvant radiation therapy. The associated cure rates have not changed significantly in the past 40 years, although adjuvant chemotherapy has allowed increased organ preservation when combined with radiation therapy. Head and neck cancer is associated with tobacco and/or alcohol abuse; thus these patients often have concurrent illnesses and occasionally concurrent malignancies such as bronchitis, pulmonary
emphysema, and/or cardiovascular disease. If the tumor interferes with eating, then weight loss, malnutrition, anemia, dehydration, and electrolyte imbalance can be significant. Thus the anesthesiologist’s job is not simply to put the patient to sleep and to wake him or her when surgery is over, but to maintain homeostasis during surgery. To do this, the anesthesiologist must plan for the rare situations in which a patient’s medical problems may exacerbate acutely, and at the same time manage the patient’s anesthesia, remaining mindful of any chronic medical conditions.

**PREOPERATIVE EVALUATION**

The ultimate goals of preoperative medical assessment are to reduce the morbidity of surgery and to return the patient to a desirable level of daily function as quickly as possible. These goals are best achieved by optimizing the patient’s health before surgery and by planning the most appropriate perioperative management. Therefore it is important for the anesthesiologist to obtain pertinent information about the patient’s medical, surgical, and psychiatric history to determine which tests and consultations are needed. The history should include a thorough review of systems, and a complete physical examination is required. The anesthesiologist should also educate the patient about anesthesia, perioperative care, and pain management to reduce anxiety, facilitate recovery, and make perioperative care more efficient and less expensive. The importance of these goals should not be overlooked during preoperative evaluation. Most of the data indicate that recovery occurs more quickly when the anesthesiologist allays the patient’s concerns and informs the patient about what is to come. Appropriate preoperative evaluation not only improves perioperative outcome but also reduce costs. Data supporting this claim are substantial, but indirect.

Studies of perioperative morbidity over several decades have repeatedly shown that preoperative patient conditions are significant predictors of postoperative morbidity. The data suggest that preoperative treatment of conditions such as congestive heart failure and diabetes can reduce the severity of disease and thus perioperative morbidity and mortality. It is important for preoperative evaluators to take a thorough history and to determine the extent of consultation needed with the primary care physician to judge optimal health and the potential to improve the patient’s preoperative status.

**Airway Evaluation**

Because airway problems cause substantial risk, the most important consideration regarding the respiratory system is securing the airway. Therefore airway evaluation must be set up to reveal any evidence of airway obstruction or restriction of neck and jaw movement. A personal interview is usually sufficient to reveal the condition of the airway, the respiratory reserve, and the possible need for laboratory evaluation, such as pulmonary function testing. The personal interview may also be the best time to educate the patient and family members about the time needed for cessation of smoking to be beneficial. The physical examination is used to assess for the
same conditions sought in the history as well as for conditions not solicited during history-taking. Examination of the airway and mouth for neck mobility, tongue size, oral lesions, and ease of endotracheal intubation are important. Initially the anesthesiologist performs a simple inspection from the front and side to identify obvious problems, such as massive obesity, a cervical collar, a traction device, external trauma, or any indications of respiratory difficulty, such as stridor. The presence of ear and hand anomalies often suggests that the patient may have a difficult airway as well. It is essential to establish nostril size and patency before considering nasal intubation.

Mouth opening, which is largely a function of the temporomandibular joint, is of prime importance to allow insertion of a laryngoscope blade and subsequent glottic visualization. Adults should be able to open their mouths so that there are 30 to 40 mm between the upper and lower incisors. Problems with mouth opening should not be underestimated, because they can make visualization of any laryngeal structures impossible. It may be risky to assume that a limited mouth opening is caused by a spasm that will reverse after neuromuscular blockade. Conversely, in some patients who are able to open the mouth widely while awake, adequate mouth opening while anesthetized is only possible when the mandible is pulled forward. Examination of the oral cavity focuses on identifying a long narrow mouth with a high arched palate that is associated with difficult intubation. A large tongue in relation to oral cavity size may make laryngoscopy more difficult. Mallampati et al emphasized the importance of the base of the tongue in determining the difficulty of laryngoscopy. If the faucial pillars (palatoglossal and palatopharyngeal arches) and uvula cannot be seen in a patient who is seated, vocalizing, and has the tongue protruding, then visualization of the glottis is likely to be more difficult than in patients in whom these structures are readily visible.

Head and neck patients are evaluated and treated as representing difficult endotracheal intubation and potential problems in airway management. Airway management may be complicated by an obstructing lesion or preoperative radiation therapy that has further distorted the patient’s anatomy. The anesthesiologist confronted with decisions regarding airway management and difficult endotracheal intubations for patients with compromised airways must have a thorough knowledge of the physical and functional anatomy of the larynx. Serious doubt about the security of an airway justifies the presence of an otolaryngologist during induction to establish an airway surgically, if necessary.

**Cardiovascular Assessment**

A patient’s cardiovascular status may have a significant impact on the types of ablative and reconstructive procedures that may be used to treat an upper aerodigestive tract malignancy, as well as on intraoperative and postoperative management. One of the earliest attempts to define cardiac risk was performed by Goldman et al at Massachusetts General Hospital. These investigators studied 1001 patients older than 40 years who were undergoing noncardiac surgery. Using multivariate logistic re-
progression, these authors demonstrated nine clinical factors associated with increased morbidity and mortality. Furthermore, numerous studies have evaluated the importance of single variables in perioperative risk. The presence of hypertension has been examined in several studies. Goldman and Caldera \textsuperscript{15} evaluated a cohort undergoing noncardiac surgery with general anesthesia, and many subsequent authors suggested that surgery be delayed in patients with a diastolic blood pressure higher than 110 mm Hg. Consistent with these findings, Hollenberg et al \textsuperscript{16} identified both hypertension and the presence of left ventricular hypertrophy as predictors of perioperative ischemia. In addition, multiple studies have demonstrated an increased incidence of reinfarction in patients who had sustained a previous myocardial infarction, if the myocardial infarction was within 6 months of surgery. \textsuperscript{17,18}

Preoperative systolic blood pressure has been found to be a significant predictor of postoperative morbidity.\textsuperscript{19-22} Patients found to have hypertension should be educated about the importance of lifelong treatment.\textsuperscript{19-22} Previous studies have shown that perioperative hemodynamic fluctuations occur less frequently in patients with treated hypertension when compared with those who have untreated hypertension, and hemodynamic fluctuations have some relationship to morbidity.\textsuperscript{15,23} In view of this, we recommend that patients diagnosed with hypertension take antihypertensive medications preoperatively.

Preoperative evaluation and management of ischemic heart disease is important. Any of the following conditions may indicate the presence of ischemic heart disease: a history of viselike chest pain, with or without radiation to the inner arm or neck; dyspnea on exertion, on exposure to cold, with defecation, or after eating (especially in postmenopausal women who do not take estrogen); orthopnea; paroxysmal nocturnal dyspnea; nocturnal coughing; nocturia; previous or current peripheral or pulmonary edema; a history of myocardial infarction; a family history of coronary artery disease; a diagnosis of myocardial infarction by ECG or elevated levels of enzymes; and cardiomegaly. Other patients who should be suspected of having ischemic heart disease include those who have diabetes, hypertension, left ventricular hypertrophy as documented by ECG or echocardiogram, peripheral vascular disease, asymptomatic carotid artery occlusion, unexplained tachycardia, or fatigue.\textsuperscript{24-26}

The important point to remember is that history is the best indicator of coronary artery disease. The presence of coronary artery disease, its severity, the time of most recent myocardial tissue death, the arteries affected, the complications, and the treatment of the disease are important information for the anesthesiologist. These variables influence the manner in which anesthesia will be administered and, in fact, may determine whether anesthesia and surgery should be postponed. Treadmill exercise testing, bicycle ergometer, dipyridamole-thallium imaging, dobutamine stress echocardiography, preoperative Holter monitoring, noninvasive imaging, and cardiac catheterization also add information to the history, increasing knowledge about the patient’s cardiac function and the likelihood of a perioperative cardiac event.\textsuperscript{27,28}
Patients should be evaluated if they have congestive heart disease, cardiomyopathies, ischemic heart disease, hypertension, disturbances in cardiac rhythm, pericarditis, arteritis, or other manifestations of atherosclerosis. These conditions require further evaluation to ensure that optimal treatment has been achieved before surgery. The intravascular volume loading that occurs during and after microvascular reconstructive surgery through the use of dextran and hydroxyethyl starch can negatively affect patients with congestive heart failure and poor ventricular function.

**Assessment of Patients With Diabetes**

The presence of diabetes has long been assumed to increase perioperative risk. Surgical mortality rates for patients with diabetes are, on average, five times higher than those for patients without diabetes. Because diabetes represents at least two disease processes, its perioperative management may differ. Long-term, “tight” control of type I diabetes probably prevents, retards, or even, to some degree, ameliorates some of the chronic complications of diabetes. Different regimens permit almost any degree of perioperative control of blood glucose levels, but the tighter the control desired, the more frequently blood glucose levels must be monitored. Individuals with type II diabetes tend to be elderly, overweight, relatively resistant to ketoacidosis, and susceptible to the development of a hyperglycemic-hyperosmolar nonketotic state. Plasma insulin levels are typically normal or elevated but are relatively low for the level of blood glucose. This hyperinsulinemia by itself is postulated to cause accelerated cardiovascular disease. Therapy for type II diabetes usually begins with exercise and dietary management. A 5 to 10 kg weight loss over 8 weeks, associated with a 20% reduction in calories and an increase in daily physical activity to 30 minutes, is often associated with normalization of fasting blood glucose. However, this is a difficult task for many patients, who then progress to the use of oral hypoglycemic medications that act by stimulating release of insulin by pancreatic beta cells and by improving the tissue responsiveness to insulin by reversing the post-binding abnormality.

Acute complications for diabetic patients include hypoglycemia and diabetic ketoacidosis, as well as hyperglycemic, hyperosmolar, nonketotic coma. Diabetic patients are also subject to a series of long-term complications, including cataracts, neuropathies, retinopathy, and angiopathy involving peripheral and myocardial vessels; these complications can lead to considerable morbidity and premature mortality. Many of these complications will bring diabetic patients to surgery. The evidence that hyperglycemia itself accelerates these complications, or that tight control of blood glucose levels decreases the rapidity of the progression of microangiopathic disease, is becoming more definitive.

The major risk factors for patients with diabetes undergoing surgery are the end-organ diseases associated with the disease: cardiovascular dysfunction, renal insufficiency, joint collagen tissue abnormalities (limitations of neck extension or poor wound healing), inadequate granulocyte production, and neuropathies. Thus a
major focus for the anesthesiologist should be the preoperative evaluation and treatment of these diseases, with appropriate consultation as necessary, to ensure optimal preoperative conditions.

**Assessment of Patients With Cirrhosis of the Liver**

Various complications associated with cirrhosis may require intervention before a patient undergoes anesthesia and surgery. Portal hypertension is associated with complications that are often refractory, including ascites, varices, and hepatorenal syndrome. Normally, pressure in the portal vein ranges between 5 and 10 mm Hg but rises when progressive disruption of the hepatic architecture distorts the normal channels for portal blood flow. When the portal pressure exceeds 10 mm Hg, a collateral circulation develops between the high-pressure portal system and neighboring low-pressure splenic veins, whereby portal blood is diverted to the systemic circulation.

The most clinically important portal system shunts are in the gastric and esophageal veins. These varices may rupture, resulting in gastrointestinal tract hemorrhage. Initial management of patients with gastrointestinal hemorrhage involves intravenous fluid resuscitation to correct hypovolemic shock; however, overvigorous fluid resuscitation can cause variceal rebleeding. Simultaneously, the specific source of bleeding must be sought. Although varices are common in patients with alcoholic cirrhosis, they are not the only source of bleeding, and endoscopy is necessary to establish the source. Thereafter, a combination of mechanical and pharmacologic interventions will limit the bleeding.

Ascites and generalized fluid retention are caused by portal hypertension and sodium retention that occurs with cirrhosis. Ascitic fluid is in dynamic equilibrium with plasma. If massive abdominal paracentesis is performed, a marked reduction in plasma volume occurs, resulting in hypotension and oliguria unless intravenous crystalloid and colloid solutions are given simultaneously. Ascites is usually treated by sodium and water restriction and administration of diuretics. In addition, the Child-Turcotte laboratory and clinical criteria are good predictors of operative survival. These predictions were based on a surgical cohort of patients undergoing portosystemic shunts.

Complicated alterations in drug pharmacokinetics occur in patients with chronic liver disease, making it difficult to predict the appropriate drug therapy for a particular patient. If possible, drugs that are excreted through the liver should be avoided or given in smaller doses. Intravascular fluid balance may be particularly difficult to manage intraoperatively, especially in patients with ascites who undergo laparotomy. Ascitic fluid is in dynamic equilibrium with plasma, so abdominal paracentesis will result in intravascular volume depletion. Rapid rehydration with a sodium-free colloid solution should be initiated as soon as ascitic fluid is lost. In patients with gastrointestinal hemorrhage, aggressive blood replacement should be initiated, preferably with whole fresh blood, in which the coagulation factors have been preserved.
Assessment of Dental and Oral Hygiene

Edentulous patients are seldom difficult to intubate unless other associated problems are severe. Protuberant upper incisors, on the other hand, can make laryngoscopy difficult and expose the teeth to damage. Isolated loose teeth are particularly prone to damage. These should be noted, as well as the location of crowns, bridges, braces, and other significant dental work. Bridges and dentures should be removed if possible, unless dentures significantly improve mask fit. Very loose teeth are best removed before laryngoscopy to avoid aspiration of the teeth. Most important, patients should be warned of likely damage to teeth both in person and in preoperative handouts.42

Most patients with head and neck cancer require radiation therapy for locoregional control.43 Therefore attention should be given to the dental health of these patients to prevent postradiation osteomyelitis resulting from untreated dental caries. Patients with fairly healthy teeth may need nothing more than dental health education and routine fluoride treatments. However, patients with multiple carious and/or fractured teeth require full-mouth dental extraction. A preoperative oral surgical assessment may help the operative planning for patients undergoing osseous free tissue transfer who want postoperative dental restoration.

Mucositis and xerostomia are the most common oral complications from nonsurgical cancer therapy. Mucositis is particularly disabling; it is commonly seen in cancer therapy and is almost universally seen after radiation therapy involving the oropharynx.44 The management of mucositis consists of palliative care and protection of the mucosa. Palliation may involve a topical anesthetic such as 2% lidocaine (Xylocaine) or narcotics in severe cases. Many commercially available compounds can be used to alleviate the discomfort of mucositis, which is generally a self-limiting condition that improves within 2 months after radiation therapy; however, it may persist in immunocompromised patients. Adequate hydration and nutritional intake is critical when dealing with a patient with severe mucositis.

Radiation therapy also may adversely affect the salivary glands, resulting in xerostomia. Radiation damage to the acinar and ductal salivary gland cells results in diminished or obliterated salivary flow. In patients who have undergone radiation therapy, the saliva has a lower pH, resulting in a more acidic oral environment.45 This leads to an increase in dental caries and oral infections. Patients also may have problems with speech, swallowing, and chewing food. Further complications of xerostomia may include esophagitis and nutritional insufficiencies. Xerostomia is often difficult to manage. Patients should be encouraged to increase their water intake, reduce dietary sugars, and use fluoride treatment to minimize the risk for developing dental caries. Artificial saliva substitutes are available that offer lubrication and protection of the mucosa and may aid in swallowing.
Assessment of Nutrition

Malnutrition occurs in 35% to 60% of patients with head and neck cancer, particularly those with oropharyngeal and hypopharyngeal squamous cell carcinoma.46,47 The cause is often multifactorial and may be related to tumor cachexia, odynophagia, or neuromuscular swallowing dysfunction related to the presence of the tumor or to lifestyle, dietary habits, and general inanition associated with several comorbid conditions.48 In addition, patients with head and neck cancer frequently have anorexia, early satiety, debilitation caused by prior chemotherapy and/or radiation therapy, and muscle wasting from the increased basal metabolic rate created by tumor metabolism.48 Mortality rates of up to 30% have been associated with a 20% preoperative weight loss.47

In patients without significant weight loss or who may not be aware of significant weight loss, serum albumin levels provide a good indicator of nutritional status.49 Because this protein has a half-life of approximately 20 days, it is a useful predictor of long-term protein storage. Serum protein indicators can be abnormally low in patients with liver disease. In this situation, the total lymphocyte count can be used as a marker of chronic inflammation.50 Clinical trials suggest that preoperative nutritional supplementation may benefit severely malnourished patients with head and neck cancer by decreasing the incidence of postoperative complications, because nutritional status has a critical effect on wound healing and immune function.51,52 Enteral feeding is the preferred route, and supplementation should be started at least 7 to 10 days before surgery.47 Nasogastric feeding tubes should be placed in patients who are unable to take adequate alimentation by mouth, although gastrostomy tubes are better tolerated. Intravenous hyperalimentation has also been found to be effective for nutritional support in patients with head and neck cancer but is associated with significant morbidities, including venous thrombosis and sepsis.50

ANESTHESIA

Intubation (Nasal or Oral) Versus Tracheostomy

Airway management may be complicated by an obstructing lesion or by preoperative radiation therapy that has distorted the patient’s anatomy.53 As always, if there is serious doubt regarding potential airway problems, intravenous induction should be avoided in favor of awake direct or fiberoptic laryngoscopy for cooperative patients (Fig. 7-1). On the other hand, inhalational induction should be used, with maintenance of spontaneous ventilation, for uncooperative patients. In any case, the equipment and personnel required for an emergent tracheostomy must be immediately available at the time of induction.
Nasotracheal intubation is generally preferred for resection and reconstruction involving the oral cavity. The nasotracheal tube should be positioned away from the operative field and must be adequately secured with tape or sutures. The nasotracheal tube, along with the patient’s occiput, should also be well padded to prevent pressure ulceration. Elective tracheostomy under local anesthesia is a prudent option, particularly if indirect laryngoscopy shows the lesion to be susceptible to dislodgement during intubation.54

It should be remembered that the presence of an endotracheal tube might lead to edema, desquamation, inflammation, and ulceration of the airway.55 The first three conditions usually are self-limited, whereas ulceration is more serious. Typically it occurs over the posterior half of the vocal cords, the medial arytenoids and posterior cricoid surfaces, and the anterior portion of the trachea. Severity may be related to the duration of intubation.56 In addition, the endotracheal tube should be set up carefully to prevent any possible pressure sore over the nasal area. Tracheostomy is

Fig. 7-1  Correct technique for manipulating a fiberoptic bronchoscope through a tracheal tube. A, Postoperative view of a patient who underwent surgery for buccal carcinoma. B, Correct technique for handling a flexible fiberoptic bronchoscope. C and D, Insertion of nasal tracheal tube with the assistance of a fiberoptic bronchoscope.
associated with tracheal erosion, particularly into the esophagus or brachiocephalic artery. Tracheostomy tubes generally sit lower in the trachea and have a built-in, fixed curve. They are more rigid and do not necessarily conform to the shape or morphologic features of the trachea, potentially causing pressure on tissues at the tube tip. It should be noted that a major complication is tube malposition. As soon as a tracheostomy tube is placed, end-tidal concentrations of CO₂ and oxygen saturation must be checked. Inspections should be made for other complications as well, such as bleeding and local emphysema.

Maintenance of Anesthesia

Deliberate hypotension has been used successfully for a variety of surgical procedures, including head and neck surgery, procedures on the cranium, and radical cancer operations. According to one definition, deliberate hypotension is a decrease in mean arterial pressure to 50 to 65 mm Hg in normotensive patients. A mild hypotensive technique may be helpful in limiting blood loss, thereby improving operating conditions or decreasing the need for blood transfusions. Body positioning, the hemodynamic effects of mechanical ventilation, and changes in heart rate and circulatory volume can be used along with drugs to lower blood pressure to the desired level. The appropriate use of physiologic maneuvers helps decrease the dose of potentially toxic drugs needed to produce hypotension. An ideal agent for inducing hypotension would be easy to administer and have a predictable and dose-dependent effect, rapid onset and recovery from effects, quick elimination without the production of toxic metabolites, and minimal effects on blood flow to vital organs.

Many anesthetic and vasoactive drugs have been used successfully to produce deliberate hypotension, including volatile anesthetics, direct-acting vasodilating drugs, autonomic ganglion-blocking drugs, alpha-adrenergic receptor blocking drugs, beta-adrenergic receptor blocking drugs, combined alpha-adrenergic and beta-adrenergic receptor blocking drugs, and calcium-channel-entry blocking drugs. When considering the many facets of deliberate hypotension, the concern of the anesthesiologist should be directed toward not only selection of the most appropriate hypotensive drug but also the type of surgery, length of procedure, need to decrease blood loss, and patient suitability. In addition, several relative contraindications for deliberate hypotension must be considered. For example, a history of cerebrovascular disease, renal dysfunction, liver dysfunction, or severe peripheral claudication suggests that the patient is less likely to have good organ perfusion during hypotension. Similarly, patients with hypovolemia or severe anemia are not suitable candidates, because their reserves for adequate organ perfusion are markedly diminished. Beat-to-beat measurement of arterial blood pressure is essential for patients undergoing clinically significant and deliberate decreases in blood pressure. We suggest that an arterial catheter be inserted for continuous monitoring of blood pressure as a routine practice. This catheter also allows for intermittent sampling of arterial blood for blood gas analysis.
During radical lymph node dissection of the neck for carcinoma, manipulation of the carotid sinus may elicit a vagal reflex that causes bradycardia, hypotension, or even cardiac arrest. Although venous air emboli are usually associated with neurologic procedures, open neck veins create the possibility of air emboli during head and neck surgery. An end-tidal CO₂ monitor can indicate a sudden fall in CO₂ tension, and a precordial Doppler probe can pick up the murmur characteristic of venous air embolism.

Following reanastomosis of a microvascular free flap, blood pressure should be maintained at the patient’s baseline level. Vasoconstrictive agents (such as phenylephrine) should be avoided, because, even though systemic blood pressure increases, flap perfusion decreases because of vasoconstriction of graft vessels. Likewise, vasodilators (such as sodium nitroprusside or hydralazine) should be avoided because of decreased perfusion pressure.

**Fluid**

The goal of intravenous fluid therapy in microvascular surgery is to maintain intravascular fluid volume for optimal tissue blood flow and oxygen transport to all tissues, including the transferred free tissue. General problems include prolonged surgical procedures that often result in hypothermia and peripheral vasoconstriction, which may affect blood flow to the transplanted tissue. The surgical wounds may also be extensive and can cause profound and sometimes underestimated fluid and blood loss. The choice of fluids is important, because free flaps and replants have an increased risk of developing edema from lack of lymphatic drainage and a decreased ability to reabsorb excessive interstitial fluid. Therefore it is suggested that crystalloids be used only for insensible fluid loss, but that synthetic colloids be used for the replacement of plasma constituents. Blood loss can be rapid and substantial. To optimize blood flow to a free flap, it is advisable to use moderate hemodilution. This facilitates the maintenance of high cardiac output and low peripheral vascular resistance. In addition, body temperature should be kept as close to normal as possible and, after completion of the microvascular anastomosis, arterial blood pressure should be kept near normal, to ensure adequate perfusion pressure. Transfusion decisions must balance a patient’s medical problems with the possibility of an increased cancer recurrence rate as a result of immune suppression following blood transfusion. Diuresis should be avoided during microvascular free flap surgery to allow adequate graft perfusion in the postoperative period.

**Monitoring**

Because of the substantial blood loss associated with many head and neck procedures and the prevalence of coexisting cardiopulmonary disease, these patients often require arterial cannulation for blood pressure, blood gas, and hematocrit monitoring. A minimum of two large-bore intravenous lines should be secured and a urinary
A catheter placed. Arterial and venous lines should not be set up over a donor area. A urinary bladder catheter is usually adequate for assessing intravascular volume and cardiac output, and central venous catheters are not necessarily helpful in routine cases. They should, however, be considered for patients with significant renal dysfunction in whom intravascular volume should be carefully monitored, and for patients with significantly impaired ventricular dysfunction or coronary artery disease. 

Inspiratory gases should be warmed and humidified, and a forced-air warming blanket should be positioned over the nonoperative body surface to help maintain normal body temperature. Intraoperative hypothermia and consequent vasoconstriction can be particularly detrimental for perfusion of a microvascular free flap. In addition, because of the proximity of the airway to the surgical field, the anesthesiologist's location is more remote than usual. This increases the likelihood of serious intraoperative airway problems such as endotracheal kinking, disconnection, or perforation by a surgical instrument. Airway monitoring of end-tidal CO\textsubscript{2}, peak inspiratory pressures, and esophageal stethoscope breath sounds attains increased importance in such cases. Moreover, particular attention should be paid to the draping around the endotracheal tube to ensure easy access of the tubing connections and the balloon of the cuff during the operation.

**Extubation**

The ability to predict adequate respiratory function after extubation depends on many factors. In broad terms, anesthesia and specific pharmacologic therapies used to permit tracheal intubation and mechanical ventilation must be sufficiently reversed. In addition, any underlying pathologic determinants of the need for mechanical ventilation, such as pneumonia, must be treated, so that spontaneous ventilation can sustain adequate cardiopulmonary function. Predicting whether a patient will tolerate tracheal extubation after general anesthesia also requires knowledge of the patient’s current cardiopulmonary status as well as the presence and impact of residual anesthetics, including muscle relaxants. The cardiopulmonary system is of particular concern, especially if organ dysfunction and pathologic conditions might preclude immediate postoperative extubation. Cardiopulmonary function criteria focus primarily on ventilatory, hemodynamic, hematologic, and neuromuscular considerations. Specific respiratory concerns include breathing pattern, ventilatory drive, airway function, ventilatory muscle strength, and gas exchange. Cardiovascular concerns include hemodynamic stability to ensure adequate circulation and respiratory gas transport. Hemoglobin levels sufficient for adequate oxygen transport and hemostasis should be achieved. The impact of residual neuromuscular blocking agent and determination of its adequate reversal is also important.

Whereas certain circumstances may demand a “deep” extubation, it is our recommendation that extubation of the trachea should be performed while the patient is fully awake, if at all possible. For most patients in our intensive care unit, adequate
recovery of the ability to maintain and protect the airway must be demonstrated after the use of neuromuscular relaxants. It is important to remember that adequate ventilation through an endotracheal tube does not guarantee muscle strength to maintain the airway. There are several ways to increase the successful rate of extubation. Sustained (at least 5-second) head lift is an excellent way to clinically assess the adequacy of reversal. If head lift is contraindicated or painful, leg lift or sustained tongue protrusion can be similarly assessed. In addition, the pattern of spontaneous breathing provides information about respiratory efficiency and the likelihood of successful extubation. Two types of breathing patterns, either a rapid, shallow breathing pattern or a paradoxical breathing pattern (asynchronous motion of the rib cage and abdomen), indicate an increased risk that extubation will not be successful or that it is failing.

Rapid, shallow breathing is often caused by mechanical dysfunction and causes inefficient gas exchange. Yang and Tobin studied patients in intensive care units and found that the frequency of breaths per minute divided by the tidal volume in liters (f/Vt) is a reliable predictor of extubation success. Patients with f/Vt values of less than 100 had successful tracheal extubation. Paradoxical breathing can imply the onset of respiratory failure, especially in cases of pulmonary insufficiency. Respiratory muscle fatigue can underlie this phenomenon, and in an attempt to conserve energy, the intercostal muscles and diaphragm contract alternately. Paradoxical breathing patterns are also seen in patients with significant residual neuromuscular blocking and/or airway obstruction.

Experience, technique, and clinical skill are essential for routine postoperative tracheal extubations. Our recommendations are based on our experience as well as that of others. Before extubation, patients should be free of processes known to cause or exacerbate airway obstruction. The possibility of such a problem is likely to be increased with surgery of the head and neck. Often a quick, gentle look with a laryngoscope can detect potential problems, such as edema or persistent bleeding in the airway. In addition to direct visualization, gentle suctioning can also be diagnostic, as well as therapeutic, by removing substances such as blood. Although finding some bloody debris during initial suctioning is not unusual, repeat efforts should be less productive. The ease or difficulty of ventilation by bagging and masking and that of the subsequent intubation should also be considered.

Obviously, adequate spontaneous ventilation should be established before tracheal extubation. The tube is removed after a positive pressure breath has been given with the anesthesia bag to allow expulsion of secretions out of the glottis. An advantage of this method is reduced coughing on the endotracheal tube that may lessen laryngotracheal trauma and cause less adverse effects. There are a number of potential high-risk extubations for which special care must be taken when the ability to immediately reestablish the airway is questionable. The endotracheal tube may be removed while leaving a device such as a tube changer within the trachea so that the airway can be
immediately reestablished if necessary.\textsuperscript{64} Note that the presence of such a device does not guarantee that the tracheal tube can be replaced. The presence of an individual who can establish a surgical airway (along with the necessary equipment) may be reasonable in selected instances of anticipated difficult extubation. If there is a chance of postoperative edema involving structures that could potentially obstruct the airway, the patient should remain intubated.

**CRITICAL POINTS**

**Must Know**
- Head and neck cancer patients are evaluated and treated as if they will have difficult endotracheal intubation and problems in airway management.

**Should Know**
- If there is serious doubt regarding potential airway problems, intravenous induction should be avoided in favor of awake direct fiberoptic laryngoscopy (in cooperative patients) or inhalational induction while maintaining spontaneous ventilation (in uncooperative patients).
- The equipment and personnel required for an emergency tracheostomy must be immediately available.

**Synopsis**
- Patients with head and neck cancer often have concurrent illnesses and, occasionally, concurrent malignancies.
- The purpose of preoperative evaluation is to be able to plan the anesthetic procedures based on the patient’s physiologic limitations and to minimize risk to the patient by recognizing and optimizing comorbid conditions.

**References**

Successful preoperative evaluation and perioperative anesthetic management of cardiac patients undergoing noncardiac surgery require good communication among the patient, the anesthesiologist, and the surgeon, as well as excellent cooperation between the surgeon and anesthesiologist with a tacit understanding of the perioperative risks. In this study, 196 cardiac patients undergoing noncardiac surgery were followed. Risk factors were varied. Only 26.5% (52) and 16.8% (33) of the patients had been preoperatively evaluated by a cardiologist and an anesthesiologist through consultation. The number of preoperative specific cardiac tests totaled 34, and 41 patients (20.9%) required postoperative intensive care. There were two perioperative fatalities and 14 perioperative cardiac events.


Various noninvasive tests have been proposed to stratify perioperative cardiovascular risk, including dipyridamole thallium scintigraphy (DTS), ejection fraction estimation by radionuclide ventriculography (RNV), ischemia monitoring by ambulatory electrocardiography (AECG), and dobutamine stress echocardiography (DSE). The authors evaluated 56 studies examining one or more of the four tests. The authors conclude that DTS, RNV, AECG, and DSE are effective in predicting the cardiac outcome after vascular surgery.


This study is of a novel system for management of anticipated difficult airway (responsive contingency planning). It is based on the notion that almost all problems in airway management have already been experienced, so they can be anticipated and prepared for using worst case planning. Thirty-two patients with dental abscess were recruited for anaesthetic airway management based around the new scheme. Data collection involved a preoperative assessment of problems specific to dental abscess, fascia-spaces involved, details of the contingency planning process, laryngoscopy grade, and comments regarding the efficacy of the new system. The system fulfilled expectations for its use at this stage of development.


The authors suggest a need for elective tracheostomies in patients with extensive malignancies and in those for whom two-staged surgery is planned. For head and neck onc plast ic surgery, the authors also suggest that tracheostomies may be more frequently indicated for postoperative reasons than for securing the airway for the anesthetic and postoperative period.


The goal of intravenous fluid therapy in microvascular surgery is to maintain intravascular fluid volume for optimal tissue blood flow and oxygen transport to all tissues, including the free transferred tissue. General problems include prolonged surgical procedures, frequently resulting in hypothermia and peripheral vasoconstriction, which may affect blood flow to the transplanted tissue. The choice of fluids is important, because free flaps and replants are at increased risk of developing edema from lack of lymphatic drainage and a decreased ability to reabsorb excessive interstitial fluid. Therefore the author suggests that crystalloids be used only for insensible fluid loss and that synthetic colloids (preferably pentastarch) be used for the replacement of plasma constituents. Hypertonic saline solution may have beneficial effects in ischemic and edematous flaps and replants.


The traditional predictors of the outcome of weaning from mechanical ventilation are minute ventilation and maximal inspiratory pressure. The authors developed two new indexes: the first quantitates rapid, shallow breathing as the ratio of respiratory frequency to tidal volume, and the second is termed CROP, because it integrates thoracic compliance, respiratory rate, arterial oxygenation, and maximal inspiratory pressure. The authors conclude that rapid, shallow breathing, as reflected by the \( f/V_T \) ratio, is the most accurate predictor of failure and its absence the most accurate predictor of success in weaning patients from mechanical ventilation.
Postoperative care of microsurgical patients is of the utmost importance, because the viability of the flap is most at risk in the immediate postoperative period. Good quality care ensures that any flap circulatory problems are identified early and, particularly in patients who undergo head and neck microsurgery, can help ensure an uncomplicated recovery. In addition to the microsurgical issues in head and neck patients, consideration must often be given to airway management, because many of these patients have a tracheostomy at the time of surgery. Flap circulation is an im-

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portant issue, and although we have moved away somewhat from the large-volume IV fluid regimens,\textsuperscript{1} it is nevertheless important to ensure adequate hydration, room temperature, and analgesia.

Head and neck patients are somewhat unique among microsurgical patients, because they are generally older, frequently have significant comorbidities, and often have a history of smoking. Although smoking may have a significant impact on the survival of pedicled flaps, this does not seem to be the case with free flaps.\textsuperscript{2} We have previously shown that microsurgery is safe in older populations, though the risk of medical complications is significantly higher.\textsuperscript{3} Prior radiation therapy is another common feature in the head and neck patient. It has been shown that prior radiation has no effect on free flap survival; however, it does create problems with wound healing and pedicled flaps,\textsuperscript{2} particularly when the pedicle is within the irradiated field.

Some issues of management are intuitive. For example, tracheostomy ties should not be used because of the risk of pedicle compression. Instead, the tracheostomy can easily be sutured in position, eliminating the need for ties.

Fluid resuscitation has evolved with microsurgery and with our comfort in performing these procedures. In the early days, it was popular to overhydrate patients. In young, healthy patients undergoing a free flap surgery for trauma, problems with overhydration are rare. However, because many head and neck patients are older and have comorbidities, they are less tolerant of high fluid volumes. Therefore fluid management for microsurgical patients should be similar to that used for postoperative patients requiring normal hydration.

**Patient Positioning**

The head of the bed is generally elevated 30 degrees for postoperative head and neck patients. This helps minimize postoperative edema and facilitates airway management. The donor site must also be considered and supported. When a fibula flap is used, the patient’s leg should be elevated to minimize edema. Similarly, the forearm should be elevated if the radial forearm flap is used.

**Flap Monitoring**

Although we have not found the ideal monitoring device for flaps,\textsuperscript{4} a combination of modalities can be used to monitor flaps reasonably well. A dedicated clinical nursing staff adept at clinical monitoring is essential. Clinical monitoring remains the benchmark index, and no single device is a substitute. This is best achieved in a dedicated microsurgical step-down unit where all flap patients receive care immediately after surgery. However, this is a luxury that is not universally available. Clinical monitoring becomes difficult when the flap is buried and not visible or is difficult to see—a
situation that occurs not infrequently in the head and neck. In this situation, all the tools available must be used to monitor the flap, including a combination of clinical and Doppler monitoring in the form of an implantable Doppler probe, a surface Doppler reading, or both. The Cook-Swartz implantable Doppler device\textsuperscript{5} can be a very effective adjunctive tool in postoperative flap monitoring. The use of microdialysis is also reported to be effective for continuously monitoring flaps postoperatively.\textsuperscript{6} Regardless of the monitoring technique used, the goal is to detect any circulatory problems in the flap as early as possible; flap salvage is more likely to be successful if the patient is returned to the operating room for reexploration as soon as possible.\textsuperscript{7}

**Postoperative Nutrition**

The management of postoperative nutrition depends on several factors, such as a patient's status, the surgery performed, and anticipated complications. Patients who have undergone free flap reconstruction generally have an NPO status for 24 hours postoperatively in case they need to return to the operating room for flap reexploration. Depending on the procedure performed, patients may remain intubated and/or sedated for the first 24 hours. In these cases, oral intake is resumed once a patient is fully awake and recovered. Patients who have any form of intraoral reconstruction are not fed orally in the initial postoperative period. These patients generally have a nasogastric tube inserted through which nutrition can be resumed when they are fully recovered from anesthesia and the chance of reoperation is less likely. Depending on the protocol, these patients are tube fed for 7 to 10 days to allow intraoral healing before beginning oral food. Furthermore, it may be necessary to evaluate a patient's capacity to swallow before oral feeding begins. This is particularly relevant in patients who have had surgery to the tongue, pharynx, and pharyngoesophagus. Some of these patients may never resume oral feeding, so each patient needs to be evaluated individually.

**Tracheostomy Care**

Many head and neck patients undergo a tracheostomy before or during the procedure. This is often a temporary tracheostomy, and a protocol needs to be developed for its management. Such a protocol is available in most units and consists of regular suctioning and cleaning, changing the cuffed tube to a fenestrated tube after the initial postoperative period, and decannulating within 7 to 10 days of surgery. Obviously, this protocol is individualized for each patient and presumes ultimate removal of the tracheostomy. Laryngectomy patients have a permanent tracheostomy, and the teaching of “trach” care needs to be part of the postoperative teaching and nursing care.
MANAGEMENT OF THE DONOR SITE

Whether the donor site requires special attention depends on the donor site and a patient’s general condition. Donor site incisions do not usually require special care. However, if the donor site has been skin grafted, a decision has to be made regarding its management. In general, our practice is to mobilize patients as early as possible in the postoperative period to avoid complications, including deep venous thrombosis (DVT) and pulmonary atelectasis. If subcutaneous heparin is used for DVT prophylaxis, which is our routine, it is typically administered until the patient is ambulatory. Patients who have had lower limb flaps, such as the anterolateral thigh or fibula flap are mobilized early in the same way as any other patient. However, if the fibular donor site has been grafted, we immobilize the limb in a below-knee plaster backslab and maintain the patient on bed rest for 5 days. At that time, if the graft has taken, the patient is slowly mobilized over the next several days, starting by dangling the leg over the edge of the bed to ensure graft stability and supporting the limb in an Ace or Tensor bandage.

PAIN MANAGEMENT

Effective pain management minimizes patient discomfort while maximizing patient alertness to avoid interference with mobilization. Patient-controlled analgesia (PCA) is an effective way to ensure adequate pain management while restoring control to the patient. The use of a pain pump through which bupivicaine is topically delivered to the wound is often an effective way to control donor site pain. It has the added benefit of reducing the patient’s narcotic requirement and contributes to early mobilization.

ANTIBIOTIC AGENTS

Antibiotic agents are given to most patients who undergo head and neck surgery. The choice depends on the individual features of the case. For most patients, broad-spectrum coverage is required. When the oral cavity has been in the surgical field, coverage for anaerobic microorganisms is also included. Antibiotics are typically administered intravenously in the operating room before beginning the procedure. The duration of treatment is the surgeon’s choice and depends on the nature of the surgery, the risk of postoperative infection, and the presence of surgical drains, among other factors.

DRAINS

The management of drains varies according to each surgeon’s preference. However, drains are generally left in place until drainage has reduced to a fairly minimal amount. Most surgeons arbitrarily choose 50 ml/day, but the amount depends on the individual circumstances of each case.
DRESSINGS

Dressings are not typically a major issue in head and neck reconstruction and are generally used only on the donor site. Most of the time, incisions are treated with topical antimicrobial ointments such as bacitracin. The exception is the situation in which the flap has to be skin grafted, such as when a scalp defect is covered with a skin-grafted latissimus flap. Each surgeon has his or her preference. We prefer to cover the graft with a nonstick gauze, such as a Vaseline-impregnated gauze or Xeroform dressing covered with a loose layer of dry gauze secured with tape or, more frequently, stapled in position. Above all, constrictive dressings that may cause pressure on the flap pedicle should be avoided.

CRITICAL POINTS

Must Know

- Ensure optimal patient positioning to minimize postoperative edema and maximize airway management.
- Ensure appropriate flap monitoring to recognize flap circulatory problems as early as possible.
- Ensure donor site integrity through early but cautious mobilization.
- Ensure adequate pain management using PCA.

Should Know

- Make certain that the patient is educated in appropriate temporary and permanent tracheostomy care.
- Order tube/oral feeding to allow adequate nutrition intake during the healing stage.
- Provide a wide range of antibiotic agents to ensure appropriate coverage.
- Remove drains when drainage is minimal.
- Prevent pressure on the flap pedicle by avoiding constrictive dressings.

Synopsis

- Proper and adequate postoperative care in patients with head and neck cancer ensures that any flap circulatory problems are identified early, which assists in an uncomplicated recovery.
References


   The anaesthetic management of patients undergoing free flap transfer is discussed in the light of experience over 4 years. There is no single factor responsible for the success of this type of operation. But as the team gained experience, the incidence of vessel spasm and/or occlusion was greatly reduced.


   This paper discusses a review of 854 consecutive free flaps to determine whether the choice of flap used for reconstruction influenced the probability of a successful outcome. Flaps were grouped into nine categories. There was a strong trend favoring survival of flaps without a bone component, and a weaker trend favoring survival of flaps in nonobese patients. Smoking, age, and previous irradiation had no significant effect on flap failure rates. Surgeons should consider the flap success rate as one (but not necessarily the most important) factor in choosing the best reconstruction for any patient.


   Free tissue transfer is a commonly used reconstructive tool. Vascular compromise is still a common complication, and salvage rates of compromised flaps are approximately 50%. Numerous monitoring techniques have been tried, yet no single technique has enjoyed universal acceptance. This paper reviews the available techniques and indicates where current trends are leading.


   Approximately 5% of microvascular free tissue transfers fail, often from microvascular or perianastomotic thrombosis. Various reports have advocated the use of thrombolytics for salvage of these flaps, although clinical evidence supporting this approach is sparse. The authors review their own and other published results and present an algorithm for the use of thrombolytics to manage failing free flaps. There was no statistically significant difference among groups with respect to preoperative risk factors, age, gender, flap type, and site of anastomotic thrombosis. Although early detection and reexploration are crucial for salvaging failing free flaps, flaps unresponsive to other standard interventions may benefit from selective use of thrombolytics.


Drugs in Microsurgery

Patrick Addison, Peter C. Neligan, Cho Y. Pang

HIGHLIGHTS

- Maintaining adequate blood flow in tissues, organs, and flaps is vital for successful flap surgery.
- Understanding the roles of cellular mechanisms, such as those of erythrocytes, platelets, neutrophils, and the endothelium, is important for the practicing microsurgeon.
- Intraoperative vasospasm can increase the risk of flap failure.
- The ischemic tolerance of pedicled flaps is higher than that of free flaps.
- Severe ischemia-reperfusion injury (IRI) culminates in vasoconstriction that may prove difficult to overcome, despite adequate arterial and venous anastomoses.
- Pharmacologic intervention in microsurgery includes a wide range of systemic and topical preparations, such as anticoagulants, thrombolytic agents, and antispasmodic agents.
- Nonpharmacologic therapies, such as flap cooling, washout, and ischemic preconditioning, have been used to minimize flap ischemic complications.
Advances in our understanding of the physiology of flap perfusion, IRI, and the causes of flap failure have helped to reduce the overall failure rate to less than 5%. This reflects improved microsurgical technique, better patient monitoring and postoperative management, and pharmacologic manipulation of the normal circulatory physiology when necessary to prevent or manage complications and, in some cases, to augment flap survival. This chapter presents all aspects of normal flap physiology and the potentially beneficial and harmful effects of pharmacologic intervention in microsurgery.

Research in wound healing, coronary and peripheral vascular disease, and tissue transplantation provides great insight into the physiologic and pharmacologic control of flap microcirculation. However, the specific physiologic responses to the processes of harvesting and transferring flaps are complex. These effects are the subject of intensive, ongoing research that aims to further reduce the rate of flap failure.

**NORMAL REGULATION OF BLOOD FLOW**

The local regulation of blood flow depends on the balance among neural, humoral, metabolic, and mechanical influences (Table 9-1; Fig. 9-1). Neural control is exerted through the sympathetic (adrenergic) nervous system, which causes vasoconstriction, and through the parasympathetic (cholinergic) nervous system, which causes vasodilation. Humoral substances released by the endothelium and a variety of blood cells also regulate local blood flow. Vasodilators include the endothelium-derived relaxing factors (prostacyclin and nitric oxide), bradykinin, histamine, and cytokines, such as vascular endothelial growth factor. The common vasoconstrictor substances include norepinephrine, endothelin-1, serotonin, thromboxane A₂, leukotriene, thrombin, and hemoglobin. A fine and complex balance exists between these substances that tightly regulates local blood flow to different organs and tissues. The metabolic influences include hypoxia, hypercarbia, and acidosis, resulting in systemic vasodilation at the expense of local flap perfusion. Therefore maintaining adequate ventilation, oxygenation, and circulatory volume are also essential prerequisites for successful flap surgery. The mechanical or physical factors that influence blood flow include vascular distention, blood viscosity, and hypothermia, all of which promote vasoconstriction; hyperthermia and reduced blood viscosity have the opposite effect. The importance of keeping the patient warm, normotensive, and well perfused in the postoperative period is logical and well established.
### Table 9-1  Factors Influencing Blood Flow

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<td>Hypothermia</td>
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Factors in lightface type are vasodilatory; factors in **boldface type** are vasoconstrictive. *VEGF,* Vascular endothelial growth factor.

*Fig. 9-1*  Neurohumoral, metabolic, and physical controls in local regulation of blood flow in tissues and organs.
NORMAL CIRCULATORY PHYSIOLOGY

Skin

The basic anatomy and functions of the skin are well known. With a surface area of around 2 m² in the adult and a variable thickness of 0.5 to 4 mm, skin composes, on average, 5% of the total body weight and receives about 2% of the total cardiac output, approximately 400 ml/min. Blood flow is highly variable and tightly regulated through a series of interconnected, horizontal plexuses in and around the dermis. The oxygen consumption of skin is low, so there is little difference between oxygen tension in the arterial and venous circulation. Instead, flow is largely nutrient (10%) and thermoregulatory (90%). For this reason, skin has a relatively high critical ischemia time.

The skin also serves as a reservoir of blood. In a resting adult, the dermal vessels contain approximately 10% of the total circulatory volume, most of which can be returned to the core circulation by peripheral vasoconstriction if required.

Other functions include regulation of body temperature, synthesis of vitamin D, and sweating. The latter serves to excrete salt and some organic compounds. Protection from the damaging external environment, including trauma, infection, dehydration, and ultraviolet radiation, is provided through the mechanical and physiologic properties of skin.

The circulatory physiology of the skin is of most concern to microsurgeons. Arterial vessel walls contain smooth muscle innervated by sympathetic nerve fibers under central control. Decreased arterial blood pressure causes reflex vasoconstriction to restore the pressure. The vessels are also sensitive to local metabolites such as nitric oxide and prostanoids, which mediate the reactive hyperemia that follows brief periods of ischemia.

Veins that drain these vascular beds comprise large venous plexuses, especially in the limbs, providing a large surface area for heat exchange. Arteriovenous anastomoses (AVAs), composed almost exclusively of smooth muscle, are numerous in the palms, soles, and skin of the ears, nose, and lips. Flow here is nonnutrient, and the vessels have a low basal tone that is very sensitive to sympathetic stimulation and influenced by core and external environmental temperatures. The AVAs and the systemic blood pressure are regulated by pre-AVA sphincters under postganglionic sympathetic control.3,4 An increase in core temperature, sensed in the hypothalamus, results in a reduction of norepinephrine release, vasodilation, and thus heat loss through the skin. Under these conditions, skin blood flow may increase by a factor of 30. The converse is also true, although maximal vasoconstriction normally only reduces skin circulation by a factor of 10, to the minimum nutritional requirement of about 40 ml/min.5
Vasoconstriction is naturally accompanied by relative ischemia of the skin, but to mitigate the effects of this ischemia, the skin circulation is known to cycle between periods of vasoconstriction and vasodilation when subjected to prolonged exposure to a cold environment. The mechanism underlying this phenomenon may be the loss of smooth muscle contractility as a direct result of cooling. In addition, cooled skin promotes the accumulation of vasodilatory metabolites.

The local application of heat directly to the skin stimulates vasodilation, and the direct application of cold causes vasoconstriction. These responses are independent of core temperature changes and occur in denervated skin, demonstrating a locally mediated reflex control of vascular tone. This is important in the maintenance of flap circulation in the postoperative period, because free flaps are completely denervated and pedicled flaps are denervated to a large degree. Neuronal pathways permit peripheral vasodilation or constriction in response to a local, topically applied hot or cold stimulus, even when the core body temperature is unaltered.

Precapillary sphincters regulate nutritional flow through the capillary bed. Vasodilation occurs in response to either hypoxia or the accumulation of metabolites, resulting in an increase in oxygen delivery and a washout of the metabolites.

Blood is distributed to the skin by a number of large arteries that send branches to the skin and perforate through muscle, either along the intermuscular septum or directly in the subcutaneous plane. Most of these are accompanied by one or two vena comitantes, and heat is exchanged between the artery and vein along this axis. Each arteriovenous unit supplies a defined, though variable, cutaneous territory known as an angiosome. Neighboring angiosomes overlap, resulting in some redundancy of the skin circulation that is exploited in the design of many different flaps. So-called choke vessels communicate between neighboring angiosomes and can be encouraged to open up, extending the territory of a particular angiosome. This is one of the mechanisms thought to be responsible for the delay phenomenon. Similar, though less-well-characterized vascular territories, exist in the deeper levels of muscle and connective tissue.

Flap color depends on the skin thickness, pigmentation, and dermal blood flow and oxygenation. A cold environment postoperatively decreases the dissociation of oxygen from oxyhemoglobin, leaving the tissue deprived of oxygen while the flap remains a healthy color.

Other stimulants, such as pain and anxiety, induce vasoconstriction through humoral and neural mechanisms and must be minimized in the postoperative period.
Muscle
Approximately 20% of the cardiac output flows through the body’s musculature at rest, which is around 1 to 4 ml/min/100 g. During maximal exertion this can rise significantly, to between 50 and 100 ml/min/100 g, equivalent to a 20- to 50-fold increase. The arterioles are the main point of blood flow regulation to the skeletal muscle. The increased metabolic demands that occur during exercise are not normally applicable in free flap surgery. However, although normal muscle contraction aids local blood flow, this effect is lost in muscle transfers, at least until functional recovery begins.

At rest, significant sympathetic tone results from the vasoconstrictive effects of alpha-adrenoceptor stimulation. This may be alleviated with alpha-blocking drugs, but in the denervated free flap, the same effect occurs without medication. Muscle blood flow in the reperfused muscle transfer flap may increase relative to the pretransfer state. During exercise, vasodilation results from beta2-adrenoceptor stimulation by agonists such as epinephrine and from the activation of sympathetic cholinergic nerves. In addition, local factors such as tissue hypoxia, adenosine, K+, CO2, H+, and nitric oxide may override the sympathetic vasoconstrictor influences. Muscle also demonstrates autoregulation of blood flow. In situations of decreased flow, vessels dilate to restore flow toward normal.

Bone
As in skin and muscle, the regulation of blood flow and nutrition in bone involves the autonomic nervous system and humoral and local factors. Endogenous norepinephrine controls flow through a constrictor effect on the bone vasculature. Blood flow at the bone ends initially decreases for 2 days after an injury, followed by a significant and prolonged increase, specifically at the site of the injury. The mechanism of this effect has yet to be completely understood.

Local Regulation of Blood Flow in Pedicled and Free Flaps
Most of the neurohumoral pathways described previously also play a central role in the local regulation of blood flow in pedicled flaps, but in free flaps this balance is altered. Division of the neurovascular pedicle before the flap transfer denervates the flap and eliminates the influence of the autonomic nervous system. It is likely, therefore, that humoral and local reflex and mechanical influences are most significant. The sources of these humoral substances and their significance in free flap surgery are discussed in more detail in the following sections.
THE CELLULAR MECHANISMS OF BLOOD FLOW CONTROL

The Role of Erythrocytes

Oxyhemoglobin, released from red cells during surgery as a result of hemolysis, induces local vasoconstriction.8,9 The mechanism may involve the production of superoxide anions that destroy endothelium-derived relaxing factors, such as nitric oxide, and promote an increase in intracellular calcium. The presence of a hematoma near the vascular pedicle of a flap therefore promotes vasospasm and presents a risk of external, mechanical compression (Fig. 9-2).

The Role of Platelets

Platelets are intimately involved in the pathogenesis of vasospasm and thrombosis. Adherence to the damaged endothelium at the anastomosis leads to the activation and release of ADP, ATP, serotonin, thromboxane A2, thrombin, and norepinephrine. Each of these exacerbates local vasoconstriction and encourages further aggregation of platelets and neutrophils, decreases red blood cell deformability, and increases vascular permeability, resulting in trapped red cells and thrombosis.10

The Role of Neutrophils

Neutrophils play a key role in IRI in many organs, including cardiac muscle, skin, and skeletal muscle.11 Many substances released from platelets and endothelial cells at the site of ischemia recruit and activate neutrophils, which adhere to the vascular
endothelium. This causes microvascular occlusion and edema. Neutrophils also migrate into the interstitial space and release oxygen free radicals and proteinases, which can cause irreversible cell damage.

Clinical studies with antineutrophil therapies have produced disappointing results in attenuating myocardial IRI. This may reflect the variable role of neutrophils in the pathogenesis of vascular dysfunction and thrombosis, with the duration and conditions of ischemia and reperfusion.

**The Role of Endothelium**

The endothelium is one of the most important factors in the local regulation of blood flow. Endothelial cells synthesize and release vasoconstrictor and vasodilator substances to maintain optimal local perfusion and homeostasis. Endothelin-1 is an extremely potent vasoconstrictor that has been shown to be involved in the pathogenesis of skin-flap ischemia. Surgical trauma in general is known to increase circulating levels of endothelin-1.

Although endothelial cells can synthesize this potent vasoconstrictor, they also produce nitric oxide and prostacyclin (PGI₂), which are vasodilators, to regulate local blood flow. Experimental evidence indicates that the vasoconstriction induced by exogenous norepinephrine or through stimulation of adrenergic nerves is associated with the simultaneous release of endothelium-derived nitric oxide and PGI₂, but the mechanism is unclear.

Hypoxia can stimulate endothelial cells to synthesize and release vascular endothelial growth factor, which stimulates endothelial cells to synthesize and release the vasodilators nitric oxide and PGI₂. Nitric oxide also stimulates angiogenesis in hypoxic tissues. Vascular endothelial growth factor is therefore a potent vasodilator with demonstrable activity against the constrictor effect of norepinephrine, endothelin-1, and thromboxane A₂ in skin vasculature. The subcutaneous injection of vascular endothelial growth factor in rat skin flaps has been shown to significantly increase the skin content of nitric oxide and blood flow within 9 hours of surgery. Skin capillary density (angiogenesis) increased within 24 hours of surgery.

**The Pathogenesis of Vasospasm**

Vasospasm plays an important role in the pathogenesis of hypoperfusion and thrombosis, risking partial or total flap failure. Although vasospasm may be seen within 72 hours after free flap surgery, intraoperative vasospasm is often more problematic. This is frequently attributed to vessel trauma; however, it may be partly attributed to the induction of a myogenic response to local hemorrhage or mechanical trauma, although the pathophysiology is not clear. In addition, surgical trauma may induce sympathetic nerve endings to release norepinephrine and platelets to release adenosine, their vasoactive compounds.
Endothelial dysfunction in traumatized blood vessels may result in a decreased synthesis of endothelium-derived relaxing factors nitric oxide and PGI2. An excessive local release of vasoconstrictor substances without a compensatory increase in the synthesis and release of endothelium-derived relaxing factors tilts the balance in favor of vasospasm and thrombosis.

Veins are more susceptible to vasospasm than arteries, and once established, vasospasm may be more difficult to resolve in veins than arteries. In addition, experimental evidence indicates that venous ischemia is more injurious than arterial ischemia in flap surgery.

**ISCHEMIC TOLERANCE**

Tissue necrosis and flap failure are the most concerning complications in microsurgery through the perioperative and early postoperative periods. Avoidance of this complication demands that the warm ischemia time of transplanted tissue be kept to a minimum. To achieve this, the donor vessels are prepared before the flap pedicle is divided. In addition, the anastomoses must be carried out promptly and precisely so that blood flow is rapidly restored. In the case of free flaps, an obligatory period of absolute primary ischemia occurs while this work is performed. With pedicled flaps there is no obligatory ischemic period, but there may be a period of relative ischemia as a result of vasospasm and altering of the circulatory dynamics. Secondary ischemia may occur later in any type of flap as a result of pedicle obstruction by external pressure, kinking, or thrombosis. The tolerance of tissues to a secondary ischemic insult may be worse in free than in pedicled flaps, which in turn may reflect an increase in anastomotic complications with free flaps.

The tolerance of different tissues to ischemia varies. Following are approximate critical ischemia times at 25° C: skin, 12 hours; muscle, 4 hours; bone, 4 to 7 hours; and nerve tissue, up to 8 hours. Within a composite flap, the overall tolerance must equal that of the least tolerant component. Several techniques can be used to increase these ischemic tolerances of flaps, and these are presented on p. 175.

The restoration of blood flow is a primary objective in free tissue transfer, but doing so does not necessarily end the process of tissue damage. Restoring flow after a prolonged period of ischemia may even exacerbate the process.

**ISCHEMIA-REPERFUSION INJURY**

The restoration of blood flow to ischemic tissues is essential in free flap surgery to prevent irreversible tissue injury and necrosis, but doing so may result in a local and systemic inflammatory response that paradoxically compounds tissue damage. This response is described as IRI and is seen after coronary reperfusion, organ transplantation, limb reperfusion, and free flap surgery. Severe IRI culminates in vasoconstriction that may prove difficult or impossible to overcome, despite good arterial
and venous anastomoses—the so-called no-reflow phenomenon. Several processes occur during early posts ischemic reperfusion. These include the production of oxygen free radicals, followed by inflammatory mediators, leukocyte rolling and adhesion, and finally arteriolar vasoconstriction.30

During the initial ischemic phase, a number of cellular responses occur. Oxidative phosphorylation is reduced, resulting in a failure to synthesize ATP and phosphocreatine. A secondary failure of ATP-dependent ionic pumps results in the influx of calcium, sodium, water, NADPH, and hypoxanthine into the cell, causing an osmotic swelling and direct cellular damage.31,32 In addition, intracellular calcium triggers the production of xanthine oxidase, which becomes the main source of reactive oxygen species when tissue circulation and oxygenation are restored. When this occurs, the accumulated hypoxanthine becomes a substrate for xanthine oxidase, resulting in the rapid production of reactive oxygen species, including superoxide anions, hydroxyl radicals (OH−), and hydrogen peroxide (H2O2).

The reactive oxygen species may contribute to tissue injury and dysfunction as a result of their potent oxidizing and reducing potentials. The peroxidation of lipids damages cellular membranes directly. Reactive oxygen species also stimulate leukocyte chemotaxis, adhesion, activation, and cytokine expression.

Pharmacologic agents that scavenge reactive oxygen species or block production have been shown in animal models to increase the ischemic tolerance of flaps.33,34 Unfortunately, these have not proved clinically effective in humans.35,36

The initial ischemia also promotes the expression of other inflammatory mediators, such as the following:

- Histamine (increases vascular permeability and leukocyte rolling)
- Platelet activating factor (platelet aggregation, leukocyte activation and adhesion, vascular permeability, and vasoconstriction); platelet activating factor receptor antagonists have also been shown experimentally to increase the survival of ischemic skin and muscle37
- Leukotriene B4 (leukocyte chemotaxis, degranulation, and free radical formation)
- Tumor necrosis factor and interleukin-1 (leukocyte adhesion)
- Endothelin and thromboxane A2 (platelet aggregation and vasoconstriction)

The production of other protective molecules, such as nitric oxide synthase, prostacyclin, and thrombomodulin, is suppressed.

Leukocytes are mobilized from the intravascular space to cross the endothelium. Initially, “rolling” of these cells along the endothelium is mediated through glycoproteins known as selectins. Subsequent adhesion results from the interaction of “integrins” on the leukocyte and from endothelial intercellular adhesion molecules. Finally, vasoconstriction occurs as a result of leukocyte adhesion and is probably related to a reduction in the vasodilator nitric oxide.38,39 The no-reflow phenomenon is ev-
ident when vasoconstriction, platelet-leukocyte aggregation, and interstitial edema occur, because the restoration of blood flow to the flap is often incomplete, despite satisfactory completion of the arterial and venous anastomoses and an apparently adequate arterial inflow.

It has been shown that inhibiting the action of selectins, integrins, and intercellular adhesion molecules with monoclonal antibody preparations protects against IRI.

Reperfusion also activates complement, which further stimulates leukocyte activation and chemotaxis and may exacerbate the inflammatory response through the production of proinflammatory cytokines such as interleukin-1, interleukin-6, and tumor necrosis factor-α. Complement has also been implicated in the inhibition of endothelium-dependent relaxation.

**AGE, SMOKING, COMORBIDITIES, AND TEMPERATURE**

A recent study of the factors affecting free flap complication and failure rates demonstrated a high complication rate in diabetic patients, flaps used for salvage procedures, and flaps requiring free vein grafts. Surprisingly, other factors, such as smoking, peripheral vascular disease, prior radiation therapy, age, and operative time, did not have a significant effect on the outcome.

In a similar study, the following factors did not affect the outcome: the recipient site (for example, head/neck, breast, and lower limb); indications for surgery (for example, trauma and cancer); flap transfer in very old or very young patients, smokers, or diabetics; arterial anastomosis with an end-to-end versus end-to-side technique; irrigation of the vessel without or with heparin added to the irrigation solution; and a wide spectrum of antithrombotic drug therapies. However, the use of a skin-grafted muscle flap or the placement of a flap in an irradiated recipient site was a predictor of flap failure.

Poor nutritional status is not a contraindication to free flap surgery but has an effect on the wound-healing rate and may contribute to complications, particularly in head and neck cancer patients who may have difficulty achieving a good nutritional status. Other risk factors, including diabetes, hypertension, and hypercholesterolemia, may potentiate the effects of IRI.

**PHARMACOLOGIC INTERVENTION IN MICROSURGERY**

The prophylactic use of systemic or topical preparations to guard against anastomotic thrombosis and vasospasm is widely practiced. Local protocols differ widely in their preferred agent, dosage, and administration. Different centers may use single- or double-agent prophylaxis, and some may use none at all. Overall, there is little and conflicting evidence to support this practice in the medical literature, and much
is based on each surgeon’s experience and preconceptions. Work has yet to be done to find which, if any, pharmacologic intervention is beneficial. The following sections describe some of the more routinely used agents.

**Anticoagulant Agents**

Anticoagulation is routinely used in the perioperative period for prophylaxis against deep venous thrombosis and pulmonary embolism, though no global consensus exists on the best method of anticoagulation, and human clinical studies are limited. Some patients may already be taking prescribed anticoagulation medication in the form of warfarin (Coumadin), aspirin, or clopidogrel (Plavix) for coexisting cardiovascular disease. The objective in all patients is to balance the risk of peripheral or central thromboembolic events against that of overanticoagulation, which could cause blood loss and hematoma formation and compromise flap survival.

Venous occlusion is more often the cause of free flap compromise than arterial occlusion, and it generally occurs slightly later than thrombosis at the arterial anastomosis, 90% of which occur within 24 hours. Venous thrombosis involves the formation of a fibrinous clot, and arterial thrombi are related to platelet aggregation and fibrin clots. Heparin, aspirin, and dextran are the three anticoagulants commonly used in microsurgery.

**Heparin**

Heparin is a polylglycosaminoglycan, which potentiates the activity of antithrombin III, and thereby deactivates clotting factors II, IX, X, XI, and XII and, indirectly, factors V and VIII. Heparin also has a direct vasodilatory property. Its therapeutic effect is determined by monitoring the activated partial thromboplastin time (APTT); a level above 2 seconds is considered to be therapeutic. Higher levels reduce the incidence of vessel thrombosis but concurrently increase the risk of hemorrhage and hematoma. By comparison, heparin appears to be more effective than aspirin in maintaining vessel patency, and this may relate to the observation that fibrin clot formation is more significant than platelet aggregation in the development of arterial thrombi.

Intraluminal or topical heparin use during the operation has not been shown to reduce thrombosis rates but may reduce hematoma and hemorrhage rates with respect to systemic administration. Concentrations of up to 100 IU/ml can be used without affecting the APTT.

Low-molecular-weight heparin retains activity against factor X, but has less anti-thrombin (factor II) activity and therefore provides similar anticoagulation with fewer side effects, including heparin-induced thrombocytopenia. It also has higher bioavailability, a longer plasma half-life, and the added benefit of not requiring the monitoring of blood levels.
A retrospective review of systemic anticoagulant use in free flap surgery found that the hematoma rate was lowest in patients receiving no anticoagulation (5.3%) and in those with a single intraoperative bolus of 5000 IU heparin with (6.5%) or without a postoperative infusion of 100 IU/hr or 400 IU/hr heparin (6.5% and 6.7%, respectively) daily for 5 to 7 days postoperatively. In patients receiving high-dose heparin (500 to 1200 IU/hr) or dextran 40 (25 ml/hr), the hematoma rates were 20% and 9.1%, respectively. Intraoperative blood loss was unaffected by the method of anticoagulation. In addition, there was a nonsignificant reduction in flap loss in patients given low-dose heparin compared with the group given no anticoagulation (1% versus 4.4%; not statistically significant). More specifically, the pedicle thrombosis rate was also reduced in the low-dose groups (2.2% versus 6.2%). The researchers concluded that low-dose heparin regimens are safe in free flap surgery and do not significantly increase the hematoma rate or blood loss.

Some patients have preexisting coagulopathies, such as protein C and protein S deficiencies, which increase their risk of developing deep venous thrombosis and pulmonary thromboemboli. There is no evidence, however, that the same conditions increase the risk of flap failure. Together, proteins C and S deactivate coagulation factors V and VIII, downregulating the clotting cascade. In addition to deficiencies of protein C, protein S, and antithrombin III, which together are associated with only 5% to 10% of thromboembolic disease, resistance to activated protein C is relatively common (up to 15% of Caucasians and 20% to 60% of patients with venous thromboembolism). One study, however, found no increase in thrombotic events for patients in these groups undergoing free flap surgery, all of whom received routine heparin perioperatively. It was suggested that routine screening for these coagulopathies is not justified.

**Dextran**

Dextrans are polysaccharides synthesized from sucrose by *Leuconostoc mesenteroides* or produced synthetically in a 40 or 70 kDa preparation. The electronegativity of red blood cells, platelets, and endothelium is increased through binding to dextran, which reduces their adhesiveness.

Dextrans also decrease factor VIII and von Willebrand factor, thereby altering platelet function and increasing plasminogen activity to render the fibrin clot more susceptible to thrombolysis. Furthermore, the larger dextrans act as volume expanders and may improve blood flow and patency across the anastomosis.

Dextran 40 is the most popular dextran used for microsurgery, but is not without its side effects, which include anaphylaxis, pulmonary and cerebral edema, and renal failure. It is largely excreted by the kidneys within 24 hours of administration. A single dose of dextran preoperatively has been shown to improve vessel patency postoperatively, but the benefits are not seen beyond 1 week. A comparison of dextran- and aspirin-related complications in patients undergoing microvascular re-
construction for head and neck malignancy found a greater incidence of complications in the dextran group (relative risk 3.9 to 7.2; overall risk 29% to 51%).66 These patients were also administered heparin, which may have confounded the results.67 To date there are no randomized controlled studies relating to the efficacy of dextran treatment in microsurgery. The dose commonly prescribed is 25 to 50 ml/hr over 12 to 24 hours or 8 to 10 ml/kg/day in children. An infusion may be started at the completion of the anastomoses and continued for 24 hours to 5 days. Some centers administer a 5 ml test dose before the full dose to guard against anaphylaxis.

**Aspirin**

Aspirin inhibits cyclooxygenase and thus reduces the production of arachidonic acid metabolites, most notably thromboxane, a potent vasoconstrictor that also promotes platelet aggregation, and prostacyclin, a vasodilator that inhibits platelet aggregation. Thromboxane is produced from platelet-derived cyclooxygenase, whereas prostacyclin originates in the endothelium.

Aspirin may also impair thrombin production at the anastomosis68 and decreases the incidence of microvascular thrombosis at the anastomotic site, though less effectively than heparin.69,70

Low doses of aspirin (75 mg/day) may need to be administered early before surgery and may minimize the adverse affects of high-dose aspirin, such as gastric hemorrhage, renal failure, and the inhibition of prostacyclin.50 The results from the Antiplatelet Trialists’ Collaboration71 suggest that aspirin is effective in preventing coronary graft occlusion, whether given preoperatively or within 24 hours of surgery.

**Thrombolytic Agents**

For flaps not responding to standard salvage procedures, the use of thrombolytic agents such as streptokinase, urokinase and tissue plasminogen activator (tPA) has been advocated. Until recently, reports on the efficacy of this therapy have been limited to individual case reports and a few small series.72-76

Group C beta-hemolytic streptococcus produces streptokinase, which enhances the conversion of plasminogen to plasmin with subsequent fibrinolysis. Streptokinase has been used widely in the treatment of myocardial infarction, pulmonary emboli, deep venous thromboemboli, and acute limb ischemia. Early use of high-dose systemic streptokinase for these indications resulted in significant systemic complications, and an alternative low-dose regimen was developed.77 Streptokinase induces anaphylaxis in approximately 0.1% and in most patients induces antibody production that lasts for 6 months, preventing readministration in the same patient within a year.78 High concentrations of streptokinase (4000 units/ml or more) may result in decreased availability of free plasminogen and therefore limit the effectiveness of the drug. The effective dose is from 1000 to 3000 units/ml in blood.
Urokinase is obtained from human fetal kidney cells. It is capable of the direct conversion of plasminogen to plasmin but has a short half-life. The theoretical advantages of urokinase over streptokinase include less antigenicity; direct plasminogen activation, which allows use in high concentration; and a reduction in systemic effects seen clinically.

tPA is produced by vascular endothelial cells and, similar to urokinase, is a direct activator of plasminogen. In addition, its activity is enhanced in the presence of fibrin. Theoretically tPA results in fewer systemic bleeding complications, but this has not been shown to be clinically significant. A handful of animal studies have shown an advantage in tPA thrombolysis in microsurgery that has been supported by case reports in humans.

It is not clear that the more expensive urokinase and tPA are significantly more effective than streptokinase; their primary benefit is a reduction in complication rates and systemic effects. To date, the largest clinical study of the use of thrombolytic agents to salvage free flaps demonstrates a 30% salvage rate overall in flaps with good arterial inflow but poor venous outflow after other causes of pedicle obstruction are excluded.

Studies on reocclusion rates following cardiac thrombolysis suggest the need for antiplatelet therapy with or without the use of heparin to reduce the incidence of rethrombosis.

Antispasmodic Agents
A variety of antispasmodic agents are used in microsurgery to mitigate the effects of vascular spasm that are inevitable after the direct and indirect injury to the microvasculature as a result of pedicle dissection, division, and anastomosis. Most of these agents are applied locally to avoid systemic complications. The most commonly used agents are papaverine and lidocaine and the calcium channel blockers, nifedipine, verapamil, and recently, nicardipine.

Papaverine is an opiate alkaloid commonly used to relieve vasospasm. The exact mechanism is not clear, but it functions as a phosphodiesterase inhibitor to cause an elevation of cAMP levels and smooth muscle relaxation.

Lidocaine is a local anesthetic agent that acts as a potent vasodilator without significant hemodynamic effects. Although its mechanism of action has not been discovered, it is thought to be related to the alteration of ionic conduction, especially at the sodium-calcium exchange pump. The effects of lidocaine are dose related.

A comparison of the efficacy of papaverine and lidocaine in differing concentrations in an animal model found a dose-dependent vessel relaxation with papaverine and a biphasic (contraction at low dose and relaxation at high dose) response to lidocaine. This led to the conclusion that papaverine (30 mg/ml) or high-dose lidocaine (20%)
were of use in microsurgery, but low-dose lidocaine, such as that typically used for local anesthetic procedures (1% to 2%), should be avoided. The benefit of 20% lidocaine continued after the drug was washed out with heparinized saline solution.86

Calcium channel blockers work by blocking voltage-gated calcium channels in vascular smooth muscle. This prevents calcium influx and weakens muscle contraction. Nicardipine has been promoted for relief of vasospasm in microsurgery and may be more effective than papaverine.87

**OTHER PHARMACOLOGIC INTERVENTIONS**

A number of other agents have been tested in animal models to determine their efficacy in augmenting flap survival. Thus far none have significantly affected clinical practice. These include vascular endothelial growth factor,21 platelet-derived growth factor,88 prostaglandin E1,89 and S2-serotonin-receptor antagonists.90

**NONPHARMACOLOGIC THERAPY AGAINST ISCHEMIC INJURY**

A variety of nonpharmacologic interventions have been used to minimize flap ischemic complications. These include flap cooling, washout with physiologic preservative solutions during ischemia, and more recently, ischemic preconditioning.

Cooling the ischemic flap while the anastomoses are performed reduces cellular metabolism and increases critical ischemia time and has been used clinically to improve free tissue transfer success rates.91 Although cooling is useful if a flap is ischemic for a prolonged period, in normal circumstances this does not occur, and it can be difficult to maintain cooling during microvascular anastomoses.

Physiologic washout solutions include preparations used in organ transplant, such as Euro Collins solution and University of Wisconsin solution.92-94 Their use, though not widely practiced, has been reported to be effective in free tissue transfer.

**Ischemic Preconditioning**

Ischemic preconditioning is perhaps the most promising modality for the augmentation of flap survival and currently the subject of much research. As recently as 1986, it was shown that the myocardium can be preconditioned to survive a prolonged period of ischemia by subjecting it to brief periods of ischemia beforehand.95 This discovery has been shown to hold true for skeletal muscle and other organs, such as the CNS, liver, kidneys, and bowel, across a range of species, including humans. It has also been suggested that ischemic preconditioning protects endothelial cells from IRI and postischemic microvascular dysfunction.96,97
This technique could prove beneficial to patients undergoing microsurgery by increasing the tolerance of transferred tissue to primary and secondary ischemic insults. In addition, patients may be protected from adverse consequences of typically prolonged surgery, including myocardial infarction, stroke, and organ dysfunction.

The mechanism of ischemic preconditioning has been widely investigated in a range of animal models, and a consensus is emerging. A number of factors produced during preconditioning ischemia, including adenosine, bradykinin, and endogenous opiates, are subsequently released into the circulation where they act alone or in concert to stimulate metabolic pathways and culminate in the opening of mitochondrial potassium channels and cellular protection from ischemia. Although no individual pharmacologic agent identified to date is capable of fully replicating the innate ischemic preconditioning effect, it is hoped that research will ultimately allow pharmacologic manipulation of microsurgical patients to avoid ischemic complications and augment intrinsic flap limitations.

Recently, it has been shown that the benefits of ischemic preconditioning can be realized in skeletal muscle by a remote preconditioning stimulus.98

**Critical Points**

**Must Know**
- Intraoperative vasospasm can increase the chance of flap failure.
- The tolerance of pedicled flaps to secondary ischemia is higher than that of free flaps.

**Should Know**
- Maintaining regulation of the blood flow in tissues, organs, and flaps is vital for successful flap surgery.
- Severe IRI culminates in vasoconstriction that may prove difficult to overcome, despite adequate arterial and venous anastomoses.
- Pharmacologic intervention in microsurgery includes a wide range of systemic and topical preparations, such as anticoagulant, thrombolytic, and antispasmodic agents.
- Ischemic preconditioning is one of the most promising modalities used to augment flap survival and may protect endothelial cells from IRI and postischemic microvascular dysfunction.

**Synopsis**
- The decreasing rate of overall flap failure, which is now less than 5%, reflects improved microsurgical technique, patient monitoring, postoperative management, pharmacologic manipulation, and emerging nonpharmacologic interventions.
The blood supply to the skin and underlying tissues was investigated using ink injection studies, dissection, perforator mapping and radiographic analysis of fresh cadavers and isolated limbs, and the results were correlated with previous regional studies. The authors determined that blood supply is from a continuous three-dimensional network of vessels in all tissue layers. The anatomic territory of a source artery in the skin and deep tissues was found to correspond in most cases, giving rise to the angiosome concept. The primary supply to the skin is direct cutaneous arteries that vary in caliber, length, and density in different regions. This primary supply is reinforced by numerous small indirect vessels, which are “spent” terminal branches of arteries supplying the deep tissues. An average of 374 major perforators were plotted in each subject, revealing that there are still many more potential skin flaps. The authors’ arterial roadmap of the body provides a basis for logical planning of incisions and flaps.


   The authors investigated the differences in sensitivity to vasoconstrictors and vasodilators of the human musculocutaneous perforator (MCP) artery and vein. This study lends support to the clinical impression in flap surgery that veins appear to be more susceptible to vasospasm than arteries, and venous vasospasm seems to be more difficult to resolve than arterial vasospasm in cutaneous and musculocutaneous flap surgery.


   This study was designed (1) to determine survival rates in both cutaneous and myocutaneous flaps following a secondary venous ischemic insult, (2) to compare this with findings following a secondary arterial ischemic insult, and (3) to determine the reliability of laser Doppler flowmetry and dermofluorometry to predict necrosis following both venous and arterial ischemic insults. As expected, as the length of ischemia increased, the rate of flap survival decreased. Although laser Doppler performed slightly better than dermofluorometry, both were relatively poor predictors of survival or necrosis. However, under conditions of immediate reperfusion following secondary arterial ischemia, dermofluorometry proved to be a superior predictor.


   Experimental evidence indicates that injury to the muscle during reperfusion is most likely mediated by oxygen-derived free radicals (oxygenradicals). The major oxygenradical-generating system in the skeletal muscle has yet to be identified so that an appropriate oxygenradical-generating inhibitor and/or scavenger can be selected. The role of locally released vasoconstrictive substances and/or chemoattractants for leukocytes in the pathogenesis of ischemia-induced reperfusion injury in muscle flaps has yet to be determined. The authors review the pathophysiology of ischemia-induced reperfusion injury to the skeletal muscle in muscle flaps.


The essence of microsurgery comprises delicate tissue handling, meticulous attention to detail, and acceptance of nothing short of perfection. This sounds like an unattainable goal, but if attention is paid to each step of the procedure and meticulous technique is followed, success is almost always ensured. The most common cause of free flap failure is technical error. Occasionally, other factors cause flap demise, but they are rare. These include anatomic anomaly, infection, or some unrecognized patient factor, such as a clotting disorder. In general, unfortunately, the fault lies with the surgeon! This chapter is not intended to be a primer on microsurgical technique but rather an attempt to highlight points that are salient to a discussion on head and neck reconstruction in particular.
GENERAL TECHNIQUE

Being comfortable when performing surgery is essential. Flap dissection and microvascular anastomosis are generally time consuming and demand intense concentration and single-minded focus. Several hours of delicate dissection and microvascular anastomoses are required for each procedure. Being physically comfortable ensures greater accuracy and less fatigue. Whether to sit or stand is each surgeon’s choice and is, frankly, unimportant. The most comfortable position is the correct position. Awkward positions must be avoided. The surgeon should take time to walk to the other side of the table if the dissection will be easier from that side. Assuming an awkward position for a long period is very tiring and can increase the risk of error. Similarly, the necessary preparations should be taken to be comfortable once under the microscope. The time spent doing this ultimately shortens the operative time and optimizes the chance of success. For example, appropriate wrist and hand rests can be built with towels or other props, and numerous custom-designed microvascular stools and chairs are available that incorporate adjustable arm rests and various other supports. The choice to use one of these depends on each surgeon’s preference.

Instruments

Surgeons need to be familiar and comfortable with their instruments. I find several instruments particularly useful. When dissecting flap pedicles, my preference is to combine sharp and blunt dissection. This, of course, is a personal choice, and surgeons must use whatever works best for them and whatever they are most familiar with. I use a mosquito forceps, a nontooth fine forceps such as a DeBakey, and a tenotomy scissors to perform dissections. I also find a baby right-angle or a baby Lauer (Fig. 10-1) very useful for dissecting around the pedicle and isolating the vessels. In addition, a baby Satinsky clamp (Fig. 10-2) is particularly useful for head and neck reconstruction. This instrument is very helpful for partially clamping a vessel such as the internal jugular vein to facilitate an end-to-side anastomosis.

Fig. 10-1  A right-angle forceps is useful for pedicle dissection.
**Tissue Handling**

The need to be delicate when handling tissues cannot be overemphasized. This is particularly true when dissecting the pedicle of a perforator flap. Care and attention to the delicacy of the perforator dissection is extremely important. Safe tissue handling is facilitated by using correct instrumentation, feeling comfortable in the operative setting, and having quality assistance.

**Vessel Dissection**

Delicate tissue handling is also essential when dissecting the recipient vessels, whether in the neck or elsewhere in the head and neck. The same meticulous attention to detail is necessary to preserve the maximum length and minimize the risk of vessel injury. The issue of vessel geometry is also important and is discussed on p. 184.

**Sutures**

The choice of sutures depends on the surgeon’s preference. Stated simply, the suture chosen should be appropriate for the job. In my practice, 9-0 nylon is the most commonly used microvascular suture. However, I use 10-0 nylon for smaller vessels and, generally, 11-0 nylon for microneural anastomosis.

**Anastomosis**

The choice of anastomotic technique depends on the circumstances of each case. For end-to-end anastomosis, it is easiest if the axis of the anastomosis is at a right angle to the surgeon’s axis of gaze. In this way, one vessel end is on the right and the other is on the left. It is easy to see both lumens during the anastomosis.

---

**Technical Tip for End-to-End Anastomosis**

When the vessels are vertically oriented, it is not always easy to see both lumens, and the surgeon is at a relative technical disadvantage. Although it is not always possible to reorient the anastomosis to this optimal position (that is, at a right angle to the axis of the surgeon’s gaze), it is frequently possible and worth taking the time required to set it up in this manner.
The basic rules of microsurgery apply: do not suture the anastomosis under tension; try to avoid significant redundancy; and make certain the vessels are not kinked. If the anastomosis is in the neck, it is most commonly performed with the patient’s neck extended and the head turned away from the surgeon. This is not the position in which the vessels lie postoperatively, and it is usually a good idea to check the vessels as they lie in different positions on completion of the anastomosis. The technique of anastomosis is, again, a personal choice. I prefer to perform a back-wall technique, because this allows visualization of the lumen throughout the suturing process and does not require any changes in the position of the vessels. However, surgeons should use the anastomotic technique that is most comfortable for them. I also frequently use a venous coupler from Synovis Life Technologies for venous anastomosis (Fig. 10-3). This expedites the procedure and is very safe and effective. However, even though the use of the coupler has been reported for significant size discrepancies between the veins, I generally prefer to suture widely discrepant anastomoses. As mentioned previously, the baby Satinsky clamp is particularly useful for end-to-side anastomoses.

**Pitfalls**

- The use of surgical drains requires caution. Some surgeons prefer not to use a suction drain in the neck for fear of impingement on the vessels, causing pedicle thrombosis.
- If suction drains are used, they should be sutured in position with a fine absorbable suture, such as 5-0 chromic catgut or Vicryl Rapide, to minimize the risk of drain migration and vessel compression.
Vein Grafting and Vascular Loops

Although it has been shown that the use of vein grafts increases the risk of thrombosis,5,6 it is nevertheless sometimes necessary to use vein grafts. It is important to anticipate their use. Surgeons tend to encounter problems with vein grafts when they are used as a salvage procedure. In some cases, the flap may already be perfused or partly perfused when a problem arises and the surgeon realizes that a vein graft is needed. Frequently, a separate site has to be prepared quickly for the graft harvest, because the previously placed flap is deteriorating. Therefore it is advantageous if the vein graft is anticipated and the site already prepared. The use of the arteriovenous (AV) loop is another very effective way to address this problem.6 Fig. 10–4 shows an AV loop used as part of the planned procedure to revascularize a radial forearm flap to the contralateral side of the face.

Fig. 10–4 An AV loop is used as part of the planned procedure to revascularize a radial forearm flap to the contralateral side of the face.

Tips on Microsurgical Technique

- Each step of the case should be carefully planned.
- Surgeons should be familiar with all instruments used.
- It is important to be physically comfortable during surgery.
- Problems should be anticipated and dealt with proactively.
- The geometry of the pedicle must be checked when it is in different positions.
- The need for vein grafts should be anticipated when possible.
CONCLUSION

There is no mystery about microsurgery. It demands precision and careful planning. If each step of the procedure is carefully planned and executed, the risk of failure is minimized.

CRITICAL POINTS

**Must Know**
- The use of appropriate wrist and hand rests helps to optimize a surgeon’s comfort level during the procedure.
- Appropriate instrumentation choice is vital to the success of the procedure.
- Delicate tissue harvesting and vessel dissection require meticulous attention to minimize the risk of vessel injury.
- Despite the risks associated with vein grafts, the need to use them must be anticipated.

**Should Know**
- A surgeon’s comfort level must be a priority.
- The choice of sutures and anastomotic technique is based on each surgeon’s discretion and the requirements of the procedure.

**Synopsis**
- Meticulous technique in microsurgery is essential to minimize errors that would lead to flap failure.
- Optimal comfort level, proper instrumentation, delicate tissue handling, and overall awareness of appropriate technique help to ensure success.

References

   *Members of the International Microvascular Research Group participated in a prospective survey of their microvascular free flap practice. Data were recorded for 60 variables covering patient characteristics, surgical technique, pharmacologic treatment, and postoperative outcome. The results present a current baseline for free flap surgery to which future advances and improvements in technique and practice may be compared.*


The 3M microvascular anastomotic coupling device, a polyethylene ring-pin device, was found to be highly successful in numerous animal studies. It has been available for use in humans, but clinical experience remains sparse. The authors describe their experience with the 3M coupler. They conclude that the 3M device is best suited for minimally discrepant, soft, pliable venous microvascular anastomoses and is unsuitable for end-to-side anastomoses in clinical situations.


The use of interposition vein grafts has been associated with a high complication and flap failure rate. Ninety-three vein grafts in 55 patients over a 46-month period were analyzed to evaluate the clinical reliability of vein grafts in a predominantly trauma patient population. The authors conclude that the use of vein grafts is not associated with a higher flap failure rate when technical pitfalls can be avoided and close monitoring is carried out by an experienced staff.


The authors describe their concept of harvesting a single graft of adequate length to create an initial arteriovenous loop for clinical situations in which both arterial and venous interposition grafts are needed. A satisfactory recipient anastomosis can be achieved prior to bisecting the loop, with subsequent immediate donor tissue transfer. Concern for prolonged warm ischemia time is thereby minimized.
CHOOSING RECIPIENT VESSELS

Amélie Bourget, Fu-Chan Wei

HIGHLIGHTS

• Knowing the vascular anatomy of the head and neck is critical when choosing the appropriate recipient vessels in this area.
• Atherosclerosis, radiation therapy, and previous neck surgeries are the major factors influencing the selection of neck vessels.
• The location of the ideal recipient vessel should allow a direct anastomosis to the flap vessels. The recipient vessel should have a healthy lumen with a good blood flow. Its caliber and wall thickness should ideally approximate those of the pedicle vessels.
• The most commonly used arteries are the facial, superior thyroid, superficial temporal, and transverse cervical arteries.
• The most commonly used veins are branches of either the internal jugular vein or the external jugular vein, which run in proximity to the arteries previously mentioned.
• The options of recipient vessels should always proceed from simple to complex. The use of vein grafts should be avoided by selecting a flap with proper pedicle length. Unusual alternatives are available, but their use should be limited to complex cases.
• The ideal anastomosis is tension free and without pedicle compression or kinking.
• Close collaboration with the oncologic team facilitates reconstruction planning.
Finding adequate recipient vessels for a free flap is one of the first steps in planning a microsurgical procedure. In the absence of adequate recipient vessels, a free tissue transfer is not an option. Furthermore, once the recipient vessels are chosen, the choice of flap depends on the pedicle length that can be harvested to allow a tension-free anastomosis. There are numerous potential recipient vessels in the head and neck area for microsurgical reconstruction. Basically, all expandable vessels with adequate flow and suitable size and wall thickness can potentially be used as recipient vessels. However, the anatomy has frequently been altered by previous reconstructive attempts, neck dissection, or radiation. These situations are not contraindications for free tissue transfers. In addition, the threshold for performing another free flap in failed or complicated head and neck reconstruction is much lower than that for other areas of the body. Adequate coverage of the brain and major neck vessels must be provided. Major aesthetic and functional complications brought by failure to provide adequate coverage can be devastating. Special knowledge and expertise are needed to overcome these difficulties. This chapter reviews pertinent arterial and venous anatomy and discusses in-depth decision-making for recipient vessels and methods of optimizing results of free tissue transfers in complicated head and neck reconstructions.

**ANATOMY**

**Arterial Anatomy**

The arterial blood flow to the head and neck is provided by the external and internal carotid arteries (Fig. 11-1). The internal and external carotid arteries are branches of the common carotid artery, which arises from the brachiocephalic trunk on the right side and directly from the aortic arch on the left side.

The internal carotid artery is not a suitable recipient vessel for microsurgery because of its location, its usual lack of side branches before entering the skull, and its vital importance for brain perfusion.

The external carotid artery begins at the level of the upper border of the thyroid cartilage. Because it has multiple branches that are easy to expose, these branches are usually the first choice for recipient vessels in the head and neck region. The most useful branches, based on their size and location, are from proximal (inferior) to distal (superior): the superior thyroid artery, the facial artery, and the temporal artery. In certain circumstances, the lingual artery stump can also be used when it has been preserved after hemiglossectomy and neck dissection.

The superior thyroid artery is the first branch to come off the anterior surface of the external carotid. It courses anteriorly and inferiorly, deep to the sternohyoid and omohyoid muscles and reaches the upper pole of the thyroid gland.
The lingual artery arises from the anterior surface of the external carotid artery, just above the superior thyroid artery at the level of the greater horn of the hyoid bone. It courses superiorly and deep to several structures: the stylohyoid, the posterior belly of the digastric muscle, and the hypoglossal nerve. It is usually only accessible after a combined wide tumor excision and neck dissection.

The facial artery also arises from the anterior surface of the external carotid artery, above the origin of the lingual artery. It courses anteriorly and superiorly, deep to the digastric and stylohyoid muscles, and travels superficial to the submandibular gland. The vessel crosses the mandibular border at the mandibular notch, where it can be palpated just anterior to the masseter muscle. Its tortuous course provides length that can accommodate neck motion. This is a useful characteristic that can help to achieve a tension-free anastomosis.

The superficial temporal artery is the terminal branch of the external carotid artery. Its origin is located in the parotid gland, posterior to the neck of the mandibular condyle. It runs superiorly, anterior to the auricle. This artery is accompanied posteriorly by the auriculotemporal nerve, a sensory branch of V5. It divides into a temporal and a parietal branch, 5 cm superior to the zygomatic arch. Above the arch, the artery is quite superficial and can easily be palpated as it travels in the superficial
temporal fascia, allowing easy access for microsurgery. The caliber of this terminal branch is smaller than that of the other branches of the external carotid artery, but it still provides sufficient flow for microanastomosis.1,4,5

The maxillary artery is the largest branch of the external carotid artery. It courses anteriorly, medial to the mandibular ramus. It perfuses the pterygopalatine fossa and maxillary complex. Its deep location and mostly intraosseous course make it an impractical choice for microsurgery.2

The ascending pharyngeal artery arises from the posteromedial aspect of the external carotid artery, near its origin. It runs superiorly, between the internal and external carotid arteries and perfuses the pharyngeal constrictors. Because this vessel is very deep and is usually of small caliber, it is rarely used in microsurgery.2

The occipital artery takes off from the posterior surface of the external carotid artery, opposite the origin of the facial artery. It lies deep to the origin of the posterior belly of the digastric and the stylohyoid muscles. On its way to the posterior scalp, it crosses the hypoglossal nerve. The artery is superficial to the internal carotid artery, internal jugular vein, and vagus and spinal accessory nerves.3 It emerges at the apex of the posterior triangle and gives numerous ramifications to the branches of the posterior auricular and superficial temporal arteries. Ramifications also reach across the posterior and superior calvarial midline to anastomose with the contralateral occipital, posterior auricular, and superficial temporal arteries. This vessel’s last portion is accompanied by the greater occipital nerve. Because the occipital artery runs relatively deep and close to major neurovascular structures, its dissection is more delicate and not as straightforward as that of other branches. However, it has an adequate caliber and can be particularly useful as a recipient vessel for posterior defects of the neck and scalp.4,6

The posterior auricular artery arises from the posterior aspect of the external carotid artery, between the posterior belly of the digastric muscle and the stylohyoid muscle.3 This artery is usually small or absent and is often replaced by a branch of the occipital artery. It is therefore rarely used in head and neck reconstruction.7 Its use has been reported for certain cases of ear replantation.8,9

Alternatively, arterial branches from the third part of the subclavian artery can be used. These arteries can be found at the base of the neck, just lateral to the lower third of the sternocleidomastoid muscle.3 The most useful branch is the transverse cervical artery, arising from the thyrocervical trunk. Other branches of the thyrocervical trunk are the inferior thyroid artery, the ascending cervical artery, and the suprascapular artery.10 Although these could be used despite their smaller diameter, their routine use has not yet been reported in the literature.
**Venous Anatomy**

As in the rest of the body, arterial branches of the head and neck usually have their corresponding venous counterparts (Fig. 11-2). However, venous drainage is more variable, superficial, and plexiform than its corresponding arterial drainage. Most veins drain into the internal jugular vein, leaving only the posterior division of the retromandibular vein, the posterior auricular vein, and the anterior jugular vein to drain in the external jugular vein.

The internal jugular vein arises from the sigmoid sinus at the jugular foramen and descends into the neck, lateral and more superficial to the carotid arteries, to the level of the sternoclavicular joint. It joins the subclavian vein to form the brachiocephalic vein. The external jugular vein runs just deep to the platysma but superficial to the sternocleidomastoid muscle. It drains into the subclavian vein.

![Fig. 11-2 The anatomy of the common recipient veins of the neck.](image)
Veins of the head and neck can usually be found in the vicinity of their corresponding arteries, sometimes with slight variations. For example, the superior thyroid, lingual, and facial veins often merge into a thyrolinguofacial trunk before joining the internal jugular vein. The retromandibular or posterior facial vein is the venous segment that drains the superficial temporal artery into the common facial vein. It is posterior to the mandibular ramus and does not have an arterial equivalent per se. Similarly, the anterior jugular vein has no corresponding artery. It is formed by the confluence of superficial veins in the submental area and descends directly to join the external jugular vein just before it drains into the subclavian vein. It runs between the midline and the anterior border of the sternocleidomastoid muscle.

Anatomic studies on the veins of the head and neck show that these vessels have valves at random intervals, mostly around areas of branching and around the mandibular border. The authors suggest that any microvascular anastomosis on the facial vein should be made away from these areas to limit the risk of associated thrombosis. If this cannot be avoided and a valve is seen under the microscope, shortening of the vessels by a length equal to twice its diameter should completely eliminate the valve. The presence of valves in the venous system does not seem to preclude the use of retrograde flow venous anastomosis in some difficult cases.

Although not a vascular structure per se, the anatomy of the thoracic duct must be mentioned, because this structure might be encountered or injured during neck exploration. The thoracic duct ascends through the thorax behind the aortic arch and left subclavian artery. After entering the neck, it arches 3 to 4 cm superior to the clavicle and descends anterior to the subclavian artery. It then joins the venous system at the junction of the left subclavian vein and internal jugular vein. It varies in size and can present as a plexus, making it difficult to identify. An unrecognized thoracic duct injury can lead to the complex problem of chyle leak. The thoracic duct is particularly at risk during exploration of the base of the left side of the neck for the transverse cervical vessels.

**FACTORS IN CHOOSING RECIPIENT VESSELS**

**Location of the Defect**

The location of the defect is the first consideration when choosing recipient vessels for microsurgical reconstruction in the head and neck area (Table 11-1). The flap pedicle should easily reach the recipient vessels. In the absence of suitable recipient vessels in the vicinity of the defect, choosing a flap with a longer pedicle or using two interpositional veins grafts must be considered.
Diameter of Flap Vessels
When the flap’s pedicle can reach several recipient vessels, the vessels with a similar caliber and wall thickness are preferred. Size- and wall-thickness discrepancies can be overcome by different techniques described in Chapter 10.

Quality of Neck Vessels
The quality of neck vessels can be influenced by the patient’s age, tobacco usage, diabetes mellitus, and previous neck surgery and radiation therapy. An increased flap failure rate has been reported in patients who use tobacco.

Effect of Radiation Therapy
Radiation therapy causes extensive fibrosis in soft tissues. Histologically, tissues show typical fibroblasts with large nuclei in perivascular tissues. This fibrotic reaction seems to increase with the cumulative radiation dose and the time elapsed since the completion of radiation therapy. The dissection of blood vessels is more tedious, and using a microscope is sometimes necessary. Carotid ruptures have been reported during vessel dissection after radiation therapy.

Radiation decreases the number of endothelial cells and smooth muscle nuclei in blood vessels. Although experimental studies show a higher risk of thrombosis in irradiated vessels after microanastomosis, especially in veins, clinical studies on free flap transfers to irradiated vessels do not correlate with these findings. Thus irradiated vessels are not an absolute contraindication to microanastomosis, but their usage is technically more demanding.

<table>
<thead>
<tr>
<th>Location</th>
<th>Recipient Arteries</th>
<th>Recipient Veins</th>
</tr>
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<tbody>
<tr>
<td>Neck and inferior third of the face</td>
<td>Facial artery</td>
<td>Facial vein</td>
</tr>
<tr>
<td></td>
<td>Superior thyroid artery</td>
<td>Thyroinguofacial trunk</td>
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<tr>
<td></td>
<td>Superficial temporal artery</td>
<td>Internal jugular vein</td>
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<tr>
<td></td>
<td></td>
<td>External jugular vein</td>
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<tr>
<td></td>
<td></td>
<td>Retromandibular vein</td>
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<tr>
<td></td>
<td></td>
<td>Superficial temporal vein</td>
</tr>
<tr>
<td>Superior two thirds of the face</td>
<td>Facial artery</td>
<td>Facial vein</td>
</tr>
<tr>
<td></td>
<td>Superficial temporal artery</td>
<td>Retromandibular vein</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superficial temporal vein</td>
</tr>
<tr>
<td>Scalp and posterior surface of the head and neck</td>
<td>Superficial temporal artery</td>
<td>Superficial temporal vein</td>
</tr>
<tr>
<td></td>
<td>Occipital artery</td>
<td>Occipital vein</td>
</tr>
</tbody>
</table>
Effect of Atherosclerosis

Atherosclerosis is a frequently encountered vascular pathology that affects the vessel quality. Risk factors associated with atherosclerosis include high cholesterol, elevated blood pressure, diabetes mellitus, and smoking. Although atherosclerosis in a patient is not a contraindication to free tissue transfer, it increases free flap surgical complications and the risk of systemic cardiovascular complications such as stroke and myocardial infarction. Locally, atherosclerotic arteries are thickened, with a loss of elasticity and the development of plaque. Atherosclerotic plaque consists of intimal deposits of lipid, carbohydrates, blood products, fibrosis, and calcium. Arterial bifurcations are the most affected areas because of high blood velocity and turbulent flow in these locations. Atherosclerosis can affect any artery in the body. The femoral, iliac, and coronary arteries are the more commonly affected. The carotid artery is also frequently diseased, especially around the carotid sinus. Atherosclerosis can cause aneurysmal dilation, thrombosis, and embolism.

Healthy vessels with good caliber and adequate arterial spurring should always be the first choice. In atherosclerotic vessels, a meticulous microsurgical technique is of primary importance and must be performed under higher magnification. (See Chapter 10 for further details on microsurgery of the atherosclerotic vessels.)

Effect of Neck Surgery

When planning a reconstruction for neoplastic diseases of the head and neck, previous or concurrent neck dissection can limit the availability of recipient vessels for free flaps. The site and type of neck dissection performed are important in the planning of the reconstruction. Although adequate recipient vessels can be found in the field of a previous selective or functional neck dissection, they might not be available after a radical or even a modified radical neck dissection. In these patients, it may be necessary to use the contralateral neck vessels.

Neck dissection can be an ally and an obstacle to reconstructive surgeons. It provides unparalleled exposure of major neck vessels but often sacrifices multiple useful branches. Communication with the ablative team is of crucial importance, because it ensures that usable vessel stumps are left behind for microsurgical reconstruction, without compromising the oncologic resection.

Neck dissection can cause internal jugular vein thrombosis, especially if local infection occurs postoperatively. The incidence reported in the literature varies from 3% to 33%. This risk is probably increased in patients who have had previous radiation therapy or microsurgical reconstruction. Determining the patency of the internal jugular vein through Doppler studies in patients presenting with these risk factors provides a noninvasive method of enhancing preoperative
planning. However, the survival of a flap drained by the internal jugular vein has also been reported, despite internal jugular vein thrombosis.\textsuperscript{31,36,38} This can be explained by neovascularization.\textsuperscript{38} Acute internal jugular vein thrombosis could jeopardize the survival of a free flap.

Understanding the implications of the different types of neck dissections allows reconstructive surgeons to communicate with oncologic surgeons for a more appropriate microsurgical reconstruction. In the last decades, better comprehension of the behavior of regional metastasis of head and neck tumors has played a major role in the evolution of classic radical neck dissection into more selective neck dissections. The neck regions have been divided and standardized into different node groups to facilitate communication and outcome comparisons. The common lymph node regions are shown in Fig. 11-3. An overview of the different neck dissections and their indications is given in Table 11-2 (see also Chapter 4). Indications and techniques can still vary among surgeons. It is essential to consult previous operative reports when they are available to obtain a clear picture of exact structures that have been resected or injured during the neck dissection.

![Fig. 11-3](image) The lymph node zones for neck dissection.
<table>
<thead>
<tr>
<th>Table 11-2  Neck Dissection Types</th>
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</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
</tr>
<tr>
<td>Radical neck dissection</td>
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<tr>
<td>Modified radical neck dissection</td>
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<tr>
<td>Type I</td>
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<tr>
<td>Type II</td>
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<tr>
<td>Type III (or functional neck dissection)</td>
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<tr>
<td>Selective neck dissection</td>
</tr>
<tr>
<td>Supraomohyoid neck dissection (anterolateral neck dissection)</td>
</tr>
<tr>
<td>Lateral neck dissection</td>
</tr>
<tr>
<td>Posterolateral neck dissection</td>
</tr>
<tr>
<td>Anterior neck dissection</td>
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</tbody>
</table>

*IJV*, Internal jugular vein; *SAN*, spinal accessory nerve; *SCC*, squamous cell carcinoma; *SCM*, sternocleidomastoid muscle.
COMMONLY USED RECIPIENT ARTERIES

Facial Artery

The facial artery can be palpated on the lower border of the mandible, in the mandibular notch, just in front of the masseter muscle insertion. It can also be identified using a handheld Doppler probe.

The incision is made 2 to 3 cm inferior to the mandibular border in an orientation parallel to neck wrinkles (Fig. 11-4). The platysma muscle should be carefully dissected until the marginal mandibular branch of the facial nerve is identified. It courses 1 cm inferior to the mandibular border, deep to the platysma but superficial to the artery.

Fig. 11-4  The skin incisions to approach the vessels. 1, Superficial temporal vessels. The incision is made in front of the ear, from the tragus to the root of the helix. 2, Facial and superior thyroid vessels. The incision is made 2 to 3 cm below the mandibular border, parallel to the neck lines. 3, Transverse cervical vessels. The incision is made 2 cm above and parallel to the clavicle.

Advantages

The access to the facial artery is straightforward. In addition, the artery has a relatively large caliber and good flow, making it suitable for microanastomosis.
Disadvantages
The marginal mandibular branch crosses the artery within 1 cm of the mandibular border. Meticulous dissection in this area is required to avoid ipsilateral depressor anguli oris palsy. In buccal and mandibular cancer, the facial artery is often resected with the tumor. It can be absent on one side of the face in up to 2% of the population. When this anatomic variation is encountered, the choice of vessels can be redirected to the transverse facial artery, which becomes sizable.

Superior Thyroid Artery
The access used for the facial artery can also be used for the superior thyroid artery (see Fig. 11-4). Its origin can be found 1 cm inferior to the origin of the facial artery on the external carotid artery. It courses anteriorly and inferiorly to reach the thyroid gland.

Advantages
Similar to the facial artery, the superior thyroid artery is easily accessed and has a suitable caliber and flow for microanastomosis. It is often spared in patients whose facial artery has been sacrificed.

Disadvantages
The downward orientation of the superior thyroid artery could theoretically increase the risk of pedicle kinking. However, this has not been our experience. If it occurs, it can be overcome by proper perivascular dissection or by using the distal stump in a reverse fashion. The backflow of the distal stump generates enough blood flow for free tissue transfer.

Superficial Temporal Artery
The superficial temporal artery is usually palpable in the preauricular area, just above the zygomatic arch. Its course can be identified using a Doppler unit.

The incision is planned in front of the ear, from the tragus to the root of the helix, and extended in the temporal scalp if necessary (see Fig. 11-4). Once the skin is incised, blunt dissection quickly reveals the vessels, which lie superficially on the temporoparietal fascia. Distally, the superficial temporal artery bifurcates in a parietal and a frontal branch. The latter runs close to the temporal branch of the facial nerve.

Advantages
At the level of the zygomatic arch, the superficial temporal artery lies subcutaneously, where it can easily be accessed and traced back proximally. This vessel is usually spared by previous surgery and radiation therapy. The preauricular incision
for the approach usually leaves an inconspicuous scar.\textsuperscript{42} The flow is adequate to sustain a free flap transfer,\textsuperscript{15,42} but the caliber can be relatively small and challenging for microsurgical anastomosis, especially when a size discrepancy is present.\textsuperscript{7} Its tortuous course provides extra length when the vessel is adequately dissected.

**Disadvantages**

From the preauricular incision, additional dissection must proceed with caution to avoid injuring the facial nerve. If the dissection is pursued in a retrograde fashion into the parotid gland, care must be taken not to injure branches of the facial nerve that cross over the artery. Alternatively, if the dissection of the superficial temporal artery is extended along its frontal branch, the temporal branch of the facial nerve must be identified and protected. Incomplete dissection might lead to kinking of the vessel because of its tortuous course.

**Transverse Cervical Artery**

Two different incisions can be used to approach the transverse cervical artery. The choice depends on whether or not the exploration is performed concomitantly with a neck dissection. Commonly performed neck dissections use an apronlike incision, and do not usually expose the base of the neck (Fig. 11-5). From this incision, a vertically oriented incision can be made from the midpoint of the lateral border of the sternocleidomastoid muscle, reaching down to the midpoint of the clavicle. In patients not undergoing concomitant neck surgery, an incision can be made 2 cm above and parallel to the clavicle, lateral to the sternocleidomastoid muscle (see Fig. 11-4).
If the external jugular vein is encountered, it should be protected. The fatty tissue lateral to the sternocleidomastoid muscle and cephalad to the clavicle is bluntly dissected. The artery can be found deep and cephalad to the vein (Fig. 11-6).

**Fig. 11-6** Dissection of the left transverse cervical vessels. The middle supraclavicular nerve is a cutaneous branch of the cervical plexus.

**Advantages**

The transverse cervical vessel can be used even in severely scarred necks. It is usually spared during previous radical neck dissection surgery, and its caliber is usually greater than 2 mm in diameter.\(^{14}\) It is usually less affected by atherosclerosis than the carotid system.\(^{10}\)

**Disadvantages**

In certain anatomic variations (around 20%),\(^{43}\) the transverse cervical artery can pass through the brachial plexus. This is problematic only if the vessels must be traced for some length distally to accommodate a short flap pedicle. In the other 80% of patients, the artery runs superficial to the brachial plexus.\(^{43}\) The proximity of the thoracic duct requires careful dissection when the transverse cervical vessels on the left side are explored. Its use eliminates the option of a future ipsilateral trapezius flap.\(^{10}\)
COMMONLY USED RECIPIENT VEINS
The internal and external jugular veins are the two main venous systems draining the head and neck. Some authors report better results using the internal jugular vein in microsurgical head and neck reconstruction\textsuperscript{33,44} but this remains controversial.

Branch of the Internal Jugular Vein
The useful branches of the internal jugular vein include the facial, superior thyroid, and lingual veins. They sometimes merge into one thyrolinguofacial trunk. Other branches are deeply seated and hardly used. The same surgical approach as that used for the corresponding arteries is performed. The retromandibular vein is seated in the parotid gland. Proximally, it courses superficial to the carotid artery but deep to the facial nerve branches to drain in the common facial vein. The facial nerve must be carefully identified and protected during dissection. The approach is similar to the one used for the facial artery.

Advantages
The internal jugular vein has the advantage of having an important blood flow that could be increased by the respiratory pump effect.\textsuperscript{45} Its branches are easily found in the vicinity of the corresponding arteries. This vein is seldom sacrificed, except for cases of radical neck dissection.

Disadvantages
The internal jugular vein lies relatively deep. In some instances its branches have adequate caliber only very proximally, which can make the anastomosis more challenging. There is a risk of thrombosis with neck dissection, infection, and radiation\textsuperscript{31-38}.

Branch of the External Jugular Vein
The course of the external jugular vein is easy to identify in most patients when they perform a Valsalva maneuver. The branches of the external jugular vein are the superficial temporal vein (via the posterior division of the retromandibular vein), the posterior auricular vein, and the anterior jugular vein (see Fig. 11-2). The superficial temporal vein also drains to the internal jugular vein and is most often found through the same incision as the one made to access the superficial temporal artery. The posterior auricular vein is usually very small and rarely used.

The external jugular vein can be used directly with either an end-to-end or end-to-side anastomosis. It can be approached through the same incision as the one used to find a carotid branch in the upper neck or through the same incision as that used to find the thyrocervical trunk in the lower neck.
Advantages
The superficial location of the external jugular vein makes it easy to access. It may not be sacrificed, even in radical neck dissection. It can be ligated distally if necessary but can still be used proximally as a recipient vessel without compromising an oncologic resection.\textsuperscript{10}

Disadvantages
The superficial location of this vein also puts it at greater risk of trauma or overzealous ligation.

Anterior Jugular Vein
The anterior jugular vein is also a tributary of the external jugular vein near its junction with the subclavian vein. It usually has a small caliber. In patients with a tracheostomy, its proximity to the stoma can increase the risk of thrombosis as a result of trauma or inflammation.\textsuperscript{10}

OPTIONS FOR DIFFICULT NECKS
A “frozen neck” or “stiff neck” (Fig. 11-7) is not uncommon in head and neck reconstruction, especially in the oncologic setting. A frozen neck can be defined as a scarred neck with severe fibrosis with a loss of tissue planes, secondary to surgery and radiation.\textsuperscript{14} Moreover, previous neck dissections often jeopardize the use of the usual neck vessels. In patients with recurrence or failed reconstruction, a second free flap still yields better results than other reconstructive options.\textsuperscript{1} This is why a complete knowledge of the alternatives to common recipient vessels is essential to all surgeons involved in head and neck reconstruction.

Fig. 11-7 A typical case of frozen neck with extensive scarring and fibrosis caused by surgery and radiation therapy.
Recipient Vessels in the Contralateral Neck

The vessels of the contralateral neck are the first option when the ipsilateral vessels are not suitable. In 2001 Wei et al.\(^1\) reported the use of contralateral recipient vessels in 35\% of cases requiring a second free flap for head and neck reconstruction. With proper planning, the use of vein grafts can be avoided in most cases, even for second and third free flap reconstructions to the same area.\(^{1,46,47}\) The use of the contralateral recipient vessels should be considered when patients present with a scarred neck on one side and a contralateral side free from previous surgery or radiation therapy. It has the disadvantage of necessitating flaps with a longer pedicle, usually more than 10 cm, depending on the distance between the deficit and the location of the recipient vessel.

End-to-Side Anastomosis to Ipsilateral Carotid Artery and Internal Jugular Vein

An end-to-side anastomosis to major neck vessels is a useful alternative. Its patency rate is comparable to that of end-to-end anastomosis\(^16\) and has been described for use on the internal jugular vein and the carotid artery.\(^48\) Halvorson and Cordeiro\(^44\) reported using an end-to-side anastomosis on the internal jugular vein in a majority of head and neck reconstructions, with minor complications in less than 5\% and no flap failures.

Advantages

End-to-side anastomoses can overcome a size discrepancy between the recipient and flap vessels and allow multiple anastomoses.\(^{45,48}\)

Disadvantages

End-to-side anastomoses are technically more demanding, because the carotid arteries and internal jugular veins cannot be mobilized. Anastomosis leakage from major neck vessels can lead to massive bleeding.

Vein Graft and Arteriovenous Loop

With adequate planning and a proper choice of free flaps with long pedicles, the need for a vein graft is infrequent.\(^{13,30}\) However, it remains a necessary option in selected cases. A long vein graft can be used to create an arteriovenous loop if both the artery and the vein need vein grafts. A two-stage arteriovenous loop (with a few days delay between its creation and the flap transfer) does not present any advantage over a single-stage arteriovenous loop (creation of the arteriovenous loop and flap transfer during the same procedure).\(^{49}\)
Advantages
Vein grafts avoid tension on microanastomoses and help to overcome size discrepancies. They can allow the resection of diseased vessels until healthy intima is visualized. Using an arteriovenous loop decreases the ischemia time of the flap compared with that of vein grafts, because half of the anastomoses are already completed at the time the flap is anastomosed. The interval between the loop creation and flap inset offers the vein the opportunity to dilate and surgeons the opportunity to confirm the anastomosis patency.49

Disadvantages
This option increases the total operation time and doubles the number of anastomoses compared with the standard direct anastomosis of a flap with a long pedicle, thus increasing the risk of thrombosis and flap failure.25,50,51

UNUSUAL RECIPIENT VESSELS
Other options using unusual recipient vessels are available that have been reported as “lifeboats” in the literature.

Deep Temporal Vein
Davison and Kaplan52 reported the successful use of the deep temporal vein as an option for the absence of venous recipient vessels in a case of head and neck reconstruction. The deep temporal vein is better known as the “sentinel vein” that indicates the proximity of the temporal branch of the facial nerve in brow lift surgery. It runs in the deep temporal fascia and dives deep to join the pterygoid plexus. This vein anastomoses with the superficial temporal venous plexus.3

Advantages
The deep temporal vein usually presents a larger caliber than the superficial temporal vein.52

Disadvantages
The vein runs close to the temporal branch of the facial nerve. It presents a short length and a deep course.
Posterolateral Cervical Vein

Yagi et al\textsuperscript{53} reported the use of a vein that they called the 
\textit{posterolateral cervical vein} in cases of difficult neck reconstructions. It runs inferiorly on the anterior border of the trapezius muscle.

Advantages and Disadvantages

The posterolateral cervical vein can be a useful alternative for venous anastomosis, but it is not always spared in extensive neck dissection and does not necessarily eliminate the use of vein grafts.\textsuperscript{53}

Cephalic Vein

The cephalic vein could be used either as an arteriovenous loop or simply as a recipient vein in patients with no available neck vessels.\textsuperscript{19,54} If no vein is available in the neck, the cephalic vein can be transposed to the neck. The transposition is accomplished by dividing the cephalic vein distally in the forearm and dissecting proximally until the transected part reaches the neck. It is anastomosed to the flap vein.

If the recipient artery and vein both need a vein graft to reach the flap vessels, an arteriovenous loop can be created with the cephalic vein. The loop is created by transposing the cephalic vein to the neck as described previously. However, the transected end of the cephalic vein is anastomosed to the nearest recipient artery to create the arteriovenous loop. The loop is transected and the segment previously anastomosed to the recipient artery is anastomosed to the flap’s artery. The segment that is still in continuity with the cephalic vein is anastomosed to the flap’s vein.\textsuperscript{19} Horng and Chen\textsuperscript{54} also described one case in which a whole forearm free flap was transposed to the neck through a tunnel in continuity with the cephalic vein. Only the arterial anastomosis needed to be performed on a branch of the carotid artery. These techniques can certainly be used as a lifeboat in cases where no vessels can be found in the head and neck area.

Advantages and Disadvantages

The cephalic vein has one anastomosis less than a vein graft. However, it requires an extensive dissection, which increases the risk of thrombosis associated with the arteriovenous loop.\textsuperscript{49}
**Thoracodorsal Vessels**

The thoracodorsal vessels can also be transposed to the neck to be used as the recipient vessel in special cases of bilaterally scarred neck.\(^{55}\) The vessels are approached through an incision on the posterior axillary line, dissected proximally, and transposed subcutaneously to the neck, over the pectoralis minor muscle and the clavicle.

**Advantages**

This technique has the advantage of bringing a scar-free artery of good diameter in addition to its accompanying veins. It avoids any manipulation of a severely scarred carotid system.

**Disadvantages**

In patients with an intact pectoralis major muscle, the vessels could be tethered on the muscle border during contraction. This precludes using a thoracodorsal artery perforator or latissimus dorsi flap at a later date.

**The Subclavian Artery and Its Branches**

The thoracoacromial artery can also be transposed to the neck to serve as recipient vessels.\(^7\) The subclavian vessels can be used as recipient vessels for end-to-side anastomosis. Division of the clavicle facilitates the microsurgery but can complicate the operation.\(^7\) Yagi et al\(^{56}\) reported using the internal mammary artery as the recipient vessel to reconstruct a defect involving the neck and lower third of the face. Omental flaps, alone or as a flow-through for a second flap, were used in these cases.

**The Pedicle of a Previous or First Free Flap**

The use of a pedicle from another flap, in the acute or delayed setting, as the recipient vessels of a second flap has been reported.\(^{15,57-60}\) The vascular anatomy of the forearm flap, the fibular flap, and the anterolateral thigh flap are especially appropriate for flow-through circulation. Each flap should be inset independently before the sequential anastomosis to limit the risk of trauma to the anastomosis and kinking of the vessels during the insetting. The pedicle of any other flap or a side branch of a pedicle can be used for an end-to-side anastomosis.\(^{61}\)

**Advantages**

A long pedicle avoids the additional use and risks of vein grafts. It increases the versatility of both flaps, allowing more independent insetting of each flap. It limits the dissection for recipient vessels when more than one flap is needed. In certain cases
of large composite anterior defects of the mandible in which the two flaps can be transferred en bloc after securing one to the other, one anastomosis can be performed on a side table.\textsuperscript{59}

**Disadvantages**

Higher partial and total failure rates have been reported when this technique is used.\textsuperscript{57,62} If the proximal anastomosis thromboses, the risk of losing two flaps is high. The subsequent circulation could have negative hemodynamic consequences on the first or second flap (steal phenomenon and increased thrombogenicity). Careful dissection is needed when the pedicle of a previous flap is used within the first months after the free flap transfer.\textsuperscript{60} In addition, the venous part of the pedicle can be thrombosed.\textsuperscript{60}

**The Previously Used Recipient Vessels**

On rare occasions, it may be necessary to rely on recipient vessels used for a previous flap. If this previous flap has been in place for at least 4 months,\textsuperscript{60} its blood supply can be completely divided without later necrosis,\textsuperscript{60} and the divided end can be used as the recipient vessel for the present flap. Patency of these recipient vessels must be evaluated before performing the anastomosis. The arterial patency can be assessed by preoperative angiography or confirmed intraoperatively along with the venous patency.\textsuperscript{60,61} Patency rates can be decreased in veins.\textsuperscript{60}

**OPTIMIZING OUTCOMES**

The head and neck are made of many complex and mobile structures, increasing the difficulties encountered in their reconstruction. Urken et al\textsuperscript{10} used the term \textit{geometry of the vascular pedicle} to refer to its tridimensional positioning, its tension, or redundancy. In their experience with head and neck free flaps, failure is more commonly caused by inadequate vascular geometry than by flaws in the anastomotic technique. The tridimensional motion of the neck area makes it even more difficult to adequately plan the vascular pedicle geometry.

**Avoiding Kinking of Vessels**

The recipient artery and vein should be close and parallel to each other to avoid kinking of the flap vessels at their junction point.\textsuperscript{10} When this is not possible, the artery and vein of the pedicle must be carefully dissected from each other to allow the appropriate degree of freedom. Unnecessary redundancy of the vessels increases the risk of kinking and should be avoided. However, neck motion must be accounted for and some redundancy must be present when the flap is in the face area and the anastomoses are on neck vessels. The easiest way to measure the appropriate vessel
length is to perform the anastomosis without tension, with the head turned in the opposite direction. Once the anastomoses are completed, the head should be turned back to a neutral position, and the course of the vessels checked to ensure that kinking is absent. The use of sutures or other devices, such as absorbable gelatin sponges (for example, Gelfoam), can maintain the vessels in the adequate position. Because of their small caliber, feeding vessels of perforator flaps are prone to kinking and twisting. Clinically, this can present as a vascular compromise of the flap with patent anastomosis. Thus particular attention must be given to the insetting of perforator flaps.

Avoiding Vessel Compression

Recipient or flap vessels can be compressed by surrounding tissues, the flap itself, or an expanding hematoma. When the flap pedicle must be tunneled, important considerations are the type of tissues surrounding the tunnel, the diameter and course of the tunnel, and the position of the pedicle in the tunnel. The tunnel must be several times wider than the pedicle, at least one finger breadth. If muscle surrounds the tunnel (for example, a tunnel through the floor of the mouth), compression must not occur with muscle contraction. The course must be as direct as possible and avoid any acute angle that could tether the pedicle. When the pedicle passes over the mandibular border, it is sometime necessary to burr out a notch to avoid compression. The pedicle should never be twisted in the tunnel. This can sometime be difficult to recognize. Performing the arterial anastomosis first and evaluating the venous back flow from the flap can help confirm that the vessel’s position is adequate. Drains should be left in place to avoid compression from hematomas. Direct compression of the internal jugular vein by the flap could increase the risk of venous thrombosis.63

Avoiding Tension on the Anastomosis

In all cases, tension on the anastomosis must be minimized. When a pedicle crosses from the lower neck to the head, the anastomosis should be performed with the head turned to the contralateral side to avoid avulsion of the pedicle during neck motion. Further dissection of the recipient vessels and further isolation of the pedicle vessels help to decrease tension on the anastomosis. The submaxillary gland can be removed to obtain additional vessel length of the facial or superior thyroid artery.15 The use of a vein graft adds the risk of an additional microanastomosis but is always preferable to undue tension.
The success of a free flap to the head and neck starts with choosing adequate recipient vessels. Preoperatively, surgeons must have a thorough knowledge of the vascular anatomy of the head and neck and the surrounding areas. Care must be tailored to each patient’s situation. Reports of previous radiation therapy or surgeries to the head and neck must be obtained. Some patients may need further workup to confirm the patency of the major neck vessels. During surgery, communication with the oncologic team can help avoid sacrificing useful vessels. Meticulous dissection of diseased or scarred vessels can reduce the need to resort to second-choice and more distant vessels. The simplest solution should be considered before contemplating more-complex ones (Fig. 11-8). When to resort to more-complex alternatives remains a difficult question. Each patient presents a unique challenge. Only through good judgment, experience, and ability can each surgeon find the answer.

Fig. 11-8 An algorithm for the choice of recipient vessels in the head and neck. (ECA, External carotid artery; EJV, external jugular vein; IJV, internal jugular vein.)
CRITICAL POINTS

Must Know
- Surgeons must have a thorough knowledge of the vascular anatomy of the head and neck.
- The location of the defect and the preferred recipient vessels for a particular location (see Table 11-1) must be determined for each patient.
- Records of a patient’s previous surgery and radiation therapy in the head and neck area must be reviewed to optimize treatment.
- The surgical technique for fragile vessels should be applied when needed.
- Surgeons must know how to avoid tension, compression, and kinking of the vessels.
- Alternative recipient vessels in patients with difficult necks are the thoracodorsal, thoracoacromial, and internal mammary vessels and the cephalic, deep temporal, and posterolateral cervical veins.

Should Know
- Effective communication with the oncologic team is needed to avoid sacrificing useful vessels.
- The different types of neck dissections should be understood (see Table 11-2).
- The preoperative risk of internal jugular vein thrombosis and carotid arteriosclerosis should be determined, and Doppler studies should be performed for further workup.

Synopsis
- Identifying optimal and alternative recipient vessels is one of the first steps in planning a free flap head and neck reconstruction.
- The choice of the recipient vessels depends on the location of the defect and the qualities of the available vessels.
- The facial, superior thyroid, and superficial temporal vessels are the vessels most commonly used. However, in patients with previous extensive head and neck surgery and radiation therapy, the thyrocervical trunk vessels, especially the transverse cervical vessels, must be considered as alternatives. More distant vessels should be used only as a last resort.
Chapter 11 Choosing Recipient Vessels

References


   This article presents an extensive review of the management of failed free flaps in head and neck and extremities. The authors compare the outcome of the following management strategies after free flap failure: a second free flap, a local flap, and conservative treatment. In the head and neck area, total flap failure is most often treated with a second free flap, with excellent results. Partial flap failure is most commonly treated using regional flaps, with acceptable results, but the risk of complications and the length of hospitalization are increased. Conservative treatment yields better results for flap failure in the extremities.


   This article reviews 16 cases of head and neck reconstruction in which the first choice of vessels was not available. The authors present alternatives, including smaller, adjacent vessels, end-to-side anastomosis to major vessels, and distant vessels such as thoracoacromial vessels and cephalic vein transposition.


   The authors stress the importance of the vascular pedicle “geometry” for free flap success. The geometry of the vascular pedicle is defined as the three-dimensional positioning of the flap pedicle along with its tension or redundancy. The axis of the pedicle should follow a longitudinal direction to avoid kinking. The motion of the neck should be considered. The authors prefer to use the transverse cervical artery as the recipient vessel and describe some relevant anatomy.


   This article presents a detailed anatomic study of the most commonly used vessels in microsurgical reconstruction in the head and neck area: the facial, lingual, and superior thyroid vessels, along with the carotid artery and jugular veins. It reports the variation in branching, the average diameter and length of vessels, and the presence and distribution of valves in the venous system.


This article presents a clinical anatomic study of the transverse cervical artery on 33 neck sides in 26 patients with frozen neck. Anatomic and technical details are given for dissection. The transverse cervical vessels were present and suitable in 92% of patients. The authors advocate the use of the transverse cervical vessels in difficult head and neck reconstruction cases.


In this study, the authors present their algorithm for choosing recipient vessels in complex composite deficits of the head and neck necessitating double-flap reconstruction. Through rational planning, they achieve high success rates with a low rate of vein grafts, even in these challenging cases. The vessels most commonly used are the superior thyroid artery (bilaterally), the contralateral facial artery, and the ipsilateral superficial temporal artery.


This retrospective study reviews 102 head and neck reconstructions, with their recipient vessels and factors possibly influencing outcomes. Tobacco use and the use of an arteriovenous loop are reported to increase the risk of flap failure. Flap failure was not related to patient age, the choice of recipient vessel, diabetes mellitus, previous radiation therapy, the method of arterial or venous anastomosis, the use of an interposition vein graft, or the timing of reconstruction. A variety of recipient vessel options are presented, such as the facial, superficial temporal, superior thyroid, and carotid artery.


This is a cohort study of flap survival in 226 irradiated and 108 nonirradiated patients who underwent head and neck reconstruction. There was a statistically significant difference between the failure rate of irradiated (3.5% failure) and nonirradiated patients (2.9% failure). In a derived case-control study of the irradiated flaps, the authors found infection and delay between radiation therapy and surgery to be the only factor associated with flap failure.


This study evaluates the outcome difference between 167 patients with preoperative radiation therapy and 187 patients without preoperative radiation therapy in head and neck reconstruction. There was no statistical difference between the two groups in terms of flap failure (5.3% versus 5.0%) or major flap complications (16% versus 11%).


This is an exhaustive review of the complete care of patients with atherosclerosis who are undergoing microsurgical procedures, from the preoperative evaluation to the surgical technique and postoperative care. The incidence of atherosclerosis increases with age and medical conditions such as diabetes. Prophylactic anticoagulation is recommended in severely atherosclerotic patients.


In this article the authors correlate the choice of recipient vessels with the type of previous neck dissection in 59 cases. The vessels in the field of previous neck dissection were used in 50% of cases with selective neck dissection. Contralateral vessels to the previous neck dissection were used in all cases of previous radical or modified radical neck dissection. There was no flap failure in this series, and the authors attribute this high success rate to the avoidance of vein grafts. A previous neck dissection should not be considered a contraindication to microsurgical head and neck reconstruction.


This study evaluates the patency of the internal jugular vein in 23 patients after modified radical or selective neck dissection and microsurgical reconstruction of the head and neck, using a Doppler ultrasound. The Doppler evaluation was performed at 24 hours and 4 months postoperatively. Only 1 patient had a partial thrombosis 24 hours after the operation. However, at the 4-month follow-up, 3 patients (15%) demonstrated complete internal jugular vein thrombosis. No acute or late flap failure occurred in any patient. Flap survival in patients with late thrombosis can be explained by neovascularization.


This clinical study compares the retrograde pressure of 20 superior thyroid arteries and 8 facial arteries with the mean systemic arterial pressure and retrograde pressure in the radial artery. The retrograde pressures in both neck vessels were similar to the retrograde pressure of the radial artery. The authors conclude that retrograde anastomosis to the facial or superior thyroid artery is possible as long as the distal stumps present good spurring.


In this review of 320 head and neck microsurgical reconstructions, the use of end-to-side anastomosis to the internal jugular vein demonstrates a high success rate and low morbidity. The authors advocate the use of the internal jugular vein because of its size, constant anatomy, the possibility for multiple anastomoses, and the absence of kinking with neck rotation. Minor wound problems were reported in 5% of cases and partial flap failure in 2%. Total flap failure and vein thrombosis occurred in 1% of cases.


In this paper, the authors present their case series of 12 microsurgical reconstructions to the head and neck using an arteriovenous loop in a one-stage operation. They report only one flap failure (8%). They compare their results with those of a literature review on two-stage versus one-stage arteriovenous loops. The authors conclude that a delay between loop creation and flap transfer is unnecessary.


Facial reconstruction has evolved over many centuries, from the early descriptions of forehead flaps for nasal reconstruction in ancient India\(^1\) to the first understanding of vascularization in “arterial flaps” described by Esser\(^2\) at the beginning of the twentieth century to the current concepts of aesthetic facial reconstruction. A plethora of facial reconstructive options using countless flaps have been described over the past decades. The general theme in facial reconstruction has been to use a flap to close a hole. Only in recent decades has the concept of aesthetic facial reconstruction started to develop more clearly. This concept makes use of the *aesthetic facial units*, which are governed by the transitions of light and shadow on the face as the facial surfaces change from concave to convex. The borders of the aesthetic facial units are ideal locations for placing scars to make them least conspicuous. Larger aesthetic facial units, such as the nose or lips, can be divided into subunits to further refine facial reconstruction.\(^3\)
The second pillar on which aesthetic facial reconstruction rests is the proper identification of the defect. For a long time, many facial reconstructive efforts have only focused on filling a hole with a single flap, often additionally guided by the principles of the reconstructive ladder. Aesthetic facial reconstruction can only be achieved with meticulous defect analysis, which includes assessment of the different aesthetic units involved, the quality of the tissues, possible structural support needed by those tissues, and the ultimate function. This analysis necessitates the use of the reconstructive elevator rather than the reconstructive ladder, so that the flap or combination of flaps is chosen according to which flap or flaps will give the most aesthetically pleasing and functional outcome.4

Reconstructive surgery also focuses on minimizing donor site morbidity. From an aesthetic viewpoint, this is largely accomplished by positioning scars in the borders of the aesthetic units. When looking at a person’s face, one first sees the eyes, cheekbones, nose, and mouth. This means that scars on the forehead or lateral to a vertical line through the lateral canthus are less conspicuous and therefore have less aesthetic donor site morbidity, even if they run through an aesthetic unit. From the perspective of functional donor site morbidity, perforator flaps have greatly diminished donor site morbidity. In facial reconstruction, the FAP flap is the first flap supplied by a single perforator that preserves facial musculature and innervation to reduce functional donor site morbidity.5

Aesthetic facial reconstruction is a highly challenging and very artistic discipline. To achieve good, reliable outcomes, it is important to make detailed preoperative plans with possible backup options. Proper planning is critical to any good outcome. In many cases, consecutive stages need to be performed as part of the initial plan or as touch-ups after a one-stage operation. To achieve a perfect result, more than a single operation is often needed. This is especially true with nasal reconstruction, which often involves three or more stages.

**SURGICAL OPTIONS**

A few common flaps with proven excellent value for facial reconstruction are discussed in greater detail in this chapter. Obviously, this chapter is not a comprehensive presentation of flaps and flap adaptations for facial reconstruction. For more extensive coverage, see Ian T. Jackson, *Local Flaps in Head and Neck Reconstruction.*6 The few options presented here are intended to supply a solid base from which to learn and eventually master additional functional and aesthetic facial reconstruction. These flaps are based on the facial, superficial temporal, supraorbital, and supratrochlear arteries and their branches (Fig. 12-1).5,6
Fig. 12-1  **A**, A cadaver dissection of the facial artery (FA) with three FAPs (I, II, and III) branching off into the medially reflected deepithelialized facial skin flap. **B**, A closer view of two FAPs branching off the facial artery into the facial skin flap. **C**, The blood supply of the face.
SKIN FLAPS ON THE FACIAL ARTERY

Skin flaps based on the facial arteries are commonly referred to as nasolabial flaps. These flaps are well known and widely used for external skin defects or intraoral lining defects. Nasolabial flaps can be planned as superior or inferior pedicle flaps. Their use as an island flap has been described to prevent the second stage, in which the pedicle requires division. A more recent refinement in the use of skin flaps based on the facial artery is the FAP flap, which is supplied by the perforating branches of the facial artery (see Fig. 12-1). The facial artery on average gives off six perforators, with an average vessel diameter of 1.2 mm and an average length of 2.5 cm, between the cranial edge of the mandible and the alar rim of the nose (Fig. 12-2). The references provided are recommended to understand basic information about standard nasolabial flaps. The FAP flap was the first true perforator flap described that could be raised in the face.

Fig. 12-2  A, The tortuous course of the facial artery between the mandible and nasal alar base. B, The bar graph shows the cumulative number and level of facial artery perforators (FAPs) that branched off the facial artery in 10 hemifacial dissections in five cadavers.
The FAP flap was originally described for the reconstruction of perioral defects. Although the flap has the ability to reach toward the lateral cheek or the lower eyelid, it is not the first choice, because transposition to those areas follows the unit principle of aesthetic facial reconstruction. However, FAP flap transposition to the perioral region allows reconstruction of an entire upper lip unit with minimal donor site morbidity. The FAP flap is harvested from the jowl area, which often has sufficient skin surplus. The flap does not interfere with facial nerve function, because it is harvested where no major facial nerve branches run. The FAP flap depends on a single perforator from the facial artery, and the venous drainage is through an accompanying vein or often, in absence of this vein, only the fibrofatty tissue around the artery. These flaps can be used successfully following neck dissection, when the facial artery may be cut more proximally because of rich collateral circulation in the face. In addition, atherosclerotic disease has not been a problem in the survival of these flaps. Preoperative and postoperative radiation therapy have been well tolerated in selected patients. Problems with tip necrosis have been reported in patients who did not stop smoking.

Indications and Contraindications

The only absolute contraindications to FAP flap transposition surgery are smoking and insufficient skin laxity, either because the defect is too large or a similar local flap was previously used. Relative risk factors, such as previous radiation therapy or previous neck dissection, and the course and size of the scars should be discussed with each patient.

Preoperative Management

Preoperative management consists of identifying patients who have risk factors for flap failure. Also, patients need to understand that even with a perfect reconstructive result, the original facial function and features may change.

Operative Technique

Before this flap is raised, the exact course of the facial artery is identified using handheld Doppler sonography. The perforators that come off the facial artery and supply the facial skin cannot often be reliably identified. On occasion, a slight crescendo indicating a FAP may be detected; however, this is uncommon. Once the exact course of the facial artery is known, a prospective flap design can be planned.
The defect is assessed and, if necessary, prepared for reconstruction by adapting it to adhere to the unit principles of aesthetic facial reconstruction. The part of the unit to be reconstructed is marked on a foil template. This template outline is marked preliminarily on the skin of the jowl area over the course of the facial artery. The flap is designed in a fashion that makes transposition easily feasible. To assess the final feasibility, either an exploratory incision along one side of the projected flap, or meticulous, subcutaneous blunt dissection in a vertical direction from the wound edge of the adjacent defect is performed to identify a FAP. It is important to stay in a plane above the facial musculature, which should be visible in the more cranial part of the dissection. To appreciate these small structures, all dissection is performed under 2.5× loupe magnification.

After the FAP is identified, its suitability for the projected flap is assessed by evaluating the flap’s possible arc of rotation. If the arc of rotation is deemed inadequate, another perforator should be found or the flap design should be changed. In the unlikely case that no suitable perforator can be identified, a conversion to a classic nasolabial flap is an option; however, these flaps also obtain their blood supply from multiple perforating vessels from the facial artery.

After a specific FAP is chosen, the flap can be circumscribed and raised in a plane above the facial muscles (see Fig. 12-3, B). The pedicle is dissected to allow good transposition into the defect without leaving unnecessary bulk at the pedicle that would require secondary thinning. In rare cases, a clearly identifiable vein runs with the FAP (see Fig. 12-3, C). Venous drainage is usually from the fibrofatty tissue around the artery, similar to the situation with digital neurovascular island flaps. The pedicle of the flap should consist of a clearly identifiable artery with a small amount of fatty tissue around it. In this fashion, the flap can be rotated over 180 degrees without any concern for the blood supply.

The flap is rotated and sutured into the defect with little tension (see Fig. 12-3, D through F). By the end of the operation, most flaps have the classic blue shimmer of slight to moderate venous congestion, a characteristic for which forehead flaps are well known. This venous congestion causes slight flap swelling in the postoperative phase and makes inset with minimal tension beneficial to postoperative circulation.
Fig. 12-3  A, A large defect was created from sweat gland cell tumor resection, exposing the maxilla and oral mucosa. The defect comprised the entire left upper lip aesthetic unit, the aesthetic unit of the left cheek, and the nose. B, A FAP was identified through the wound edge. The left upper lip aesthetic unit was re-created on the left jowl area by tracing the mirror image of a template made on the right upper lip aesthetic unit. The flap was cut in a level above the facial muscles, with the pedicle designed so that the flap rotates into the defect. C, In another patient, a very well-developed FAP ran into the flap. D, The FAP flap was rotated into the left upper lip defect, re-creating the upper lip aesthetic unit. The flap was rotated over 180 degrees and inset with minimal tension. It was only used to re-create the upper lip unit. E, The cheek and nose deficits were addressed with different flaps, because the FAP flap was only intended to re-create the upper lip unit. A cheek advancement flap and paramedian forehead flap were performed separately. F, The patient is shown 2 years postoperatively, after 66 Gy of radiation therapy.
Complications

Patient selection is an important factor in avoiding complications. The main cause of insufficient flap circulation is smoking. Patients who are candidates for this type of reconstruction typically have undergone radiation therapy or a neck dissection. All of these circumstances are only relative contraindications, but can result in higher complication rates. The FAP flap is basically very straightforward to plan and dissect. The surgeon must be meticulous to maintain optimal blood flow in the flap. The exact course of the facial artery is marked so that the flap lies directly over it. The flap is fully circumscribed once an adequate perforator is selected. An adequate perforator has a 1 mm diameter and sufficient length to provide the necessary arc of rotation into the defect. The inset should be loose enough to allow postoperative swelling without compromising circulation.

Optimizing Outcomes

Adhering to the unit principles of facial reconstruction and dissecting flaps with good circulation are important for achieving good results. To obtain a well-circulated flap, the size of the flap in relation to the size of the perforator and the location of its entry into the flap must be considered. Perforators with a diameter comparable to that of the facial artery have been reported to supply areas of skin measuring 5 by 10 cm. The FAP flap usually needs maximal transposition to reach the defect. This means that the vessel usually enters the flap at one edge of the flap. The perforator could therefore theoretically support a flap size of 5 by 5 cm. In clinical practice, this size is generally larger than primary closure will allow.

Bulky flaps can be thinned; however, care should be taken to avoid overzealous thinning. Careful thinning is performed with close visual inspection of the circulation after each thin layer is excised. The pedicle should not be thinned any further than is necessary to make it invisible when buried.

Postoperative Management

At the end of the procedure, the closed wounds are cleaned and nothing is applied to the wound. All FAP flaps are congested at the end of the procedure, but congestion resolves within the first 48 hours. In our experience, suture removal or leaching does help in a flap that was not dissected correctly. Sutures are removed after 5 days. No special measures are necessary.
PARAMEDIAN FOREHEAD FLAP

Forehead flaps have been described with many designs for different applications, but mainly for nasal reconstruction. Forehead flaps are very sturdy because of the reliable blood supply, primarily from the supratrochlear vessels and subcutaneous continuing branches from the angular artery, which form a sort of a plexus of vessels around the medial brow. There is no consensus on which forehead flap design to use; however, the paramedian forehead flap has proved well suited for nasal reconstruction.\textsuperscript{17,18} Technical refinements for this particular design of forehead flap, yielding excellent aesthetic results in nasal reconstruction, have been published over the past decades. The paramedian forehead flap is the workhorse flap for nasal reconstruction.

Surgical Options

The main indication for the paramedian forehead flap is nasal reconstruction. The flap replaces excised nasal skin and provides well-vascularized tissue for coverage of the cartilaginous framework, which has been exposed or (partially) reconstructed. Nasal defects from 1.5 cm in diameter up to total nasal amputations are suitable for paramedian forehead flap reconstruction. The folding part of the flap provides a reliable basis for reconstructing the inner lining. In general, the paramedian forehead flap is less suitable for reconstructing defects of the eyelid or medial corner of the eye because of the difference in skin thickness. Patients must refrain from smoking to avoid wound-healing complications and flap loss at the distal end, where the flap is usually most needed. If a second paramedian forehead flap is needed, the opposite side should be selected primarily. It is possible, however, to dissect a second paramedian forehead flap from the same site as the previous surgery. The collateral circulation in the median forehead is highly developed. A delay procedure is recommended in these cases.

Indications and Contraindications

Smoking is the only absolute contraindication.

Preoperative Management

Preoperative management involves identifying patients who have risk factors for flap failure. Each patient should have a clear understanding of the course and size of the scars. Often the forehead wound cannot be closed primarily and is left to heal by secondary intention. Finally, patients need to understand that even with a perfect reconstructive result, the original facial function and features may change.
Operative Technique

Before raising the flap, the area of the median brow is assessed with a handheld Doppler device. The strongest audible pulsation in the paramedian course on the forehead is investigated and traced as far as possible toward the hairline. The line of this signal is used as the center of the flap to be designed (Fig. 12-4).

The defect is analyzed and, if necessary, prepared for reconstruction by adapting it to adhere to the subunit principles of aesthetic nasal reconstruction. The part of the subunit or subunits to be reconstructed is re-created using an exact, three-dimensional foil template. This template outline is flattened and marked preliminarily on the skin of the forehead over the course of the marked line of maximum pulsation. The width at the base of the flap’s pedicle should be 12 to 15 mm, and the Doppler signal should be in the center of this narrow base (see Fig. 12-4). This narrow base allows easier flap rotation and a wider reach. The flap is designed so that it reaches the defect easily with rotation transposition, which is mimicked using a thin gauze pad. The pedicle can be lengthened by extending the dissection proximal to the brow (Fig. 12-5) or into the hair-bearing scalp.
Flap dissection begins with the incision of the skin, subcutaneous tissue, and frontalis muscle according to the exact foil template design, which was marked on the forehead. The inferior part of the flap, which becomes the cranial part on the nose once the flap is rotated over 180 degrees, extends into the pedicle and is not incised at this stage. The incision is carried down into the brow. Once the flap with its pedicle has been fully incised, it is lifted in the plane between the galea and frontalis muscle toward the brow and orbital rim. There are two ways to dissect the base of the pedicle. With the first method, the galea is incised approximately 15 mm above the orbital rim, and the dissection is continued in a subperiosteal plane until the supratrochlear vessels can be identified and released if necessary. If the arc of rotation is wide enough, dissection can stop before the supratrochlear vessels have been identified. Using the second method, the dissection is continued in the plane above the periosteum, because the rich vascular plexus supplies the dissected forehead skin through its continuations from the angular branch. In this fashion, it is possible to greatly extend the arc of rotation, because dissection can be carried all the way to the side of the nose. This very proximal dissection is usually not necessary and may cause more distortion of the medial brow, which can be difficult to correct. The flap is usually rotated clockwise to the nasal defect from the right side and counterclockwise from the left side to maintain maximum pedicle rotation.

Forehead skin is thicker than nasal skin. To achieve a nice inset, the skin along all of the edges that will become part of the reconstruction, except for the edge that runs
in continuity with the pedicle, is thinned by oblique resection of subcutaneous tissue with sharp scissors. At the same time, the wound edges along the nasal defect are gently undermined to obtain an optimal inset (Fig. 12-6).

Fig. 12-6 The forehead flap was carefully inset and the raw surface of the pedicle was dressed with Vaseline-impregnated gauze. The forehead donor site was closed directly. If the donor site cannot be closed it is left open, no matter the size, and dressed with Vaseline-impregnated gauze.

After 2 to 3 weeks, the forehead flap has grown into its recipient site and is ready for the second stage of thinning or for division of the pedicle (Fig. 12-7). Often the superior part of the donor site of the forehead flap cannot be closed. This should never be closed by applying a skin graft, but left open and covered with a Vaseline-impregnated gauze sponge for secondary healing with wound contraction. To perform a perfect reconstruction, all dissection and the inset are performed under 2.5× loupe magnification. The final result is seen in Fig. 12-8.

Fig. 12-7 During the second stage, the forehead flap was raised entirely off the nose in the subdermal plane as a very thin flap. The circulation after 2 to 3 weeks was far more robust because of the “delay phenomenon.” At this point, excess thickness of the forehead flap was sitting on the nose. The nose was sculpted as needed. During the third stage, after another 2 to 3 weeks, the forehead flap will be divided.
Complications

Proper patient selection is important for avoiding complications. Smoking is the main cause of insufficient flap circulation. Dissection of the paramedian forehead flap is straightforward, and it is extremely uncommon for this flap to fail. After dissection, the flap often looks slightly congested, which resolves in the first 24 to 48 hours. Complications with this flap can arise if excellent results are sought too hastily. Because forehead skin is thicker than nasal skin, the flap needs to be thinned and the nose sculpted to obtain excellent results. For many surgeons, the forehead flap is a two-stage procedure in which the pedicle is transected 3 weeks after transposition. This is a good option if only moderate thinning is required. At the initial stage of flap dissection, the frontalis muscle can be resected from the bottom of the flap. With loupe magnification, further thinning can be performed while maintaining the longitudinally running vessels intact. If more extensive thinning is required, venous outflow of these flaps may be overly challenged, resulting in flap tip necrosis. In our experience, more than 95% of reconstructions require more aggressive thinning if an excellent result is to be reached reliably. In the great majority of cases, therefore, it is advisable to undertake a three-stage forehead flap. This entails an intermediate stage at 3 weeks in which the flap is raised entirely off the nose (see Fig. 12-7). The flap at this time will have had time to develop a far better and more reliable circulation. It can now be thinned more aggressively, compared with a first-stage thinning, with very little risk of flap tip necrosis. Flap tip necrosis is an unsettling complication that usually results in partial loss of the cartilage framework and/or more aggressive scarring and a moderate end result at best. Less-aggressive thinning in a two-stage procedure decreases the chance of flap tip necrosis but rarely provides more than a moderate result, because the flap does not have a normal contour. A three-stage procedure offers the best chance of achieving excellent results.

Fig. 12-8  This patient is shown 2 years after nasal tip reconstruction with a forehead flap.
Optimizing Outcomes

The only way to achieve optimal results is to focus all attention on the nose. The forehead flap should be used only for the nose, and the reconstructive needs of surrounding subunits should be addressed separately. To prevent distortion of the forehead tissue and/or blood supply, the forehead is not infiltrated with local anesthetic agents and/or vasoconstrictors. Similarly, to prevent distortion of the nasal tissues, no fluids are injected locally. Whenever hair follicles can be seen on the underside of the flap during surgery, they can be teased out gently. In some patients, hair growth on the reconstructed nose needs to be removed by laser or electrical epilation no sooner than 3 months after the last procedure. The main problems that prevent a perfect result are thickness and contour or nostril stenosis and alar rim retraction. The first problem can best be tackled with the intermediate thinning stage described previously and quilting sutures, which prevent excessive edema between the forehead skin and the cartilage of the nose. Nostril stenosis and alar rim retraction are very difficult to address and should be approached by avoiding upward tension on the forehead flap using the distal or proximal extensions described previously. Even more important for nostril stenosis, however, is a well-vascularized, thin, and loose-fitting inner lining in combination with sturdy but thin, perfectly shaped structural support that holds up against the forces of circular contracture during wound healing.

At the time of the pedicle transection, the forehead donor site should be almost completely healed if the periosteum in the open wound was not damaged and the use of fat gauzes was continued. The lower part of the forehead scar is opened to allow repositioning of the brow that was cut to turn the pedicle. All pedicle skin above the brow is discarded, and a straight line closure or V-type closure is performed. No pedicle skin is repositioned into the vertical scar above the brow.

Postoperative Management

The flap is often congested immediately after surgery. This does not usually need to be addressed if the flap pedicle is not compromised by the most proximal suture of the forehead closure or kinked from insufficient proximal dissection of the pedicle. This congestion should always resolve within the first 12 to 24 hours, unless the flap has been thinned too aggressively. Also, at the end of the procedure, some blanching may be present where the flap was sutured tightly. This usually improves after a few minutes or once blood pressure rises and the patient starts to wake up. A white flap, however, must be assessed in the operating room, because it will not resolve on its own. The inset may need to be changed; the most proximal suture of the forehead closure can be released to reduce tension on the pedicle, or the pedicle can be dissected more proximal to resolve any tension-related issues of reduced flap blood supply.
In case it cannot be closed primarily, the forehead donor site should be dressed with a moist or petrolatum-type dressing to allow healing by secondary intention. The raw undersurface of the skin, consisting of adipose tissue, should also be covered with a petrolatum dressing to prevent desiccation. In some patients, a thin skin graft can be placed on the raw undersurface of the flap pedicle to facilitate care. This, however, results in another donor site.

Internal nasal splints provide compression to the reconstructed lining or counter-pressure to forehead skin quilted to the nose. These are removed after 24 to 48 hours. All nonresorbable skin and quilting sutures are removed after 5 days. A small dressing is applied to cover the fat or moist dressings of the forehead and flap pedicle.

**CHEEK ADVANCEMENT FLAPS**

Various local or regional transposition flap designs have been described for the reconstruction of cheek defects. To determine which flap is the best option, several variables such as defect location, size, shape, and depth should be considered. In addition, to achieve an aesthetically pleasing result, the aesthetic facial units must be taken into account. These aesthetic facial units are defined by the location, skin quality (color, texture, and hair bearing), contour, and natural outline of the face. The peripheral outline of the cheek unit is formed by the hard and soft tissue contours of the bordering units (forehead, eyelids, nose, lips, neck, and ear). In contour, the cheek is a relatively flat, expansive surface, except for the soft roundness of the nasolabial folds and cheek prominences. The reconstructive requirements of central facial units (nose, lips, and eyelids), which have complex and subtle contours and are seen on primary gaze with their contralateral, normal subunit available for visual comparison, should have the highest priority in reconstruction. In contrast, the units of the facial periphery (cheek and forehead) are a lesser focus of attention and therefore of secondary importance. Because the outline of the cheeks cannot be fully compared, exact symmetry is not vital. Therefore the preoperative plan includes distinguishing between central and peripheral features with regard to guidelines for unit reconstruction.

In cheek reconstruction, the most important element in restoring normal facial surface appearance is uniformity of skin color and texture, not contour and outline. Therefore cheek defects are preferably reconstructed with tissue from adjacent units, such as the neck, submental area, or chest, using local or regional flaps. These flaps may be anteriorly based rotation advancement flaps vascularized by the facial and submental vessels or posteriorly based rotation advancement flaps supplied by the superficial temporal and preauricular vessels. Large, deep, complex, and compromised wounds often require reconstruction with distant or free flaps, but they usually lead to a poor color and texture match.
Surgical Options
Primary closure or local flaps may be used to repair small cheek defects, but most defects involving more than 30% of the cheek unit require the transposition or rotation of residual cheek and neck skin. Large, deep, complex, and compromised wounds with bone defects, open sinuses, orbital exenteration, or exposed dura usually have to be reconstructed with microsurgical free flaps, introducing well-vascularized tissue and bulk to obliterate and seal dead spaces.

Indications and Contraindications
In general, smoking and a history of radiation therapy are contraindications for these extensively mobilized locoregional rotation advancement flaps, because they increase the risk of tip or partial flap necrosis considerably. In addition, anteriorly based cervicofacial flaps should be used with caution in patients with a history of ipsilateral neck dissection during which the facial vessels may have been severed. The same is true for posteriorly based cervicofacial flaps if the superficial temporal vessels have been damaged.

Preoperative Management
The location and amount of locoregional skin laxity are assessed first, because these are used to determine the flap’s design and position. Furthermore, the defect site, size, shape, and depth should be carefully assessed for the same reasons. A highly contaminated or infected wound may require delayed primary reconstruction after serial debridements or temporary split-thickness skin grafting. After cancer excision, clear margins must be ensured before definite repair. Finally, preoperative management involves identifying patients with risk factors for flap failure, especially smoking, a history of radiation therapy, and previous surgery.

Operative Technique
Anteriorly Based Rotation Advancement Flaps
The anteriorly based rotation advancement flap is indicated for posterior and large anterior cheek defects (Fig. 12-9). The incision runs transversely from the superior aspect of the defect, around or through the sideburn, inferiorly in the preauricular crease, and around the earlobe to follow the occipital hairline, with or without an inferior back cut. The flap is elevated in the subcutaneous plane to the clavicle, and the residual cheek skin is shifted forward on an anterior vascular base supplied by the facial and submental vessels. The neck is advanced upward to close the donor site (see Fig. 12-9, B). The dog-ear is removed in the anterior cheek, ideally in the nasolabial fold.
Fig. 12-9  A, This patient had a 6 by 9 cm defect on the right cheek after a radical excision of a dermatofibroma protuberans. An anteriorly based cervicofacial musculocutaneous rotation advancement flap design was marked. B, This intraoperative lateral view shows the raised flap, which is based on branches of the facial artery and part of the platysma muscle. C, The immediate postoperative lateral view. D, The patient is shown 7 months postoperatively. He has alopecia of local beard growth caused by postoperative radiation therapy. The postauricular scar is widened from tension on the skin and the course of the scar, which is not in the skin relaxation lines.
For larger defects up to 6 to 10 cm, the incision can be extended as a cervicopectoral flap, which moves neck and chest skin to the face.24,25 The incision extends from the hairline down to the neck, several centimeters behind the anterior border of the trapezius muscle, passes lateral to the acromioclavicular joint and deltopectoral groove, following the lateral pectoral border, and, finally, crosses the chest medially, parallel to the clavicle, 2 to 3 cm above the nipple-areola complex in male patients. The flap is elevated with platysma muscle and deltoid and pectoral fasciae. A back cut can be made in the parasternal area. Vascularization is through the internal mammary perforators. To enhance the flap’s blood supply, anterior cervicofacial flaps can be elevated in a deep plane below the superficial musculoaponeurotic system (SMAS) as in modern composite face-lift procedures.26 After a short subcutaneous dissection, further dissection is shifted 2 cm anterior to the tragus, under the parotid fascia and the SMAS, passing inferiorly to the neck and under the platysma muscle.

All anteriorly based rotation advancement flaps are one-stage procedures, designed to place the temple aspect of the suture line on a plane between or above the lateral canthus and helical root to support the cheek and eyelid and resurface the cheek, lower lid, and temple (see Fig. 12-9, C and D).23

**Posteriorly Based Rotation Advancement Flaps**

The posteriorly based rotation advancement flap is used for small and moderately sized anterior cheek defects (Fig. 12-10).23 A posteriorly based flap transfers the excess skin of the inferior face, jowl, and submental areas along an incision that follows the nasolabial fold to the commissure (see Fig. 12-10, B) and can continue to or across the jawline and anteriorly into the submental crease, ending with a back cut. The final result is very satisfactory, with good contour and well-hidden scars (see Fig. 12-10, C and D).23

The incision from the nasolabial fold can be extended across the jawline inferiorly into the neck, toward the midline to the middle or lower parts of the neck, and transversely toward the sternocleidomastoid muscle, roughly paralleling the mandibular border, and, finally, superiorly and posteriorly toward the earlobe and mastoid.27 For even larger defects, the midline incision can be continued inferiorly along the sternum and curved laterally and downward across the chest, above the nipple-areola complex, and toward the axilla.28 These subcutaneous flaps are vascularized through the superficial temporal, vertebral, occipital, and thoracoacromial vessels in the face, neck, and chest, respectively.21 The platysma muscle may or may not be included, but a subplatysmal approach may provide an easier plane of dissection as well as a more robust blood supply.
Fig. 12-10  A, This patient had a defect of the right cheek measuring 5 cm in diameter after Mohs surgery for a recurrent sclerosing basal skin cancer. The aesthetic units were marked to assist in planning the reconstruction. B, A posteriorly based rotation flap was designed on branches of the superficial temporal artery. The flap was dissected in a subcutaneous layer to the extent of the dotted lines. C, Immediately after rotation advancement of the posteriorly based rotation flap and closure. D, The patient is shown 9 months postoperatively. The scars are well hidden in the transitions between facial aesthetic units.
Complications

Tip or partial flap necrosis is a complication that can be prevented by ensuring adequate flap vascularization as follows: patients should refrain from smoking, excessive or linear tension of the flap should be avoided, and flaps may be raised in a deep plane under the parotid fascia and SMAS.

Cheek flaps may cause lower lid displacement because of edema, gravity, or flap tension. Lid support can be augmented by either a lateral canthopexy or a tensor fascia lata strip secured to the medial and lateral canthal ligament at the time of surgery.21,29 Although the superior border of the cheek flap can be positioned along the subciliary margin, it is often more aesthetic and safer to reconstruct the lower lid separately with a bipedicled Tripier flap from the upper lid.21 A cheek flap should be overcorrected and tension minimized. Laterally, the flap is suspended with sutures through drill holes in the lateral and inferior orbital rim. Alternatively, Mitek mini-anchors can be used. In the temporal area, over the zygomatic arch, the cheek flap can be suspended safely with sutures to the deep temporal fascia in an overcorrected position. No temporal facial nerve branches are present in the area beyond 3.5 cm anterior to the auditory canal.30

To prevent excessive and long-lasting postoperative edema, an uninvolved skin/muscle area greater than 1 cm should remain below the lateral canthus after cheek repair, if possible. Massage, time, and subcutaneous debulking later can help reduce this complication.21

Malpositioning of the beard or sideburn can occur because of anterior displacement, which is an abnormal position. The vertical “hike” deep plane flap30 advances residual cheek skin vertically and avoids anterior sideburn displacement, which is often seen after an anteriorly based rotation advancement flap.

Optimizing Outcomes

Surgeons tend to place a single flap into a single wound during a single operation.21 Reconstruction in stages, however, often gives superior results. Whenever feasible, incisions are planned along the peripheral outline of the cheek (preauricular contours of the tragus and helix, around the sideburn, across the zygomatic arch, into the lower lid–cheek junction, along the nasal sidewall into the nasolabial fold and marionette line, around the chin, and toward the submental crease). Although the presence and position of facial scarring are less important in a peripheral unit,21 vertical incisions anterior to a line drawn from the lateral canthus should be avoided.31 The shape of the wound can be converted to an ellipse or triangle to correct dog-ears created by flap shifts. The position of future dog-ear excisions can often be planned in inconspicuous contour lines.21 Primary contour deformities in deeper cheek defects can be corrected by using subcutaneous fat hinge-over flaps lateral to the defect.
after the cheek flap elevation. The advancing cheek flap can be used for coverage. Secondary contour defects can be corrected with lipofilling, dermal fat grafts, or deepithelialized pedicled or free flaps. In general, distant tissues are used only to supply hidden lining and bulk and/or to revascularize difficult wounds. Loco-regional skin can be transposed to permanently resurface the face during subsequent stages. Skin expanders increase the available surface area of a donor site. They are usually inserted in a subcutaneous plane over the SMAS or platysma through an incision perpendicular to the defect. After overexpansion by 30% to 50% more than measurements of the defect might suggest, the expanded skin can be advanced to the cheek, and incision lines can be positioned along the peripheral outline of the cheek more easily, improving the aesthetic result. The underlying scar capsule may be left in place, scored, or excised. As a rule, using tissue expanders requires two stages, but a third stage to adjust the flap position and revise scars is commonly needed. A disadvantage of expanded skin is that it is less elastic, with an inherent tendency to retract.

The angle rotation cheek flap, originally described by Schrudde and Beinhoff and recently recommended as the flap of first choice for combined cheek–lower lid reconstructions by Boutros and Zide, elevates and rotates simultaneously using a postauricular “angle” flap. It leaves a very inconspicuous donor site scar while placing the angled flap ideally in the preauricular zone. This flap design can be used in combination with tissue expansion (especially in children), and its greatest advantages are that it leaves no scars on the neck or chest and can be readvanced in the future.

**Postoperative Management**

Minivacuum or Penrose drains are left under the cheek flap for 24 hours. At the end of the procedure, the closed wounds are cleaned and nothing is applied to the wound. To minimize postoperative swelling and congestion, patients are kept in an anti-Trendelenburg position in the early postoperative phase. Sutures are removed 5 to 7 days postoperatively. No special measures are necessary.

**Lip Switch Flaps**

The reconstruction of lip defects with lip switch flaps is very well established. These flaps were described by Estlander and Abbé in the nineteenth century. Estlander described the lip switch involving tissue immediately adjacent to the commissure. Abbé described the lip switch using central lower lip tissue to add length to the short upper lip in patients with bilateral cleft lips. In cases of severe lower lip tightness, a reversed Abbé flap from the upper lip to the lower lip can be performed. However, the upper lip has less laxity and therefore provides limited tissue stock for use in the lower lip. The use of the different lip switch procedures has become a standard of care in restorative surgery of the lips. Lip defects involving up to 50% of the total length of the lip can be readily reconstructed using these flaps. For larger defects, a
Indications and Contraindications

Lip switch flaps are indicated for full-thickness defects of the lips that cannot be closed by approximation of the wound edges without compromising adequate oral function. In most cases, the defect to be reconstructed with a lip switch flap is positioned in the upper lip, because the lower lip offers much more laxity and tissue availability for reconstruction of the upper lip. The upper lip has less tissue excess to use for large lower lip defects. Larger lower lip defects are generally addressed with various perioral flaps. Lip switch flaps are contraindicated for defects that exceed 50% of the lip. If previous lip excisions and closures have been performed, the defect size amendable to lip switch flap reconstruction may be smaller. Each patient is evaluated for lip function, mouth opening, and the ability to wear dentures if needed.

Preoperative Management

Preoperative management involves identifying patients with risk factors for flap failure. In general, a standard Abbé flap is very safe and can be performed without a high risk for complications, even in smokers or patients with irradiated tissues. If an extended Abbé flap is needed, which involves a long vertical skin extension, smoking places the distal part of the flap at high risk of necrosis.

Before undergoing an Abbé flap procedure, patients must understand that the mouth opening will be very limited for 2 to 3 weeks because of the pedicled nature of this two-stage flap. This understanding helps prevent postoperative anxiety and concerns. In addition, it should be explained that even though this operation is performed in two stages, one or more additional small procedures might be necessary to achieve an excellent final result. Finally, as with all facial procedures, the positioning and extent of scarring should be made very clear before the first operation.

Operative Technique

The flap design is started only after very careful assessment of the defect (Fig. 12-11). The ideal restoration of the aesthetic units involved in the defect is planned. For optimal matching, a template from the contralateral side, which can be flipped and used as a mirror image, is a very helpful tool. A lip switch flap is easy in concept; however, it is difficult to design perfectly.

Once the plan for lip reconstruction with an Abbé flap and the appropriate template are available, the design can be drawn on the lower lip. With the Abbé flap, it is very important to design the flap in the middle of the lower lip so that the scar will be
centered, preventing asymmetrical distortion. Before cutting the flap, the exact position of the white rolls on the upper and lower lip are tattooed with ink. This prevents step deformities in the white roll, which are very visible once everything has healed.

The skin, subcutaneous tissue, orbicularis oris muscle, and intraoral mucosa are incised along the preoperatively marked line to dissect the flap. The only part of the flap that is not cut is the site of the pedicle (see Fig. 12-11, B). The Abbé flap receives its blood supply from the inferior labial vessels, which run posterior to the orbicularis oris muscle, closely underneath the cranial wet mucosa of the lip. By cutting the flap and achieving maximum rotation, the skin and lip vermilion on the anterior aspect of the flap pedicle can be released carefully and safely (see Fig. 12-11, C). When insetting the flap, the preoperatively marked location of the white rolls helps tremendously to correctly align the upper and lower lip parts. Great care is required to achieve a perfect inset of the free edge of the Abbé flap. The edge of the flap that holds the pedicle is inset as carefully as possible, but can be modified and perfected at the second operation. To properly inset the flap, the orbicularis oris muscle is carefully sutured into its new environment to prevent a whistling deformity (see Fig. 12-11, D).

Fig. 12-11  A, This central upper lip defect resulted from the resection of recurrent basal cell carcinoma. The Abbé flap was designed to restore the full width and height of the philtrum. B, The Abbé flap was cut through and through and remains attached only on its left inferior labial artery pedicle, which ran further posterior in the lip. The position of the inferior labial artery in the lip can be checked by searching for it on the side that has been cut. C, After dissection, the Abbé flap was rotated into the defect. In this patient, the white roll was carefully adjusted on the left side, because it was not ideal to readjust that side. The right side of the upper lip will be further refined when the pedicle is dissected in 2 to 3 weeks. D, The immediate postoperative view shows good inset on the left side. The scar of the lower lip is central.

Continued
Great care is also required when closing the donor site defect. The vertical height of the lip after closure should equal its preoperative height. The continuity of the orbicularis oris muscle has to be carefully restored. The white roll must sit perfectly after closure. The lip vermilion may be touched up after the pedicle division during the second operation. Everything from the white roll downward needs to look perfect.

After 2 to 3 weeks, the transposed flap has grown into its new surroundings and no longer depends on the blood supply from the inferior labial vessels. During the second operation, the pedicle is transected and the vermilion and possible white roll attachment on the pedicle side are perfected. After the wound heals and swelling subsides, further operations may be necessary to achieve a perfect reconstruction (see Fig. 12-11, E).

**Complications**

In general, the Abbé flap is very safe, with minimal flap necrosis, wound infections, and dehiscence. Wound-healing problems and distal tip necrosis may occur in flaps with an extended height, especially in patients who have had radiation therapy or who continue smoking. More commonly, complications are related to poor planning or execution of the procedure. The aesthetic units of the lips must be considered when planning a reconstruction in this aesthetic area.

**Optimizing Outcomes**

To achieve excellent results, very meticulous inset with 2.5× loupe magnification is required. Key points in optimizing outcomes include marking the white roll with a temporary tattoo at the beginning of the procedure, taking the flap from the center, and staying within the aesthetic unit. Adherence to these principles helps prevent an unsightly step deformity in the aesthetic line of the white roll, distortion of the
lower lip symmetry, and positioning of scars outside of the aesthetic units. Abbé flaps in male patients need special consideration with regard to hair growth. By turning the lower lip skin upside down, the direction of hair growth is incorrect. In addition, the hair growth on the lower lip skin is often less than that on the upper lip skin. In some cases, additional hair follicle transplants at a later date may be considered.

**Postoperative Management**

Appropriate instructions regarding nutrition are the main challenge in the postoperative management of patients with an Abbé flap. Mouth opening must be limited, because the pedicle holds the lips together. Liquid, pureed, and soft foods are usually well tolerated. No other special considerations are necessary. The skin sutures are removed after 5 to 7 days and the flap pedicle is transected after 2 to 3 weeks.

**Perioral Flaps**

Perioral flaps as described by Karapandzic, the modified Bernard-Burow flap, and fan flaps are very useful for lower lip reconstruction, although they can be used for upper lip reconstruction. It is important to replace like-with-like tissue if possible. This is usually accomplished with a lip shave or buccal mucosal advancement flap for vermilion reconstruction, and lip switch flaps, such as the Abbé and Estlander flaps, for moderate-sized (less than half), full-thickness lip reconstruction. If the defect lies centrally or more laterally with involvement of the commissure and no new lip tissue is required, the Karapandzic flap provides the ideal reconstruction, because it preserves the neurovascular supply and the integrity of the oral sphincter. The need for new lip tissue and to avoid microstomia are the best indications for the modified Bernard-Burow or fan flap procedure. For large lower lip defects measuring more than two thirds of the lip, without sufficient cheek tissue available to execute these perioral flaps, distant or free flaps are required, such as a free radial forearm flap with a palmaris longus sling or an innervated gracilis free flap.

**Indications and Contraindications**

Small, full-thickness lip defects involving up to one third of the lip can usually be closed primarily without significant problems. In medium-sized lower lip defects measuring from one to two thirds of the lip, it is important to first determine whether sufficient lip tissue remains. If sufficient tissue remains and the commissure is not involved, the defect is best closed with either an Abbé or Karapandzic flap. If lip tissue is sufficient and the commissure is involved, a Karapandzic (first choice) or Estlander (second choice) flap is indicated.

For lower lip defects measuring more than two thirds of the lip in combination with sufficient cheek tissue, the Karapandzic or modified Bernard-Burow flap is the best choice. If feasible, the Karapandzic flap is preferred, because it results in an intact
oral sphincter and normal sensation. Drawbacks of the Karapandzic procedure are the tendency for microstomia, which can be particularly troublesome to patients who use dentures, and the chance of unsightly scarring, because the incisions do not follow the normal pattern of facial aging. However, older patients who have more tissue laxity and who are likely to have only moderate scars are excellent candidates for this operation.44

The need for new lip tissue in subtotal or total lower lip defects and the necessity to avoid microstomia are the best indications for the Bernard-Burow or fan flap procedure. Drawbacks of the modified Bernard-Burow procedure include a tight lower lip with a reversal of lip relations, scar contracture at the commissures causing an unnatural “smiley face,” color mismatch of the reconstructed vermillion, and incomplete recovery of lip sensation and sphincter function causing oral incontinence.6,44 Bilateral Gillies fan flaps provide a lower lip with adequate bulk but with poor sensation and no muscular function.6

**Preoperative Management**

The defect size and location and lip and cheek tissue laxity should be assessed carefully, because they help determine which flap is indicated. After cancer excision, clear margins must be ensured before definite repair. A highly contaminated or infected wound may require delayed primary reconstruction after serial debridements. Finally, preoperative management consists of identifying patients who have risk factors for flap failure, especially smoking, a history of radiation therapy, and previous surgery. Patients should be informed that postoperative oral function can be compromised because of tightness and/or impaired lip sensation.

**Operative Technique**

**Karapandzic Flap**

The vertical height of the defect determines the width of the Karapandzic flap. This width is maintained as the incision is planned circumorally to the alar base bilaterally. Incisions are made transversely from the base of the defect on both sides (Fig. 12-12). The orbicularis muscle fibers are spread apart longitudinally, in the line of the skin incision, down to the submucosal layer. Care is taken not to damage the buccal branches of the facial nerve, the superior and inferior labial blood vessels, and the mental nerve branches if possible (see Fig. 12-12, C and D). The mucosa is incised for 1 to 2 cm from the edge of the defect. Subsequently, the edges of the defect can be closed without tension (see Fig. 12-12, E). Mucosa, orbicularis muscle, and skin edges are repaired in layers.
Fig. 12-12  A, This patient had a large squamous cell carcinoma of the right lower lip. The Kara-pandzic flap plan was marked on the opposing half of the lower lip. The vertical height of the defect was used to determine the width of the flap. B, The flap was cut on the right side to reconstruct the left lateral lower lip. C, The buccal branches of the facial nerve and the superior and inferior labial blood vessels should be saved. D, The mental nerve branches were saved with careful dissection. E, Mucosa, orbicularis oris muscle, and skin were closed in layers to allow a tension-free closure.
Webster’s Modification of the Bernard-Burow Procedure

In the modified version of the Bernard-Burow procedure, the full-thickness, lower lip defect is enlarged down to the labiomental fold (Fig. 12-13). Bilateral horizontal incisions are made, extending laterally from the commissure and from the base of the lower lip defect and curving downward following the labiomental fold. Triangles of skin and subcutaneous tissue are excised on both sides of the upper lip, lateral to the nasolabial fold and superficial to the orbicularis oris muscle (see Fig. 12-13, C). Along the labiomental fold, skin and subcutaneous Burow triangles are excised to make way for the medial rotation of the lower cheek flaps. These four Burow triangles are planned as wide as possible to allow closure without tension. The buccal mucosa is undermined superficially and less extensively than the skin, avoiding the buccal nerve branches and the orbicularis oris muscle. At this stage, the skin and mucosa have been released from the orbicularis muscle and advanced medially. Mucosa, muscle, and skin are repaired in layers. Advancing and closing the previously undermined buccal mucosa with the skin edges completes reconstruction of the vermilion (see Fig. 12-13, D). Alternatively, an anteriorly based flap from the underside of the tongue is divided and inset 10 to 14 days later to reconstruct the vermilion.

Fig. 12-13  A, This patient had a large squamous cell carcinoma, requiring lower lip resection. The resection margins and the Webster modification of the Bernard-Burrow procedure were marked. Bilateral horizontal lines were marked from the commissure and the base of the lip resection defect in the labiomental fold. These lines enclosed the intermediate tissue that was advanced medially after excising the four Burrow triangles lateral to the nasolabial fold and along the labiomental fold. B, After tumor resection, the complete lower lip was removed full thickness. C, All lines marked preoperatively were cut while saving buccal nerve branches and orbicularis oris muscle. Mucosa was released intraorally for advancement. D, After closing all advanced tissues in layers, the lower lip was reconstructed.
Chapter 12  Local Flaps

Fig. 12-13, cont’d  E, The patient is shown 6 months postoperatively. A good aesthetic outcome will be achieved as scars fade. The lower lip vermilion is not addressed with this technique, and further improvement in fullness of the lower lip can be achieved with a vermilion reconstruction.

Complications

A potential complication of the Karapandzic procedure is unsightly scarring. The incisions do not abide by the aesthetic unit principle of the face. Despite this, Karapandzic flaps usually provide excellent results, because they do not tend to show pin-cushioning. The nasolabial folds remain unchanged, and the vermilion remains normal because it is undisturbed. Another potential complication is microstomia, which can be particularly troublesome for patients who use dentures. They have to be instructed how to remove and insert these appliances so that the least amount of strain is placed on the lip.

The most common complication of the modified Bernard-Burow procedure is a tight lower lip with poor function and an overhanging upper lip, resulting in less competence than is desirable\(^6\) (see Fig. 12-13, E). Unfortunately, no procedure can adequately improve this situation. However, using an anteriorly based tongue flap instead of buccal mucosa advancement may overcome the mucosal deficiency.\(^6\)

Optimizing Outcomes

The use of a unilateral Karapandzic flap may result in asymmetry of the commissures. Therefore it is preferable to advance bilateral flaps. In the case of persistent commissural deformity, two opposing mucosal rhomboid flaps, which are transposed laterally to reconstruct the angle, may be best used. A splinting device may be used for several months to treat microstomia.
In the modified Bernard-Burow procedure, it is important that the upper bilateral Burow triangles are planned lateral to the nasolabial fold, so that after transposition of the flaps the suture lines fall exactly in the nasolabial fold. Likewise, the lower bilateral Burow triangles should be planned along the labiomental fold with a downward curve to produce less conspicuous scars on the borders of facial aesthetic units compared with those resulting from a more horizontal approach. To overcome the problem of entropion of the lower lip vermilion, it is preferable to use a large anteriorly based tongue flap that is derived from the underside of the mobile tongue and divided after 10 to 14 days.6

**Postoperative Management**

At the end of the procedure, the closed wounds are cleaned and nothing is applied to the wound. To minimize postoperative swelling and congestion, patients are kept in an anti-Trendelenburg position for 3 days. Sutures are removed 5 to 7 days postoperatively. Patients are instructed to eat a soft diet for 2 weeks and to rinse the mouth regularly for 1 week using a cleansing solution. Patients are allowed to use dentures after 2 weeks.

**CRITICAL POINTS**

**Must Know**

- The FAP flap needs a small cuff of fatty tissue around the artery for venous outflow if no vein runs with the artery.
- The FAP flap pedicle should not be excessively skeletonized to prevent the need for a second thinning operation.
- The delay phenomenon improves vascularity of the forehead flap at the intermediate stage after 2 to 3 weeks, which allows more aggressive thinning.
- Total distal release of the forehead flap during the intermediate stage must be performed for optimal thinning.
- Lip defects involving up to 50% of the lip can be reconstructed with an Abbé flap. This flap is more commonly used for upper lip repair.
- Orbicularis oris muscle repair is important to prevent loss of oral sphincter continuity.
- Perioral flaps are used for large lip defects. The Karapandzic procedure results in better sensation and replaces like-with-like tissue.
- Perioral flaps should be carefully dissected to prevent damage to the orbicularis oris muscle and nerves that are essential to functional outcome.

**Should Know**

- The facial artery should be identified preoperatively with a handheld Doppler device to optimally plan the flap.
- When transferred to the nose, the forehead flap should be given support.
• The sideburn should not be distorted in the design and subsequent transposition of the cheek flap.
• The cheek flap should be inset with minimal tension, but supported maximally by cranial bony suspension.
• Tattooing the white rolls allows proper approximation of the lips and prevents a step deformity.
• The use of perioral flaps may result in microstomia.
• Bilateral perioral advancement flaps provide better symmetry.

Synopsis
• Skin flaps based on the facial artery are powerful flaps in the perioral region.
• The FAP flap is a perforator flap based on a single perforator of the facial vessels. It provides a local tissue flap that can be used to achieve a one-stage reconstruction in selected cases.
• The paramedian forehead flap is the workhorse flap in nasal reconstruction. The use of the three-stage forehead flap for nasal reconstruction has allowed more aggressive thinning to be highly reliable and provides better outcomes.
• Cheek advancement flaps are rotation advancement flaps based on anterior or posterior subcutaneous vessels.
• Lip switch flaps are very useful for the reconstruction of many defects that are too large for primary closure but not larger than 50% of the lip. The vascularization of lip switch flaps is consistent, which makes their use predictable.
• Perioral flaps, such as the Karapandzic method or the modified Bernard-Burow procedure, allow reconstruction of large lip defects with like tissue. The flap choice depends on the defect and surrounding tissues. Oral opening and sensation should be considered the most important factors in flap selection.

References
   The author applies subunit principles to reconstruct a massive facial defect in stages using conventional techniques and local grafts. In the first stage, distant tissue is used to provide bulk, protect vital structures, recvascularize the wound, and reconstruct a stable facial platform. At a later stage or stages, local skin is used to restore facial skin quality, outline, and contour. Local tissue provides a better match and is used for aesthetic cover; distant tissue offers lining and support.

The authors perform five clinical perioral reconstructions using the FAP flap. This flap is versatile with a reliable presence of perforators, a large arc of rotation, and an aesthetically pleasing donor site. The thin pedicle makes it an ideal flap for one-stage reconstruction without secondary revisions. Flaps were rotated up to 180 degrees. Four flaps survived and one had minor distal necrosis.


The FAMM flap is a composite flap with features similar to those of lip tissue. The authors discuss the anatomy, dissection, and clinical applications of the FAMM flap in lip and vermilion reconstruction in a series of 16 FAMM flaps in 13 patients. Seven patients had upper lip reconstruction and six had lower lip reconstruction. Superiorly based FAMM flaps were used in eight patients, and eight inferiorly based flaps were performed in five patients. Three patients had bilateral, inferiorly based flaps.


The authors radiographically examine 25 facial arteries in 19 fresh cadavers injected systemically with a lead oxide–gelatin mixture. Major branches of the facial artery in the upper lip and nose were investigated, and the anatomic variations were classified into three types on the basis of the anatomy of the lateral nasal artery, which was determined as an artery running toward the alar base. Branches from the lateral nasal and superior labial arteries were observed stereographically. Vascular anastomoses between these branches were created in the upper lip, columnella base, and nasal tip, and an intimate vascular network was formed. With a vascular network in the mucosa of the upper lip, a bilobed upper-lip flap was created for a patient with a full-thickness defect of the ala.


The authors evaluate the usefulness of the inferiorly or superiorly based nasolabial flap for the unilaterial or bilateral reconstruction of local extraoral and intraoral defects. Twenty-two flaps were used in 15 patients over a period of 10 years. Defects of the floor of the mouth, nose, and chin were reconstructed. The authors conclude that the nasolabial flap is a useful procedure for the reconstruction of moderate-sized oronasal defects because of its simple elevation, proximity to the defect, and versatility.


The author examines the visual process of seeing and the psychology of perception. A method of facial reconstruction emphasizing the restoration of subunits to maintain expected contours and landmarks is derived.
PART THREE

COMMON FREE FLAPS FOR HEAD AND NECK RECONSTRUCTION
CHAPTER 13

Anterolateral Thigh Flap

Joseph H. Dayan, Fu-Chan Wei, Chih-Hung Lin

HIGHLIGHTS

- The anterolateral thigh (ALT) flap is a myocutaneous perforator flap or septocutaneous flap that provides a substantial amount of pliable soft tissue for the reconstruction of complex three-dimensional defects.
- Handheld Doppler ultrasonography aids in localizing perforators for reliable skin paddle design.
- The long and large-caliber pedicle of the descending branch of the lateral circumflex femoral artery is advantageous in head and neck reconstruction.
- Harvested chimeric fascial or muscular components can be used for composite functional reconstruction or for obliteration of dead space.

The ALT flap (or, more formally, the lateral circumflex femoral artery–vastus lateralis perforator flap) has become the focus of an unprecedented amount of study and clinical application over the last decade. Obscure for most of the 1980s and early 1990s, the ALT flap is now a ubiquitous staple in head and neck reconstruction throughout Asia and in a growing number of centers in the West. The large volume of pliable tissue, long pedicle, convenient location, and minimal donor site morbidity make the ALT flap well suited to the requirements of head and neck reconstruction. The ALT flap is a versatile and reliable option for resurfacing oral mucosal, facial skin, and pharyngoesophageal, scalp, and dural defects.
The ALT flap was first described in 1984 by Song et al as a septocutaneous flap. Despite its enormous potential, this flap remained largely unpopular until further anatomic study revealed that musculocutaneous perforators were the dominant blood supply to the anterolateral thigh skin. Increasing familiarity with intramuscular dissection and improved understanding of the local anatomy stimulated renewed interest in this donor site. Early reports of reliable ALT flap harvest began to surface in Asia: Xu et al in 1988, Koshima et al in 1989, and Zhou et al in 1991. Koshima et al and Kimata et al continued to pioneer the ALT flap for widespread clinical use. Wei et al and Celik et al exploited the use of the ALT flap in head and neck reconstruction on a large scale, contributing to its current popularity. Numerous perforator flap options have been explored over the years, and the ALT flap has emerged as the first choice in soft tissue reconstruction for head and neck defects at our institution.

**LOGISTIC ADVANTAGES**

There are several logistic advantages inherent in harvesting tissue from the anterolateral thigh. Flap dissection is performed with the patient supine, obviating the need for a time-consuming position change. The thigh is also a comfortable distance from the ablative team, allowing simultaneous flap harvest and a potentially reduced anesthesia requirement.

The ALT flap is also a useful training model in teaching hospitals, because several perforators typically supply the flap. If the oncologic resection is not finished by the time the primary surgeon has completed the first perforator dissection, a resident may practice the intramuscular dissection technique on a secondary perforator. Injury to a secondary vessel will typically not compromise the viability of the flap if the main perforator is of a sufficient caliber.

Because the thigh is populated with sizeable perforators, alternative options to the original donor thigh are conveniently confined. If the perforators are too tiny or are injured during ALT flap harvest, conversion to a free-style flap harvest is possible by dissecting medially until a sizeable perforator is encountered or superolaterally to harvest a tensor fascia lata flap.

**INTRINSIC ANATOMIC ADVANTAGES**

**Long and Large-Caliber Pedicle**

The ALT flap provides a long and large-diameter pedicle, making it particularly desirable for irradiated and reoperated necks, where recipient vessels may be scarce. The pedicle length is also greater than that of the parent musculocutaneous flap, and its mobility is not restricted by the orientation of the muscle. In a study involv-
ing 37 patients, Shieh et al\textsuperscript{13} reported an average pedicle length of 12 cm, an arterial diameter of 2 to 2.5 mm, and a venous diameter ranging from 1.8 to 3 mm. Pedicle lengths of up to 20 cm have been reported using the vastus lateralis muscle flap, which can be extrapolated to the ALT flap.\textsuperscript{14}

**Abundant Tissue**

Radical head and neck resections may require significant volume restoration and resurfacing, with sufficient allowance for tissue shrinkage following radiation therapy. The anterolateral thigh has an abundance of skin and soft tissue. Viable flaps as large as 35 by 25 cm based on a single perforator have been reported, although perforator sizes and their correlating angiosomes vary significantly.\textsuperscript{15} If a fasciocutaneous flap is inadequate for the reconstructive demands, numerous chimeric flap options are available. A multitude of tissue components, including skin, fat, muscle, fascia, and bone, may be harvested from the lateral circumflex femoral axis to provide versatile options for customized reconstruction.

**Minimal Donor Site Morbidity**

Compared with other commonly used workhorse flaps in head and neck reconstruction, donor site morbidity following ALT flap harvest is relatively minimal. The radial forearm flap requires sacrificing a major vessel to the hand and may result in a cosmetically unfavorable donor site.\textsuperscript{16} Placing an incision on the trunk (that is, for rectus abdominis or latissimus dorsi flaps) in a patient population with a high incidence of chronic obstructive pulmonary disease may interfere with deep breathing exercises in the early postoperative period. Reports of some serious complications following ALT flap harvest, including compartment syndrome and lower leg ischemia, are exceedingly rare.\textsuperscript{17,18} Most problems are limited to wound dehiscence, sensation alteration, muscle bulge, and mild lower extremity weakness.\textsuperscript{12,19,20}

Kuo et al\textsuperscript{19} quantitatively assessed the important issue of weakness in knee extension. They performed an objective functional assessment of knee extension after myocutaneous ALT flap harvest, comparing isometric power between donor and normal thighs and isokinetic peak torque ratio of the quadriceps and hamstring muscles. No significant difference was found. Only the concentric contraction test of the quadriceps muscle revealed mild weakness of the donor thigh.\textsuperscript{19} Kimata et al\textsuperscript{21} have correlated this degree of weakness to the amount of vastus lateralis muscle injury. It is likely that a number of factors influence weakness, including the extent of motor nerve injury, a patient’s preoperative physical state, and postoperative compliance with rehabilitation. In summary, the finding that functional impairment of the donor thigh is minimal after free ALT flap transfer has been corroborated in a number of studies in the literature.\textsuperscript{19-21}
ANATOMY

The anterolateral components of the thigh, including the quadriceps muscles and tensor fascia lata, are nourished by the lateral circumflex femoral artery (Fig. 13-1). This large vessel typically gives off three branches: an ascending branch, a transverse branch, and a descending branch.\textsuperscript{5,22,23} The ascending branch and the superior branch of the transverse pedicle supply the tensor fascia lata. The ascending branch continues distally to supply the iliac crest as well. The descending branch is located at the base of the interface between the rectus femoris and vastus lateralis muscles. It supplies the anterolateral thigh skin through a septocutaneous vessel or, more commonly, through musculocutaneous perforators wandering through the vastus lateralis muscle and piercing the fascia lata. In our early experience with 672 cases of ALT flaps, 87.1% were supplied by musculocutaneous perforators, and 12.9% were based on septocutaneous vessels.\textsuperscript{6} Most septocutaneous vessels, if present, are located in the proximal third of the thigh. The distal two thirds of the anterolateral thigh territory are predominantly supplied by musculocutaneous perforators.

![Fig. 13-1 Anatomic basis for the ALT flap. Although the perforators most commonly arise from the descending branch, they may also originate from the transverse branch or oblique branch (present in 35% of cases).](image-url)
Although the descending branch is the most common feeding vessel for the anterolateral thigh perforators, anatomic variability is significant. The perforators may emerge from an inferior branch of the transverse pedicle or even from an oblique branch. Wong et al\textsuperscript{23} reported the presence of an oblique branch in 35\% of cases, located between the descending and transverse branches. This anatomic diversity may influence the amount of intramuscular dissection required, the pedicle length, or the vessel caliber to some degree, but it is our observation that the overall impact on the final reconstruction is minimal. Because the dissection is performed in a retrograde fashion, the perforator eventually leads to a pedicle of adequate caliber, regardless of its origin.

**INDICATIONS AND CONTRAINDICATIONS**

The ALT flap is an appropriate choice for most head and neck reconstructions at our institution; however, an alternative donor site may be preferable in some situations. Perhaps the most frequently cited contraindication to using the ALT flap in the West is that Caucasian patients often have a fairly thick subcutaneous layer compared with Asian populations. A simple pinch test to the anterolateral thigh is a useful guide for selecting appropriate candidates and also facilitates preoperative planning with regard to satisfying the volume requirement at the recipient site.

Additional factors must be considered when determining the appropriateness of an ALT flap. Although most reports describe weakness in knee extension as transient or minimal, this may not be a worthwhile risk for patients in whom rigorous exercise is central to their daily routine. For patients with a history of smoking and atherosclerosis, or preexisting thigh trauma, the circulation to the ALT flap may be jeopardized. Patients with underlying peripheral vascular disease presenting with claudication or an absent popliteal pulse (suggestive of superficial femoral artery occlusion) may be at risk for lower limb necrosis following ALT flap harvest. In this scenario, the descending branch may provide vital collateral perfusion below the knee.\textsuperscript{18} However, in more than 3000 cases performed at our hospital, we have not observed this unfortunate complication.

In addition to the previously described relative contraindications, there are disadvantages to using anterolateral thigh skin. Reconstructions requiring external skin cover may result in a noticeable color mismatch. Fortunately, in some cases this external skin paddle can be serially excised after completing oncologic treatment. Hairy skin in men may be troublesome. For these patients, the adjacent tensor fascia lata skin territory should be considered, because it is relatively hairless. Finally, a visible and sometimes hypertrophic scar on the thigh may be unacceptable to women.
PREOPERATIVE MANAGEMENT

With the patient lying supine, a line is drawn from the anterior superior iliac spine to the superolateral corner of the patella. This should correlate with the underlying interface between the rectus femoris and vastus lateralis muscles, which can be confirmed by palpation in thin individuals. Usually, at least one perforator is located within a 3 cm radius from the midpoint of this line (Fig. 13-2). The perforators are localized using a handheld Doppler unit. An unexpectedly strong signal may be the descending branch, especially in thin patients. If, however, there is no audible signal, the patient’s blood pressure may be too low, and this is addressed with the anesthesiologist. If the blood pressure is adequate and there is no signal, the perforators may be tiny, or the limits of sensitivity of the handheld Doppler unit may be exceeded. It is still reasonable to continue with the planned ALT flap harvest, because the skin must be perfused from some source; a complete absence of perforators is uncommon. Alternatively, a musculocutaneous flap may be harvested.

Fig. 13-2 Preoperative markings. There is typically a perforator located within 3 cm of the midpoint of a line drawn from the anterior superior iliac spine to the superolateral corner of the patella. A handheld Doppler probe is used to localize and estimate the size of the perforators.

Although handheld Doppler sonography is the most commonly used method for localizing perforators, its accuracy is debatable, particularly in patients with a high body mass index.\(^6,12,24,25\) Yu and Youssef\(^25\) have successfully used a method in lieu of Doppler imaging for ALT flap harvest. With this system, the location of three cutaneous perforators is estimated: A or proximal, B or middle, and C or distal. The most consistent vessel, perforator B, is marked 1.5 cm lateral to the midpoint of the standard preoperative marking described previously. Perforators A and C are estimated to be 5 cm proximal and distal to this point, but are less reliable. More precise modal-
ities have been used such as color duplex ultrasonography and CT angiography, but these require additional time and expense.\textsuperscript{24}

Once the perforators are identified, the skin paddle can be designed to accommodate the most significant perforator or perforators. The skin paddle is typically oriented with the dominant perforator at its center. This location is not critical but may be preferable. However, sometimes an eccentrically located perforator more easily reaches the recipient vessels. The philosophy regarding the skin paddle design varies among surgeons. Regardless of the method, careful planning is critical to ensure that a reliable perforator is included in the skin paddle.

**Suprafascial Versus Subfascial Design**

The final preoperative consideration is whether to perform a suprafascial or subfascial dissection. Although a suprafascial dissection is technically more challenging because of the diminutive nature of the perforators above the fascia, the potential benefits include avoidance of a muscle bulge, preservation of the lateral femoral cutaneous nerve, and reduced tension on the skin closure. The suprafascial technique is also preferable when performing primary flap thinning. In cases where the donor site defect will require a skin graft, leaving the fascia intact provides a favorable recipient bed for grafting and prevents adhesion to the underlying muscle.

Despite the potential benefits of a suprafascial approach, a subfascial flap harvest is most commonly performed. The perforators are significantly larger immediately beneath the fascia, and the plane is relatively avascular, allowing a safe and rapid dissection. In additional, although a suprafascial approach may be useful for resurfacing a shallow wound, a fasciocutaneous flap is more appropriate for restoring volume in a complex three-dimensional defect. The additional perfusion from the subfascial and suprafascial plexus allows safe deepithelialization and volume augmentation. A flap stripped of fascia and skin may be less reliable. Finally, sacrifice of the deep fascia of the thigh does not add significantly to donor site morbidity.

**Operative Technique**

Flap harvest is performed under loupe magnification and begins with an incision on the medial margin of the skin paddle over the area of the rectus femoris muscle. Dissection proceeds in either a suprafascial or subfascial plane until the perforators are identified by carefully spreading blunt-tipped tenotomy scissors in a vertical manner, parallel to the trajectory of the perforators. If a suprafascial dissection is performed, the lateral femoral cutaneous nerve is identified and preserved. Once the perforators are exposed, the avascular plane between the rectus femoris and the vastus lat-
eralis muscles is separated, revealing the descending branch at the base (Figs. 13-3 and 13-4). The rectus femoris muscle is gently retracted medially to expose this presumed source vessel. However, at this point in the dissection it is unclear whether the perforators originate from the descending, oblique, or transverse branch. It is also unknown whether the perforators are fed by the same source vessel. The exact course of the perforators is never certain. This variability is inherent in many perforator dissections, and a systematic retrograde approach safely leads the surgeon to the relevant feeding vessel.

With the descending branch exposed, the perforators are carefully uncovered from distal to proximal (Fig. 13-5). Whenever feasible, two perforators are included in the flap to maintain a backup and help preserve the orientation of the pedicle to avoid inadvertent twist during flap inset. Following the fundamental principles of perforator dissection, every effort is made to avoid inciting vasoconstriction by using careful hemostasis, irrigation, and atraumatic technique. Meticulous hemostasis is critical for maintaining an unobscured view of the delicate vessels. Each branch is divided using either bipolar cautery or hemoclips at least 3 to 4 mm from the perforator.
duces the possibility of occult injury and provides enough room for placing a second hemoclip in case the first hemoclip slips off or tears the vessel. Liberal irrigation with lidocaine is effective in preventing the perforator from desiccating and may promote vasodilation. Direct manipulation of the perforator is avoided to reduce the risk of vasospasm. Instead of retracting the vessel, the surrounding muscle fibers are separated with small hooks to facilitate dissection. If a large side branch is encountered, it is preserved until the entire lengths of both perforators are uncovered, because it may be a communicating branch between these adjacent perforators.

Once the course of the perforators is delineated, the posterior incision is completed and the skin paddle is elevated with circumferential release of the vessels (Fig. 13-6). The dissection does not need to be carried out to the origin of the descending branch unless a particularly long pedicle is required. As the dissection approaches the lateral circumflex femoral artery, large muscular branches are encountered, including the pedicle to the rectus femoris muscle, which may be at risk for devascularization if sacrificed.11
The descending branch of the lateral circumflex femoral artery is intimately associated with the motor nerve to the vastus lateralis muscle, which is carefully separated from the pedicle. Occasionally, the motor nerve is entangled within the vessels. In this case, the nerve can be divided to liberate the pedicle, and repaired primarily. When a segment of muscle is required to fill a soft tissue defect at the recipient site, it is particularly important to clearly delineate the full course of the perforator to the descending branch or alternate source vessel, because different vessels may supply the muscle segment and the skin island.

Donor Site
Primary closure results in the most favorable aesthetic outcome, although overzealous attempts at closure may result in dehiscence or even compartment syndrome. Alternative strategies to facilitate primary closure include delayed primary closure 5 to 7 days following a temporary partial shoelace closure. Rodriguez et al\textsuperscript{26} imbricate the fascia lata to reduce tension on the skin and have successfully closed defects up to 13 cm wide using this technique. Yamada et al\textsuperscript{27} described VY advancement of adjacent thigh flaps to avoid the need for skin grafting in certain patients. Finally, in elective cases, tissue expansion may be used before harvesting the ALT flap.\textsuperscript{28}

**Optimizing Outcomes: Tips and Tricks**

- If the perforators are tiny, dissection under the microscope or conversion to a musculocutaneous flap should be considered.
- The posterior border of the skin paddle should not be incised until the perforators are identified.
- If the perforators are absent or inadequately sized, the surgeon should convert to a free-style flap and search for a perforator medially through the rectus femoris muscle and the anteromedial thigh, or superolaterally through the tensor fascia lata muscle.
- Two perforators should be included whenever possible.

**Common Pitfalls and Complications**

The most common adverse outcomes following ALT flap harvest have been previously detailed in this chapter: transient or mild and persistent weakness in knee extension, wound dehiscence, alteration in sensation, and muscle bulge. Donor site complications are significantly reduced if primary closure is achieved and skin grafts are avoided. Skin grafts not only result in an unaesthetic outcome, but the graft may adhere to the underlying muscle, causing pain and limited range of motion.\textsuperscript{21}

With the intention of avoiding the use of a skin graft at the donor site, an overzealous attempt at primary closure of a large defect may result in compartment syndrome. Muscle ischemia, compounded by surgical injury to the vastus lateralis muscle after flap harvest, may result in myonecrosis, wound infection, or sepsis. Two cases of compartment syndrome following closure of the anterolateral thigh donor
site have been reported in the literature, although this likely underestimates the true incidence.\textsuperscript{17} The widths of the donor site defects in these two cases were 10 and 12 cm, and the fascia was harvested without subsequent fascial imbrication.\textsuperscript{17} Rodriguez et al\textsuperscript{26} reported elevated compartment pressures following fascial imbrication, but without compartment syndrome. However, one patient with a 10 cm defect required release of the fascial imbrication after losing distal pulses on the table. The defect width threshold that allows primary closure varies among patients; however, it is recommended that caution be exercised when attempting primary closure of a donor site defect more than 6 cm wide.

Although quite rare, perhaps the gravest complication is lower limb necrosis following ALT flap harvest. The safest option in patients with an absent popliteal pulse or claudication is to avoid a donor site on the lower extremity.\textsuperscript{18}

**RESULTS**

The multiple tissue components supplied by the lateral circumflex femoral axis allow great flexibility in restoring cosmesis and function. The following cases are only a small representation of the degree to which the ALT flap has been applied to head and neck reconstruction.

**Intraoral Defects**

The goals of intraoral reconstruction include maintaining articulation, deglutition, and oral hygiene, and providing a watertight barrier between the oropharynx and neck. Intraoral defects may pose a complex, three-dimensional challenge involving multiple surfaces such as the soft palate, nasal lining, and maxillary antrum. Although the radial forearm flap is appropriate for two-dimensional resurfacing, as with a buccal defect, it may lack the necessary dimensions for more extensive resections. The ALT flap provides adequate bulk for large resections and is often appropriate for two-dimensional defects in thin patients (Fig. 13-7).

![Fig. 13-7](image_url) **A**, A buccal and marginal mandibulectomy defect. **B**, The buccal defect was reconstructed with an ALT flap, demonstrating its potential for resurfacing shallow defects if the donor thigh is thin.
If the defect involves multiple surfaces, the skin paddle can be separated by deepithelializing a strip of skin or by completely dividing the flap into two separate skin paddles. Vascularized fascia lata may be used as a static sling to reduce the likelihood of oral incompetence. If necessary, a small portion of the vastus lateralis muscle may be included to restore volume restoration or obliterate dead space in the maxillary antrum and floor of the mouth (Fig. 13-8). This ample supply of tissue is often desirable in an irradiated area with the attendant risk of fistula formation. In an effort to avoid fistulas, the most robust portion of the flap is inset in the most dependent and least accessible part of the defect in the oral cavity. If marginal necrosis occurs, an anterior fistula in a nondependent area is more easily managed than one with continuously pooling saliva.

Fig. 13-8  A, A complex intraoral defect requiring nasal lining and palate resurfacing with obliteration of the maxillary antrum. B, The flap was separated into two surfaces by deepithelializing a strip of skin, and a small portion of the vastus lateralis muscle was used to fill the maxillary antrum. C, The postoperative course was unremarkable with stable intraoral reconstruction.
Chimeric Flaps

The word *chimera* has been given several different applications; in this section, we use it to refer to flaps whose tissue components are fed by separate vessels that originate from a common pedicle. The benefit of using this technique is untethered, customized replacement of like-with-like tissue using a single anastomosis. Numerous chimeric flap combinations arise from the lateral circumflex femoral system. Skin, vascularized fascia lata, functional rectus femoris muscle, vastus lateralis, and iliac crest are among the possible available elements.\(^{10,29,31-34}\)

A chimeric flap design imparts an additional layer of complexity in planning, especially when performing the flap harvest during the extirpative surgery. The spatial relationships between the various flap components and their respective pedicles are important to consider when attempting to reduce the incidence of tethering, kinking, or tension on the pedicle. Additionally, the ultimate pedicle length of chimeric flaps tends to be long, because it must be proximal enough to include the origins of

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**Tongue Reconstruction**

The ALT flap is a reliable choice for reconstructing glossectomy defects. It maintains adequate volume after radiation therapy and provides ample tissue for filling in the dead space in the floor of the mouth. This is particularly important for total glossectomy defects in which sufficient bulk is required for the neotongue to coapt with the hard palate and provide acceptable speech and swallowing. Following hemiglossectomy, functional outcomes for speech are similar between the radial forearm flap and ALT flap (Fig. 13-9). Intelligibility was judged as clearly comprehensible in 90% of patients who underwent a radial forearm flap, and in 80% of patients who received an ALT flap, although this difference was not statistically significant.\(^{30}\) Thus the ALT flap is an acceptable replacement for the radial forearm flap in thin patients.

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**Fig. 13-9**  A, A hemiglossectomy defect. B, The result is shown after tongue reconstruction with an ALT flap. The patient was able to tolerate a full diet and maintained normal speech.
all tissue components. This long pedicle may be challenging to inset in the head and neck without causing a kink or twist resulting from vessel redundancy. Thoughtful planning with regard to the recipient vessel location and meticulous inset are critical.

Several strategies have been devised to fashion chimeric flaps. Using the free-style technique described by Wei and Mardini,\(^3\) the perforators are localized preoperatively using a handheld Doppler unit and explored intraoperatively with retrograde and/or anterograde dissection (Fig. 13-10). Adler et al\(^4\) describe a reliable method for chimeric flap harvest in which the lateral circumflex femoral pedicle is explored and a free-style flap is designed using anterograde dissection of the perforators.

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**Pharyngoesophageal Defects**

ALT flap reconstructions have been shown to have a number of advantages over jejunal free flaps when used for pharyngoesophageal defects in terms of morbidity, functional outcomes, and cost effectiveness.\(^5\) In a study of 57 patients by Yu et al,\(^6\) fluent speech was achieved following tracheoesophageal puncture in 89% of patients who underwent ALT flap reconstruction as opposed to 22% who underwent jejunal flap transfer (\(p <0.01\)). A full oral diet was tolerated in 95% and 65% of patients who received ALT and jejunal flaps, respectively. It has also been our observation that transit time is shorter through a skin tube than through a jejunal segment. Patients with an ALT flap reconstruction can typically tolerate a meal at a normal pace compared with those who have undergone jejunal flap reconstructions. Not only are functional outcomes superior in patients with ALT flaps, but ICU and hospital stays are shorter with a lower incidence of perioperative mortality.\(^5,\)
Hypopharyngeal cancer reconstruction presents a number of challenges that favor using an ALT flap rather than a radial forearm flap. Following extensive resection of the pharynx, larynx, and esophagus, and a bilateral node dissection, significant dead space remains. Although the radial forearm flap can be easily fashioned into a skin tube, it may lack sufficient tissue bulk to restore volume in the neck. Furthermore, the amount of skin may be inadequate to close the neck wound, because patients have commonly received radiation as an organ-preserving therapy. It is generally an advantage to have an ample supply of tissue available in this setting, making the ALT flap a preferred treatment.\textsuperscript{31,32}

A couple of common strategies are available with respect to flap design. The longitudinal axis of the skin tube can be oriented along the longitudinal axis of the thigh or perpendicular to it. If the length of the defect is 8 cm or less, we prefer to orient the length of the tube perpendicular to the axis of the thigh using a standard flap dimension of 8 by 22 cm. This allows a surgeon to create as wide a tube diameter as he or she prefers, and ensures primary closure at the donor site. The diameter is generally set at 3.5 cm at the superior inlet and 2.5 cm distally, reflecting the physiologic silhouette of the pharyngoesophageal defect (Fig. 13-11). The triangular-shaped wings on either side of the skin tube may be deepithelialized and used to cover the carotid vessels. Alternatively, the skin tube can be oriented along the axis of the thigh. The benefit of this technique is that it ensures adequate skin tube length to accommodate a large defect without undue tension on the anastomosis. The fascial component also serves as an additional layer of closure to reduce the chance of a fistula. For large defects in cachectic patients, a portion of the vastus lateralis muscle may be included to obliterate the remaining dead space. A skin paddle is externalized for monitoring and may also be used to facilitate closure of the neck or maturation of the tracheostoma.

\textbf{Fig. 13-11} Pharyngoesophageal reconstruction. \textbf{A,} Hypopharyngeal cancer specimen including larynx, pharynx, and cervical esophagus. \textbf{B,} In this case, the axis of the skin tube was oriented perpendicular to the length of the thigh.
Through-and-Through Defects

Through-and-through cheek defects pose a difficult challenge. Resection of a large tumor often includes most of the parotid gland and masseter muscle, leaving a significant volume deficit. These patients are also likely to receive radiation therapy, resulting in significant tissue contraction. The ALT flap provides adequate bulk and can be folded with a deepithelialized strip across the center, effectively separating one flap into two surfaces to reconstruct oral mucosa and external skin (Fig. 13-12). If the flap contains two perforators that are separated a safe distance from each other, the skin paddle may be completely separated into two smaller skin paddles for greater freedom during the inset. Excess tissue is deepithelialized and used to replace volume as needed. Finally, if there is a concomitant segmental mandibulectomy defect in addition to a large soft tissue defect, both a fibular and an ALT flap may be used at the same stage (Fig. 13-13).
Chapter 13  *Anterolateral Thigh Flap*

Fig. 13-12  
A, A through-and-through buccal defect. This patient's buccal mucosa, oral commissure, and external skin required reconstruction.  
B, An ALT flap including two perforators was harvested.  
C, The first stage of the reconstruction involved deepithelializing the distal portion of the flap for volume restoration and tissue banking. Commissuroplasty will be performed at a second stage, following completion of the oncologic treatment.

Fig. 13-13  
A combined fibular and ALT flap reconstruction.  
A, This patient presented with a segmental mandibular defect and required both intraoral and external skin resurfacing.  
B, Reconstruction was performed with a vascularized fibular and folded ALT flap anastomosed to separate recipient vessels.
Two Flaps From One Donor Site

The ALT flap often has several perforators, which allows the skin paddle to be split into separate island flaps along the descending branch.\(^{34,39,40}\) This provides considerable freedom in reconstructing multiple defects in proximity without tethering the pedicle. If the defects are more distant from each other, such as with a bilateral buccal defect, the split-skin paddle can be divided into two separate free flaps, making the ALT flap adaptable to many clinical situations (Fig. 13-14).\(^{10,39}\)

Fig. 13-14  A, Two ALT flaps harvested from one donor site. Preoperative planning using a handheld Doppler probe demonstrated two strong perforator signals with an acceptable distance between them. B, These two flaps were used to resurface a bilateral buccal defect and were anastomosed to separate recipient vessels. The double and triple arrows indicate perforators. N, Nerve to the vastus lateralis muscle.

Flow-Through Flaps

It is somewhat difficult to find an indication for using a flow-through flap in the head and neck, but this entity is mentioned to catalogue previous applications of the ALT pedicle. There have been reports of successfully chain-linking a second flap onto the distal ALT pedicle.\(^{41}\) Sanapanich et al.\(^{42}\) found the mean distal diameter of the descending branch of the lateral circumflex femoral artery to be 1.3 mm, which is fairly small, but theoretically adequate to perfuse a second flap. Heeding Poiseuille’s Law (\(\phi = 1\Delta P/\eta R^4/8L\)), the diameter of the distal lumen is approximately half the size of that of the proximal lumen, and the pedicle length is approximately twice as long in a chain-linked flap, effectively reducing the blood flow to the second flap by approximately \(1/2\) of the flow at the proximal flap without considering the reduced pressure differential. Although successful piggybacking is possible, it is safer to use a second set of recipient vessels because of the increased risk of flap failure.
Sensate Flaps

The lateral femoral cutaneous nerve may be harvested with the anterolateral thigh skin to provide a sensate flap. One study by Ribuffo et al.\textsuperscript{43} detailed the sensation to the anterolateral thigh territory: the lateral femoral cutaneous nerve supplies sensation to 100\% of the anterolateral thigh skin, and the superior and median perforator nerves innervate 25\% and 60\% of the anterolateral thigh area, respectively.

Although it is feasible to neurotize the skin paddle by performing a nerve repair between the lateral femoral cutaneous nerve and the lingual nerve, the results have been mixed in the literature. Kimata et al.\textsuperscript{44} concluded that sensory recovery was poor in both innervated and noninnervated flaps; neither study group obtained protective sensation based on monofilament testing. In contrast, Yu\textsuperscript{45} has had favorable results with innervated ALT flaps for intraoral reconstruction. Innervated flaps had improved sensory discrimination, swallowing function, and improved patient satisfaction compared with noninnervated flaps. Although these findings are encouraging, larger studies are needed to corroborate this evidence, because these were small studies (13 patients) and variables such as the extent and location of tumor resection may confound the data. We routinely performed sensate ALT flaps in the past but have largely abandoned this technique, because the resulting sensation would sometimes pose more of a problem than a solution. For example, some patients had phantom sensations and lacked useful proprioception. Although some reports show that sensory fidelity improves in the anterolateral thigh skin when it is transferred to the oral cavity,\textsuperscript{45} we have also observed significant hypoesthesia. Evaluating the quality of meaningful sensation in the oral cavity remains a challenging and an interesting area for future investigation.

Cranial and Dural Defects

Defects involving the cranium and significant portions of dura mater require immediate, reliable, and definitive coverage. Patients undergoing surgery of the skull base are particularly vulnerable to problems, with complication rates ranging from 11.5\% to 65\%.\textsuperscript{46} Ganly et al.\textsuperscript{46} showed that these complications were directly related to a patient’s medical comorbidities, intracranial tumor involvement, and requirement for radiation therapy. Recognizing the challenges facing these patients, Neligan et al.\textsuperscript{47} compared the efficacy of pedicled flap reconstruction with that of free flap reconstruction and reported a significantly reduced complication rate in the latter group.

Reconstructive goals include establishing a watertight dural seal to form a barrier between the brain and the aerodigestive tract, obliterating dead space, and restoring cosmesis.\textsuperscript{48} The ALT flap provides a reliable solution to these challenges, because it supplies a substantial amount of tissue with full-thickness resurfacing from skin to dura. Vascularized fascia lata is an ideal replacement for dural defects and is superior
to nonvascularized alternatives, particularly for patients who will receive radiation therapy or if the field was previously infected, because of its resistance to infection.\(^\text{49}\) There have been reports in the literature of salvaging infected, artificial dura mater with vascularized fascia from an ALT flap.\(^\text{50}\) A large flap can be harvested and partially deepithelialized to obliterate dead space in extensive tumor resections. We prefer to perform the soft tissue coverage initially and proceed with a cranial recontouring procedure at a second stage, depending on a patient’s prognosis (Fig. 13-15).

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**Fig. 13-15** Scalp and dural reconstruction. **A,** The defect is shown. **B,** An ALT flap was harvested with vascularized fascia lata. **C,** The dura was reconstructed with vascularized fascia lata, and a skin paddle was used to facilitate closure of the scalp.
**Flap Thinining**

In cases requiring significant folding of the flap or coverage of a shallow defect, the ALT flap may be too bulky. Primary thinning allows greater pliability and facilitates three-dimensional inset in a single stage. However, there is considerable variability in the literature regarding the incidence of partial flap necrosis after this procedure. Kimura et al. have published the largest series of thinned ALT flaps. Based on their early studies, these authors concluded that leaving 2 cm of adipose tissue around the perforator and thinning the flap to 4 mm allows a reliable perfusion radius of 9 cm around the perforator. More recently, Kimura et al. have used a strict microdissection technique with reliable results. This strategy takes intramuscular dissection one step further into intraadipose dissection. It is a tedious procedure that follows the intraadipose branching pattern of the perforators, allowing ultrathin flap creation. However, less predictable results have been reported in Caucasian patients, where excessive thinning may be less reliable. Dynamic cadaveric studies have improved our understanding of the anatomy of thinned flaps, but clinical translation is difficult because of the inherent limitations of an ex vivo model. If there is any doubt about the appropriateness of thinning a flap, secondary thinning procedures offer a safer alternative.

**Postoperative Management**

Numerous protocols are available for postoperative anticoagulation and monitoring. It is not our standard practice to use any form of anticoagulation either intraoperatively or postoperatively, unless a shearing injury to the perforators is suspected or the vessels have significant atherosclerotic disease.

Postoperative monitoring is centered on close clinical inspection of the skin paddle, with adjunctive needle puncture, skin temperature monitoring, and/or Doppler sonographic evaluations. Postoperative monitoring of buried flaps poses a greater challenge. Ferguson and Yu evaluated the effectiveness of various strategies, including using either an implantable or handheld Doppler device and externalizing a segment of skin for monitoring. The implantable Doppler group had a false-positive rate of 31%, resulting in unnecessary surgical exploration. Monitoring with a handheld Doppler device provided the least reliable results. Temporary externalization of a skin flap was the most reliable strategy.
CRITICAL POINTS

Must Know
• The anatomic basis for the ALT flap must be known.
• Principles of flap design using a handheld Doppler device must be followed.
• The technique of retrograde intramuscular dissection must be understood.

Should Know
• Chimeric flap options based on the lateral circumflex femoral axis offer the benefit of untethered, customized replacement of like-with-like tissue using a single anastomosis.
• Adjacent cutaneous flaps based on the lateral circumflex femoral vessels can be harvested in a free-style manner as an alternative technique.

Synopsis
• The ALT flap provides great flexibility in addressing the multifaceted three-dimensional challenges in head and neck reconstruction.
• Numerous tissue components based on the lateral circumflex femoral axis are available for reconstructions tailored to suit these complex defects.
• The reliability, long pedicle, and ample supply of tissue have established the ALT flap as a workhorse and, frequently, the first choice for head and neck reconstruction.

References
   This article presents the first description of what is now popularly called the ALT flap. Based on this initial series of nine cases, the authors describe this flap as septocutaneous in origin with a consistent cutaneous vessel located at the junction of the upper and middle thirds of the thigh.
   In contrast to the assertion by Song et al that the septocutaneous pedicle was consistent, these authors found significant variability. Two types of branching patterns of the septocutaneous vessel are described. In the Type 1 pattern, the septocutaneous vessel originates from the descending branch of the lateral circumflex femoral artery as reported by Song et al. In the Type 2 pattern, the septocutaneous vessel branches directly from the profunda femoris artery. In 5 of 13 patients, there was no identifiable septocutaneous vessel, and the procedure was converted to an anteromedial or tensor fascia lata flap harvest.

At the time of this publication, the ALT flap had yet to be widely accepted because of concerns regarding the variability in anatomy. In this series of 672 anterolateral thigh flaps, only 6 patients (0.89%) lacked cutaneous vessels to this flap. Notably, these 6 cases were performed early in this study, and the authors suspect that there were probably cutaneous vessels present, but they were most likely inadvertently divided because of inexperience. This study confirmed the reliability of the ALT flap and further clarified its anatomy: 87.1% of the cutaneous vessels were musculocutaneous perforators and 12.9% were septocutaneous vessels. The complete flap survival rate was 95.68%, with 12 complete failures and 17 partial failures. The authors highlight the wide application of this flap in head and neck, breast, chest, and extremity reconstruction with a multitude of options: chimeric flaps, flow-through flaps, multiple skin paddles, and primarily thinned flaps. This versatility, convenience, and minimal burden at the donor site led to the ALT flap’s status as a frequent first choice in soft tissue reconstruction.


The authors evaluated the cause of 8 complete and 7 partial failures in a series of 439 ALT perforator flaps. The overall success rate in this series was 96.58%, with an exploration rate of 7.74% in which complete flap salvage occurred in 56%. Of the 15 complete or partial flap failures, 11 were based on a single perforator, suggesting that flap loss may have been averted in some of these cases if a second perforator had been included. Kinking or twisting of the pedicle was the cause of flap failure in 3 cases; the authors recommend including two perforators to help maintain the orientation of the pedicle or including a small cuff of fascia around the perforator if a suprafascial dissection was performed. Hematoma instigated 3 flap failures, 2 of which were the result of a hemoclip slipping off of a branch from the pedicle, underscoring the importance of meticulous hemostasis.


This case report is the first and only publication to date in the literature regarding lower limb necrosis following ALT flap harvest. The authors performed an ALT flap on a 53-year-old man for a T4N0M0 hypopharyngeal cancer. He had a history of claudication and hypertension and did not have a palpable dorsalis pedis or posterior tibial pulse. The pedicle was harvested to the origin of the descending branch, leaving the lateral circumflex femoral artery intact. The perfusion to the foot was noted to be sufficient at the conclusion of the case. Four days following surgery, the patient reported foot pain, and necrosis of the toes, heel, and skin of the calf ensued. Angiography showed a superficial femoral artery occlusion and a patent profunda femoris artery. The patient was treated conservatively, given his poor prognosis, and he died 21 weeks postoperatively. In retrospect, the authors noted that the descending branch was unusually large, which reflected its role as a critical collateral vessel for lower leg perfusion.


Although the ALT flap is usually based on the descending branch of the lateral circumflex femoral artery, the authors describe a previously unnamed pedicle to the ALT flap. In a series of 89 patients, this oblique branch was present in 35% and was located between the descending and transverse branches of the lateral circumflex femoral artery. The average lumen diameter of the oblique branch was 1.5 mm, significantly smaller than the descending branch.


Eighty-eight ALT flaps harvested in 86 patients are reviewed in this paper, along with compartment pressure measurements in 50 consecutive patients. Notably, 1 patient lost palpable distal pulses on the table and required release of the fascial closure following an attempt to close a 10 cm wide defect. However, successful primary closure was achieved in defects ranging from 5 to 13 cm (average 9 cm) without incident. There was no evidence of muscle bulge, wound dehiscence, infection, or seroma in patients who received fascial closure or imbrication. Although compartment pressures were elevated following fascial closure or imbrication, postoperative compartment syndrome was not observed in this study.


The authors introduce the free-style flap concept, broadening the approach to perforator flap harvest. As long as an audible Doppler signal is identified, a viable flap can be based on nearly any perforator using a retrograde approach to the dissection. Variability in anatomy is not considered an obstacle, because a retrograde approach will eventually lead to an adequately sized pedicle. The authors present their series of 13 free-style flaps harvested in a suprafascial plane with a 100% success rate. Benefits include the ability to harvest tissue nearly anywhere in the body to suit the needs of the defect and the preferences of the surgeon. Disadvantages are the unknown pedicle length and the limited accuracy of Doppler imaging for preoperative planning. This publication adds an additional degree of freedom in planning and executing perforator flap harvest in the setting of diverse vascular anatomy.


CHAPTER 14

Radial Forearm Free Flap

Jeng-Yee Lin, Fu-Chan Wei

HIGHLIGHTS

- The radial forearm free flap is a thin and pliable flap with a long pedicle and constant anatomy. This makes it most suitable for reconstructing the intraoral lining to restore function.
- The arterial blood supply of this flap is based on the tiny axial vessels from the radial artery, and venous drainage depends on either the venae comitantes or the cutaneous vein.
- The skin paddle of the radial forearm flap is located at the distal forearm, but the paddle can also be harvested from the proximal forearm based on the larger septocutaneous vessels or septomuscular perforators, preserving the radial artery.
- Modification of the skin paddle design, such as using two or more separate skin paddles linked on the radial vessels, makes it more versatile for head and neck reconstruction.
- The radial forearm free flap can be harvested with the anterolateral two thirds of the radius bone for reconstruction of mandibular bone defects.
- Most of the donor sites of forearm flaps require skin grafts, therefore the appearance of the donor sites is less ideal.
The anatomy of the radial forearm flap was first described by Yang et al\(^1\) in 1981 and Song et al\(^2\) in 1982. Since then, its unparalleled reliability, flexibility, and versatility in complex three-dimensional head and neck reconstructions has propelled it to its use in mainstream reconstructive surgery.\(^3\)-\(^6\) The thin, pliable nature of the radial forearm flap, a hallmark of its versatility, as well as its ease of harvest, continues to make it an ideal option in head and neck reconstruction.

**ANATOMY**

**Vascular Pedicle**

The vascular pedicle of the radial forearm free flap is based on the radial artery and its venae comitantes (Fig. 14-1). The radial artery is one of the two continuations of the brachial artery. The other continuation, which is the ulnar artery, forms an anastomosis through the superficial and deep palmar arches with the radial artery in the hand. The radial artery, with its two accompanying veins, is located between tendons of flexor carpi radialis and brachioradialis in the lower half of the forearm and between the muscle belly of brachioradialis and pronator teres muscles in the upper half of the forearm. It courses between extensor and flexor compartments, remaining superior and anterior to the origin of the flexor digitorum profundus muscle. Initially the artery lies deep to the brachioradialis muscle, but as it courses distally along the forearm, it gradually becomes more superficial until it lies directly under the palmar fascia in the wrist (Fig. 14-2). Along the radial artery numerous tiny septal or septomuscular type vessels pierce the superficial fascia to enter the overlying skin. They are more numerous but smaller in the distal forearm than in the proximal forearm. In the upper half, the average number of cutaneous vessels is four, and the average diameter of these vessels is 0.7 mm, whereas in the lower half, the average number of cutaneous branches is nine and the diameter is usually less than 0.5 mm. These septocutaneous vessels in the distal forearm radiate from the radial artery in the intermuscular septum to form an anastomotic subcutaneous network above the fascia with similar cutaneous vessels of the ulnar and brachial arteries.

![Fig. 14-1](image_url) The arterial system and nerves associated with the vascular pedicle of the forearm free flap.
Venous Drainage System

Because of the rich network of veins in the radial forearm flap, many alternatives exist for venous drainage of the forearm flap. These can be divided into the superficial system, composed of a subcutaneous venous network that drains into the cephalic and basilic veins, and the deep system, formed by the two interconnected venae comitantes accompanying the radial artery. These two systems communicate through connecting veins (Fig. 14-3). The compact deep venous system communicates with the superficial system through generally one to three connecting veins in the distal forearm, giving it the potential drainage territory of the superficial system. Shima et al showed that the venae comitantes and the cephalic veins were of comparable size in the upper third of the forearm. Although much controversy exists in the published literature regarding the theoretical advantages and disadvantages of each system and which one should be preferentially used, I (F.C.W.) advocate the use of the larger of the two venae comitantes. It has been shown that the use of a single vena comitans is safe, reliable, of adequate size, and results in shorter operation time.

Fig. 14-2 Fine vascular connections (arrows) between the radial vascular pedicle and the overlying skin island. These must be preserved to assure flap viability.

Fig. 14-3 Venous drainage of the forearm.
SENSORY NERVE INNERVATIONS
The lateral antebrachial cutaneous nerve (C5-6) is the distal continuation of the musculocutaneous nerve and bifurcates into anterior and posterior branches. The larger anterior branch courses along with the cephalic vein and innervates the radial half of the anterior surface up to the thenar eminence. The smaller posterior branch innervates the skin of the posterior forearm to the wrist level.

The medial antebrachial cutaneous nerve (C8-T1) emerges through the deep fascia with the basilic vein in the medial distal third of the upper arm. It immediately divides into an anterior and posterior branch. The posterior branch courses anterior to the medial epicondyle to innervate the dorsal surface of the forearm. The anterior branch courses distally with the basilic vein to innervate the ulnar half of the ventral surface of the forearm.

The superficial radial nerve does not innervate this flap, but it may be included with this flap as a vascularized nerve graft. The superficial radial nerve travels along the radial margins of the forearm. Initially covered by the brachioradialis muscle in the proximal forearm, it pierces the muscle to travel just lateral to the vascular pedicle and deep to the superficial layer of the deep fascia. In the distal third of the forearm, it pierces the superficial layer of the deep fascia and divides into medial and lateral branches.

CLASSIFICATION
The radial forearm free flap is a type C fasciocutaneous flap in that the skin flap is supported by multiple small septocutaneous vessels along its length.\textsuperscript{12,13}

ADVANTAGES AND DISADVANTAGES
The radial forearm flap is thin and pliable, and is therefore suitable for reconstruction of intraoral defects, including tongue (Fig. 14-4), floor of mouth, buccal mucosa (Fig. 14-5), palate, hypopharynx, and esophagus (Fig. 14-6). It also has the advantages of a constant anatomy, reliable circulation, and a long pedicle. The success rate in our series of 1400 forearm flaps was 99%. The drawbacks of the radial forearm flap are lack of tissue bulk, limited flap dimension, sacrifice of the major vessel in the forearm, and requirement of skin grafting in the distal forearm donor site.
Fig. 14-4  Hemiglossectomy defect reconstructed with a forearm flap.

Fig. 14-5  Buccal mucosa reconstructed with a small forearm flap after release of submucous fibrosis.

Fig. 14-6  Pharyngoesophageal defect reconstructed with a tubed forearm flap. A, Surgical specimen of hypopharyngeal cancer. B, Elevated forearm flap.

Continued
INDICATIONS AND CONTRAINDICATIONS

The radial forearm free flap is a good choice for reconstruction of the intraoral lining defect given that this flap is thin and relatively hairless (in non-Caucasians), with a long pedicle and large diameter. This flap can be used as a neurosensory flap to innervate the reconstructed defect. The radial forearm flap can also include an osseous segment to reconstruct the mandibular or maxillary defect.

Patients with abnormal Allen test results require further workup for the abnormality and may not be suitable candidates for radial forearm free flap harvest. In addition, the radial forearm flap lacks tissue bulk and may not be adequate when a large volume of tissue is required for reconstruction. Although the anatomy of this flap is fairly reliable, many anatomic and clinical studies have described many variations that could potentially contraindicate its use.\textsuperscript{14-16}

PREOPERATIVE MANAGEMENT

Patients should be asked about history of any trauma to the upper extremity. The physical examination should reveal any congenital anomaly of the musculoskeletal system in the upper extremity. When this happens, the accompanied vascular anomaly should be identified by angiography or CT angiography. An Allen test is necessary to confirm the integrity of the vascular arcade of the hand.
**Allen Test**

The donor limb is elevated, and the ulnar and radial arteries are occluded by direct compression, resulting in hand blanching. One artery is subsequently released, resulting in hand reperfusion and normalization of hand color. This procedure is then repeated with the other artery. If the palmar arch is intact, a single artery (either radial or ulnar) can theoretically perfuse the hand. In these cases, the radial vessels can be sacrificed and used as a vascular pedicle for the donor flap. The presence of a superficial dorsal antibrachial artery may result in a false-negative Allen test result. Because this anomaly is associated with a strong radial artery contribution to the thumb, index finger, and deep volar arch, it will affect flap harvest. In the presence of this anomaly, a preoperative Allen test will not be accurate unless both the palmar and superficial dorsal arteries are compressed. In this case, Funk et al. recommend an intraoperative Allen test be performed before flap harvest to ensure adequate ulnar collateral circulation to the hand.

**Operative Technique**

**Flap Design**

The flap design begins with determining the course of the radial artery in the forearm based on palpation of pulse. The axis of the flap is ideally parallel to this line. If primary closure is planned, then a pinch test is performed to help assess the maximal harvestable width. Flaps designed with widths up to 2 to 3 cm distally and 4 to 6 cm proximally usually can be closed primarily. The radial margin of the flap should not exceed the radial border of the forearm to better conceal the donor site skin graft. Traditionally the skin flap is designed on the distal forearm starting from the distal crease in the wrist. With the advent of microsurgery, the radial forearm flap is no longer constrained by the intermuscular septum. The flap may be harvested as a single long paddle, or as double- or triple-paddled flaps that are either completely independent or connected by a bridge of deepithelialized dermis. If the proximal forearm skin is included for flap design, it can be harvested safely either together with or independently from the distal forearm skin paddles. The proximal radial forearm flap can also be harvested as a free flap based on the radial artery or the perforator vessel. When the latter is intended, a radial artery-sparing forearm flap, as described by Lin et al., could be a potential alternative flap, if only a short pedicle with a small skin paddle is required. This type of flap uses the free-style free flap concept first introduced by Wei and Mardini.

**Flap Harvest**

The hand is exsanguinated by inflating the tourniquet to 100 mm Hg above the patient’s systolic blood pressure. The flap is raised suprafascially from its ulnar and radial border until the radial border of the flexor carpi radialis tendon and the ulnar border of the brachioradialis tendon are reached. On the radial-side dissection, care should be taken to preserve the superficial radial nerve and the lateral antecu-
The deep layer of the deep fascia located deep to the pedicle and its attachment to the fascia over the flexor carpi radialis and brachioradialis are preserved (Fig. 14–8). In this manner the suprafascial forearm flap can be expediently harvested while preserving the deep fascial compartment of the distal forearm. Depending on the length of pedicle required, the skin incision can be extended proximal to the flap margin so that the radial artery and its venae comitantes can be harvested just before reaching confluence with the ulnar vessels. The proximal dissection is rarely extended beyond the antecubital fossa.
Variations

Neurosensory Flap

A neurosensory flap can be harvested as a standard flap, as previously described, with modifications\textsuperscript{22-24} (Fig. 14-9). During dissection of the proximal border of the skin island along the radial border of the upper arm, the lateral antebrachial cutaneous nerve of the forearm can be seen running along the cephalic vein. Along the ulnar border of the skin paddle where the basilic vein is located, the medial antebrachial cutaneous nerve of the forearm can be identified. It is important to include nerves that innervate the flap and not the nerves passing by. The nerves are dissected until a desired length for microsurgical repair is achieved. By suturing the antebrachial cutaneous nerve of the flap into the stump of the mental or inferior alveolar nerves, the flap may become sensate.

Fig. 14-8  Anatomy of the skin paddle of the radial forearm flap in relation to the antecubital fascia and radial vessels. \textit{BR}, Brachioradialis tendon; \textit{FCR}, flexor carpi radialis tendon. Route \textit{A} (dotted line) is the correct site of dissection. Route \textit{B} (dotted line) is incorrect. \textit{C} is where the fascia conjoins.

Fig. 14-9  Forearm flap including antebrachial cutaneous nerve as a neurosensory flap.
Fasciocutaneous Flap With an Osseous Segment

A segment of radius can be included with the fasciocutaneous flap as vascularized bone. The bone comprises the anterolateral third of the radius between the insertions of brachioradialis and pronator teres. It is nourished by the radial artery via perforators passing through the flexor pollicis longus, which covers the distal radius on which the vessel resides. A segment of bone up to 10 cm long, including 40% of the cross section of the radius, may be harvested. The design of skin paddle is along the distal half or third of the forearm. Flap harvest is performed as previously described until the radial vessels are reached from either side. Once the brachioradialis is retracted radially, the superficial radial nerve is identified and protected. The periosteum of the radius is incised longitudinally until the desired length is reached. On the ulnar side, the flexor carpi radialis muscle is retracted to expose the bellies of both the flexor pollicis longus and pronator quadratus, which are divided close to the radius. The periosteum is incised. Once the longitudinal osteotomy is made with a saw, the osseocutaneous flap is ready for transfer. This is the best option for bridging small lateral mandibular defects.

Tendinocutaneous Flap

The palmaris longus tendon may be incorporated into the radial forearm fasciocutaneous flap as previously described. However, rather than dissecting off the skin overlying the palmaris longus tendon, the palmaris longus tendon can be included in the skin paddle. This will preserve the vascular communication between the radial artery and the tendon. When a composite tissue defect involves the oral commissure and orbicularis oris function is not maintained, the palmaris longus tendon can be anchored to the modulus on either side of the mouth. Thus the flap can be suspended over the tendon like a curtain rod to restore oral competence and prevent drooling at rest or during food intake.

Proximal Radial Forearm Fasciocutaneous Flap

This modification of the radial forearm flap takes the skin paddle from the proximal forearm region, allowing better concealment of the donor wound and achieving primary wound closure. A Doppler probe is not accurate for preoperative detection of cutaneous branches of the radial or ulnar artery in the forearm because of the close proximity of skin branches to their originating arteries. The cutaneous vein of the
forearm should be included for either major or accessory venous drainage, depending on the requirement of the recipient site. Skin incision should be directly over the brachioradialis muscle in the proximal or middle third of the forearm and carried down to the deep fascia. This avoids inadvertent injury to the septocutaneous vessels on which the flap is based. Once the skin incision is made, skin flap dissection can proceed in the radial-to-ulnar or ulnar-to-radial direction in the subfascial plane. The radial vessels and the septomuscular or septocutaneous vessels to the skin are identified after elevation of the skin flap from either the radial or ulnar aspect. There are usually two to four septocutaneous vessels in the proximal half of the forearm. It is better to dissect these vessels using a high-magnification loupe or even a microscope. Inclusion of a small (5 mm) cuff of fascia enclosing the dissected vessel helps avoid injury to these tiny perforators (which may be as small as 0.5 mm in diameter). The pedicle can be harvested just before reaching the confluence with radial vessels or together with the radial vessels, depending on the pedicle length needed.

**Flap Inset**

Given its pliability and thinness, the forearm skin can be easily inset and sutured to intraoral defects or defects in other parts of the head and neck region. If the radial forearm flap with an osseous segment is transferred to bridge a mandibular or maxillary defect, the radius bone should have good contact with and rigid fixation to the native bones. For intraoral defect reconstruction, the flap inset should achieve a watertight wound closure to prevent saliva from leaking into the neck area where the pedicle is located, and microvascular anastomosis is commonly performed.

**Flap Revascularization**

Multiple recipient vessel choices for free flap revascularization exist in the head and neck area. The long pedicle of the radial forearm flap makes its easy to access any recipient vessels in the region. It is not necessary to include the cephalic vein in the harvested flap. Adequate venous drainage can depend reliably on one venous anastomosis between the larger of the two venae comitantes and the recipient vein. The superficial and deep venous systems of the flap are equally effective in providing venous drainage. It is unnecessary to perform multiple venous anastomoses or extensive dissections of the proximal veins to find a confluent vein draining both the superficial and deep systems.
Donor Site Management

Primary closure of the donor site is feasible only when the size of the donor site wound is smaller than 2 to 3 cm in the distal forearm (Fig. 14-10, A) and smaller than 4 to 5 cm in the proximal forearm. A full-thickness skin graft (FTSG) from the inguinal region (Fig. 14-10, B) or a split-thickness skin graft (STSG) from the thigh is used to resurface the donor site. Whenever possible, the former is preferred in our practice, because it creates less donor site pain or itching. Splinting the hand and forearm is recommended, because it may provide protection for the skin graft postoperatively. A variety of alternative approaches have been reported to close the donor site primarily, such as Z-plasty, skin traction, rotational flap, or pedicle flap.17,32-39

The surgeon must reconstruct the radial artery if there is arterial insufficiency, even though this is rare, unless an aberrant superficial ulnar artery is accidentally ligated. Radius fractures should be treated with rigid internal fixation and bone grafting to prevent a debilitating nonunion.

Complications

Donor site morbidity after radial forearm flap harvest includes skin graft loss with resultant flexor tendon exposure, numbness at the forearm and hand caused by injury to the lateral or medial antebrachial cutaneous nerve or superficial radial nerve, radius bone fracture, cold intolerance, and arterial insufficiency of the hand. Using the technique of suprafascial dissection, the possibility of skin graft loss, flexor tendon exposure, and numbness or weakness of hand can be minimized.5 Suprafascial dissection for flap harvest preserves the continuity of the deep fascia. This serves to bind the tendons, thereby preventing tenting during excursion. The deep fascia provides a vascular immobile bed that is more favorable for skin grafting. Furthermore, in the event of skin graft lost, the risk of tendon exposure is minimized, because it is
protected by the deep fascial layer. Despite intimate dissection of the superficial branch of radial nerve and harvesting of the antebrachial nerves, surprisingly few patients report chronic radial neuroma pain. Cold intolerance is variably reported in the literature, ranging from 5% to 30%. Loss of the radial artery has been postulated as a cause of cold intolerance; however, there is little evidence for this in the studies that are available. The breaking strength of the radius is weakened by 76% as a result of harvesting the bone graft. The risk of radial fracture is inversely related to the experience of the surgeon, but in most series is less than 10%. Other rare complications, such as acute or chronic ischemia of the hand, have been reported. Only one case of chronic arterial insufficiency was seen in a review of our series of 1202 radial forearm free flaps.

**CRITICAL POINTS**

**Must Know**
- Surgeons must be familiar with the regional anatomy of the forearm.
- Surgeon must be well acquainted with the Allen test.
- The indications, contraindications, and limitations of using radial forearm free flaps must be considered.
- Proper technique must be followed for suprafascial elevation of the flap.
- The proper technique for full-thickness and split-thickness skin grafts to donor sites must be understood.

**Should Know**
- The superficial and the deep venous systems can drain the radial forearm flap; however, the deep venous system is preferred because it is reliable, convenient, and less time consuming.
- Dissection of the radial forearm free flap at the suprafascial level and preservation of the deep fascia of the forearm can avoid tenting of the flexor tendons and minimize skin graft loss from the donor site.
- The radial forearm free flap can also be elevated from the proximal forearm, based on the septocutaneous vessel, to preserve the radial vessel in selected cases.

**Synopsis**
- The radial forearm free flap is a commonly used flap for head and neck reconstruction. It has the advantages of thinness, pliability, reliability, and a long pedicle, which makes it suitable for reconstructing oral lining defects.
- Its high success rate for reconstruction also contributes to its popularity (at our institution it has had a success rate of 99% among 1400 free radial forearm free flaps from 1984 through 2007).
- Although technically it is considered a relatively “easy” flap, one should bear in mind all the possible complications accompanying flap harvest to reduce morbidity and maintain good function and cosmesis in the donor site.
References

   *This is the original article that describes the radial forearm flap in Chinese.*

   *This article describes the authors' early experience with 31 forearm flaps for patients with scar contracture in the head and neck area. The anatomic basis and surgical techniques of the forearm flaps are discussed, and results of this case series are shown. The authors concluded that hand function was not affected after flap harvest.*

   *This article describes in detail the techniques of suprafascial dissection of the radial forearm free flap to minimize donor site morbidity.*

   *This paper prospectively evaluates the functional and cosmetic results of the donor forearm in 95 patients undergoing a radial forearm free flap harvest using the suprafascial dissection technique. No statistically significant difference was found in wrist and finger function between the operated hand and the nonoperated hand.*

   *This paper presents a thorough and extensive review of the vascular basis of the radial forearm flap. Through studying arterial and venous anatomy in 56 cadaver dissections using ink, latex, and barium sulfate injection techniques, the location and number of perforators in the overlying skin and vascular connections with the tendons and muscles and distal radius bone are described.*


This paper demonstrates the clinical reality of harvesting the radial forearm free flap from the proximal forearm based on a large septocutaneous or septomuscular vessel from the radial artery as a pedicle in selected head and neck reconstruction. By doing so, the donor site can be primarily closed and the major vessel can be preserved in the forearm.


This article presents a detailed, step-by-step description of the suprafascial harvest of the radial forearm flap.


Through cadaveric injection study of the radial artery, the authors conclude that an anterolateral segment of distal radius bone, if harvested together with the radial forearm free flap as a compound osteocutaneous flap, is supplied through two fascioperiosteal branches of the radial artery and a musculoperiosteal plexus at the site of the attachment of the flexor pollicis longus muscle.


CHAPTER 15

Deep Circumflex Iliac Artery Flap

Peter C. Neligan

HIGHLIGHTS

- Supplied by the deep circumflex iliac artery (DCIA) and vein (DCIV), the DCIA flap is harvested as an osseous, myoosseous, or myoosseocutaneous flap.
- The pedicle length is 6 to 8 cm, and the pedicle size ranges from 1.5 to 3 mm.
- Choosing the appropriate harvest side (right or left) is important.
- The ascending branch of the DCIA must be preserved if the internal oblique muscle is harvested.
- A 2 to 3 cm cuff of abdominal wall musculature is harvested with a crest if a skin paddle is included in the flap.
- Donor morbidity is minimized if the crest splits and only the inner table is harvested.
- Repairing the abdominal wall is very important to prevent hernias.
- The skin paddle is bulky.

In 1979 Taylor et al\textsuperscript{1,2} described the role of the DCIA in supplying the anterior ileum and the overlying skin. The same year, Sanders and Mayou\textsuperscript{3} described using the same flap to reconstruct a tibial defect. Several years later, Ramasastry et al\textsuperscript{4} described the blood supply of the internal oblique muscle, including the ascending branch of the DCIA.

The use of the DCIA flap for mandibular reconstruction was popularized in the 1980s\textsuperscript{5,6}. David et al\textsuperscript{7} introduced the concept of splitting the crest, a modification that significantly reduces donor site morbidity. Urken et al\textsuperscript{8} described using the in-
ternal oblique muscle based on the ascending branch of the DCIA for intraoral resurfacing. More recently, Brown\(^9\) described using the flap for maxillary reconstruction, also using the internal oblique component of the flap.

When the fibular osseocutaneous flap was introduced, the popularity of the DCIA flap for mandibular reconstruction declined and took a secondary role. However, it remains a useful flap whose popularity has undergone a resurgence since the publication of Brown’s work on reconstruction of the maxillectomy defect.

**INDICATIONS**

The DCIA flap is indicated for mandibular reconstruction (second-line flap) and maxillary reconstruction (with the internal oblique muscle).

**ADVANTAGES AND DISADVANTAGES**

The DCIA flap is well suited for reconstruction of the mandible and maxilla because of the natural curvature of these bones. This flap allows reconstruction of the curved structures of the mandible and maxilla with minimal adjustment. Although less bone depth is taken with the split ileum technique, it is still possible to support osseointegrated implants. When harvested as a split crest, the donor defect is very acceptable (Fig. 15-1), and defects resulting from even large skin paddles can generally be closed directly. Technically, the flap is relatively difficult to harvest, and this is a distinct disadvantage. The bulkiness of the skin paddle is a further disadvantage.

**Fig. 15-1** The donor site in a young woman who had a DCIA flap for mandibular reconstruction. Note the absence of any contour deformity.
ANATOMY

The DCIA is a branch from the lateral aspect of the external iliac artery (Fig. 15-2). At its origin, the DCIA measures up to 3 mm in diameter. It runs laterally, cephalad to the inguinal ligament and deep to the three layers of abdominal wall musculature. The DCIV or DCIVs flow into the external iliac vein, which is medial to the external iliac artery. The DCIA is therefore shorter than the DCIV. The vein or veins may pass in front of or behind the external iliac artery and are frequently separated from the DCIA by as much as 1 cm at this level. It is important to be aware of this when harvesting the flap. The DCIV may be a single vein or a pair of venae comitantes. Frequently, the paired venae comitantes merge into a single vein before flowing into the external iliac vein. At its junction with the iliac vein, it has a diameter of 3 to 5 mm. The DCIA gives off an ascending branch that supplies the internal oblique muscle. This branch must be included if the internal oblique is harvested as a component of the flap. The ascending branch usually arises approximately 1 cm medial to the anterior superior iliac spine (ASIS). On rare occasions the ascending branch and the DCIA have separate origins from the external iliac artery. The DCIA provides blood to the ileum through periosteal and endosteal branches. Musculo-cutaneous perforators supplies arterial blood to the skin overlying the iliac crest.

Fig. 15-2  Anatomy of the inguinal region showing the relationship of the DCIA vessels, the ascending branch, and the lateral femoral cutaneous nerve.
It is important to identify the lateral femoral cutaneous nerve when harvesting the DCIA flap. It has a variable relationship to the vascular pedicle; it may lie deep or superficial to the vascular pedicle. Occasionally, it lies between the DCIA and the DCIV. It may also be found between the ascending branch and the main pedicle.

**Key Points**
- The DCIA and DCIV arise from the external iliac vessels.
- The vein is longer than the artery.
- The ascending branch is 1 cm medial to the ASIS.
- The ascending branch supplies the internal oblique muscle.
- The lateral femoral cutaneous nerve configuration needs to be determined.
- The skin is supplied by musculocutaneous perforators passing through the abdominal wall’s muscle layers.

**Preoperative Management and Operative Technique**

**Design and Flap Harvest**

**Technical Tips and Tricks**
- Identify the iliac vessels first.
- Dissect from medial to lateral.
- Identify the ascending branch of the DCIA.
- Identify the lateral femoral cutaneous nerve.
- Prepare the crest for splitting.
- Identify the position of the DCIA under the iliacus fascia.
- Perform a vertical split and horizontal osteotomy.
- Complete the bone harvest with an osteotome.
- Free the remaining soft tissue attachments of the pedicle.

A large segment of bone (approximately 14 to 16 cm) can be harvested with this flap by extending the bony resection posteriorly to the sacroiliac joint. Regardless of the type of flap harvested—osseomyocutaneous, myoosseous, or bone only—the initial incision is made above and parallel to the inguinal ligament. It is helpful to locate the external iliac vessels first so that the DCIA and DCIV are easily identified. The incision is extended laterally. The flap design depends on which components are required. If skin is harvested, the axis of the skin paddle parallels the iliac crest and is centralized approximately 1 cm cephalad to the crest (Fig. 15-3). The perforators that are located along the medial aspect of the iliac crest provide the blood supply of
Once the pedicle is identified, dissection proceeds laterally. The two structures to be identified are the lateral femoral cutaneous nerve and the ascending branch of the DCIA. If only bone is harvested, then the ascending branch can be divided. The configuration of the nerve relative to the pedicle is important to appreciate, because in some circumstances the nerve must be divided to facilitate the flap harvest. The nerve may pass under the pedicle, over it, or between the ascending branch and the main pedicle. In the latter circumstance, it must be divided to harvest the flap. In either of the other circumstances, however, it can be preserved. After giving off the ascending branch, the main pedicle continues subfascially and runs along the inner bowl of the ileum, supplying the iliacus muscle and the underlying bone through a periosteal and endosteal source. It is necessary to harvest some iliacus muscle with the bone. However, it is thin, attached to the bone, and does not add appreciable bulk to the flap. Once the vascular anatomy is visualized, the crest is prepared. The harvest is modified according to the type of flap being prepared. If skin is harvested with the flap, a cuff of muscle is harvested with the bone, as described previously, to preserve the perforators supplying the skin. If the internal oblique muscle is harvested without skin, the external oblique muscle is separated from the crest, the internal oblique muscle is harvested, and the transverses abdominis muscle is swept away from the crest. The periosteum on the crest is sharply divided, and the crest is

![Fig. 15-3](image-url) The skin markings for the harvest of an osseocutaneous DCIA flap. The initial incision is made just above the inguinal ligament.

Once the pedicle is identified, dissection proceeds laterally. The two structures to be identified are the lateral femoral cutaneous nerve and the ascending branch of the DCIA. If only bone is harvested, then the ascending branch can be divided. The configuration of the nerve relative to the pedicle is important to appreciate, because in some circumstances the nerve must be divided to facilitate the flap harvest. The nerve may pass under the pedicle, over it, or between the ascending branch and the main pedicle. In the latter circumstance, it must be divided to harvest the flap. In either of the other circumstances, however, it can be preserved. After giving off the ascending branch, the main pedicle continues subfascially and runs along the inner bowl of the ileum, supplying the iliacus muscle and the underlying bone through a periosteal and endosteal source. It is necessary to harvest some iliacus muscle with the bone. However, it is thin, attached to the bone, and does not add appreciable bulk to the flap. Once the vascular anatomy is visualized, the crest is prepared. The harvest is modified according to the type of flap being prepared. If skin is harvested with the flap, a cuff of muscle is harvested with the bone, as described previously, to preserve the perforators supplying the skin. If the internal oblique muscle is harvested without skin, the external oblique muscle is separated from the crest, the internal oblique muscle is harvested, and the transverses abdominis muscle is swept away from the crest. The periosteum on the crest is sharply divided, and the crest is
split with an oscillating saw (Fig. 15-4). Care must be taken to ensure that the angle of the cut matches the angle of the bone so that the cut is parallel to the inner and outer tables. Once the vertical cut is complete, the horizontal cut is made using an oscillating saw. This is done by retracting the transversus abdominis muscle and the peritoneum away from the inner surface of the ileum. It is usually necessary to complete the harvest with an osteotome to make the medial and lateral vertical cuts that finally release the bone.

**Fig. 15-4** The crest is split (arrows) with an oscillating saw so that only the inner table is harvested, leaving the crest for contour and muscle attachment.

**Pitfalls**

- The DCIV can pass behind or in front of the external iliac artery.
- The ascending branch has a variable origin from the DCIA and may rarely be a separate branch of the external iliac artery.
- The lateral femoral cutaneous nerve may pass above, below, or between the vessels of the vascular pedicle.
- When splitting the crest, the angle of the cut must parallel the inner table. Failure to do this results in the harvest of a full-thickness segment.

**Donor Site Management**

**Technical Tips for Donor Site Closure**

- If the internal oblique muscle is harvested, replace the resected segment of muscle with mesh.
- Drill several holes in the outer table of the crest.
- Secure all layers of abdominal wall musculature (including the mesh) to the iliac crest using 0-1 Prolene or 0-1 PDS sutures secured through drill holes.

Meticulous repair of the donor site is imperative. Splitting the crest and harvesting only the inner table significantly reduces donor morbidity. When the whole crest is
harvested, donor morbidity can be significant, because several important muscle ori-
gins are disrupted during harvest. These include the sartorius muscle, tensor fasciae
lata, gluteus medius muscle, and gluteal fascia. If the ASIS is harvested with the crest,
the inguinal ligament also loses its attachment, making repair of the abdominal wall
more difficult. After harvesting the crest, these muscles and the abdominal wall
muscles are reattached to the remnants of the ileum, but patients frequently have
difficulty with mobilization and are painful in the long term. By splitting the crest,
the gluteal and thigh muscles are completely spared without any disruption. The in-
guinal ligament retains its attachment to the ASIS, preserving the integrity of the
inguinal region. Furthermore, the outer table of the crest can be used as an anchor
point for reattachment of the abdominal muscles (Fig. 15-5). When the internal
oblique muscle is harvested, mesh can be used to replace the resected segment. This
mesh and the external oblique and transversus abdominis muscles are attached to
the crest through holes drilled in the bond to create a very secure and satisfactory re-
pair and minimize the risk of hernia. Furthermore, the contour deformity that is ev-
ident when the whole crest is harvested is not seen when the crest is split. Patients
may be mobilized immediately without any problems.

Fig. 15-5  An abdominal wall repair after harvesting the DCIA and internal oblique flap.
Pitfalls

- Adequate hemostasis must be ensured, particularly from bone. Bone wax should be used if necessary.
- All layers of the abdominal wall are used in the repair.
- Special attention is required when repairing the inguinal region.

CONCLUSION

The DCIA flap continues to have a role in head and neck reconstruction. It provides good bone stock with the option to harvest muscle, skin, or both. Although it is no longer the first choice for mandibular reconstruction in most circumstances, it continues to have a role particularly in patients in whom the fibular flap may not be an option and in patients requiring significant soft tissue bulk. It also has a definite role in the management of maxillectomy defects.

CRITICAL POINTS

Must Know

- Donor morbidity is minimized if the crest is split and only the inner table is harvested.
- When splitting the crest, the angle of the cut must parallel the inner table. Failure to do this results in harvesting a full-thickness segment.
- Adequate hemostasis must be ensured, particularly with bone. Use bone wax if necessary.

Should Know

- The ascending branch must be preserved if the internal oblique muscle is harvested.
- A 2 to 3 cm cuff of abdominal wall musculature is harvested with the crest if a skin paddle is included in the flap.
- The ascending branch has a variable origin from the DCIA and may rarely be a separate branch of the external iliac artery.
- The DCIV can pass behind or in front of the external iliac artery.

Synopsis

- Despite shifting trends of flap selection toward the fibular ossecutaneous flap, the DCIA flap remains a valuable option for mandibular reconstruction in certain cases and is particularly useful for maxillary reconstruction.
References

   This paper presents 16 cases of free transfer of compound flaps from the groin, 11 using the deep circumflex iliac vessels as a stem and 5 using the superficial circumflex iliac vessels as a stem. The results show that the deep vessels, which permit greater ease in anastomosis and provide more reliable blood flow, are superior in many ways to the superficial vessels.


   Thirty specimens of the internal oblique muscle flap were dissected and studied using Microfil injection techniques, including xerograms. In about 80% of the flaps, a single ascending branch of the DCIA enters the undersurface of the muscle, arborizing within the muscle. In the remaining 20%, two or three branches enter the muscle separately, originating on the DCIA. The length of the vascular pedicle is 6 to 7 cm and the vessel diameter is 2 to 3 mm, making the flap suitable for free tissue transfer.


   The internal oblique–iliac crest osseomyocutaneous microvascular free flap was used in 20 patients for oromandibular reconstruction. The internal oblique muscle, based on the ascending branches of the DCIA and DCIV, was used to resurface mucosal defects of the oral cavity and pharynx. The iliac bone, because of its length, width, and natural contour, is the best source of vascularized bone for mandibular reconstruction. The improved soft tissue component of this composite flap markedly improved the functional results.

   The methods of using the flap in low, high, and central maxillectomy defects and in cases requiring orbital exenteration are described. The DCLA flap with the internal oblique muscle provides a reliable reconstruction for the maxillectomy, because the fistula is closed with muscle, which becomes epithelialized with minimal bulk. The large volume of bone available from the iliac crest can restore the facial contour, support the orbital contents, reconstruct the orbital rim, and provide sufficient bulk of bone for the placement of implants.
Fibular Osseoseptocutaneous Flap

Wei-Chao Huang, Fu-Chan Wei

HIGHLIGHTS

- The fibular osseoseptocutaneous flap is a composite tissue flap, providing bone and soft tissue for reconstruction of composite defects.
- The pedicle of the fibular osseoseptocutaneous flap is the peroneal artery. The skin paddle is supplied by septocutaneous vessels that originate from the peroneal artery and traverse the posterior crural septum.
- The skin paddle design of the fibular osseoseptocutaneous flap is centered at the junction of the middle and distal third of the lateral leg, along the posterior margin of the fibula. Vessels supplying the skin paddle can be mapped using a handheld Doppler probe.
- Preoperative assessments of dorsalis pedis and posterior tibial artery pulsations are critical to ensure adequacy of the blood supply to the leg and foot after fibular osseoseptocutaneous flap harvest. If there is an absence of either one or both of these pulsations, or a history of lower limb trauma, angiography should be performed.
- The fibular osseoseptocutaneous flap can be reliably harvested in a stepwise fashion: identification and dissection of the vascular supply (septocutaneous vessels) to the skin paddle; detachment of surrounding muscles, creation of an osteotomy at each end of the fibula; and dissection of the peroneal vessels. The flexor hallucis longus is reattached by suturing the muscle to the interosseous membrane.
- Donor site morbidity is minimal when the flap is harvested properly.

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Free vascularized bone transfer has become the preferred method for reconstructing segmental bone defects that are not amenable to grafting with conventional non-vascularized bone. Since its first description in 1975 by Taylor et al., vascularized fibula has become widely recognized as suitable for reconstruction of extensive bone defects, including long bone in the extremities, mandible, and maxilla. For mandible reconstruction, a variety of donor sites have been used, including fibula, ilium, scapula, radius, metatarsal, and rib. Each of these donor sites has significant advantages and disadvantages arising from differences in bone texture, available bone/pedicle length, reliability of associated soft tissues, and donor site considerations such as the potential for significant functional morbidity. The fibular osseosseouscutaneous flap is remote from the head and neck, and thus may be conveniently harvested while a patient is in the supine position. It can provide strong corticocancellous bone for teeth rehabilitation, the large and long vascular pedicle allows reliable anastomoses, the adequate skin paddle is suitable for soft tissue defects, and the rich periosteal blood supply can tolerate multiple osteotomies. Because of its numerous advantages over other vascularized osseous donor sites, the fibular osseosseouscutaneous flap has become our first choice for mandible reconstruction. To achieve successful transfer of a fibular osseosseouscutaneous flap, reconstructive surgeons should have a thorough understanding of the relevant anatomy, and perform appropriate preoperative evaluation and planning, proper flap harvesting techniques, and appropriate manipulation and shaping of flaps, without vascular damage.

**ANATOMY**

The fibula is attached to the tibia at both of its ends. The shaft of the fibula has three borders: anterior, interosseous, and posterior; and three surfaces: medial, lateral, and posterior. The anterior and interosseous borders are located on the medial and lateral surfaces of the fibula. The anterior border serves as the point of attachment of the anterior intermuscular crura (septum). The interosseous membrane is attached to the interosseous border. The posterior border, on the posterior and lateral surfaces of the fibula, is less distinct and gives rise to the posterior intermuscular septum.

Nine muscles are attached to the fibula, anterior and posterior intermuscular crura, and interosseous membrane. The peroneus longus and peroneus brevis muscles originate from the lateral surface of the fibula and occupy the lateral compartment. The extensor digitorum longus, the peroneus tertius, and the extensor hallucis longus muscles are attached to the medial surface of the fibula. The soleus, flexor hallucis longus, and tibialis posterior muscles arise in part from the posterior surface of the fibula. The flexor hallucis longus is the largest and most powerful deep muscle. It arises from the inferior two thirds of the posterior surface of the body of the fibula. The tibialis posterior muscle is the most deeply situated muscle in the deep posterior compartment.
The pedicle of the fibular osseoseptocutaneous flap is the peroneal artery. The peroneal vessels parallel the course of the bone throughout the middle third of the fibula. Proximally in the upper third, the peroneal vessels run medially and join the posterior tibial artery to form the tibioperoneal trunk. The external diameter of the peroneal artery is 1.5 to 2.5 mm at its origin off the posterior tibial artery. The available length, before reaching the posterior tibial artery, is approximately 6 to 8 cm. The fibula is nourished by periosteal and endosteal blood supplies. The periosteal blood supply for the fibular osseoseptocutaneous flap is abundant, which permits multiple osteotomies to be performed.

A skin island designed over the distal third of the lower leg and based on septocutaneous vessels running within the posterior crural septum can reliably perfuse the skin flap, without inclusion of the surrounding muscles (Fig. 16-1). There are one to four septocutaneous branches located 15 to 27 cm from the fibula head. A septocutaneous vessel refers to one remaining on the posterior intermuscular (crural) septum throughout its course, before reaching the peroneal vessel. The skin paddle of the fibular osseoseptocutaneous flap is mainly based on septocutaneous vessels from the peroneal artery. If the supplying vessel pierces a muscle belly before reaching the skin flap (musculocutaneous perforator), a variable distance of intramuscular dissection becomes necessary. If only musculocutaneous perforators are identifiable, the skin paddle will be based on perforators (traversing the soleus muscle).

Fig. 16-1 The peroneal artery runs on the deep surface of the fibula, giving off septocutaneous and musculocutaneous perforators to the overlying skin paddle. Distally, these perforators tend to be septocutaneous, running in the posterior crural septum. The lateral sural cutaneous nerve provides sensation to the skin.
The lateral sural cutaneous nerve (LSCN) supplies sensation to the skin of the lateral lower leg (the region of the fibular osseoseptocutaneous flap skin paddle). In 74% of dissections, the LSCN coursed posterior to the posterior septum, whereas an anterior branch was seen in 26%. In 54% of dissections, the LSCN was within 3 cm of the posterior septum, whereas in 86%, it was within 4 cm. The LSCN can be included to provide sensation as long as a recipient nerve is available.

**TERMINOLOGY**

We prefer to call the composite fibula and skin flap harvested using our method a *fibular osseoseptocutaneous flap* instead of a fibular osseocutaneous or osseomyocutaneous flap. This name emphasizes that there is no need to include muscles between the skin paddle and fibula, and that adequate blood supply to the skin paddle can rely on septocutaneous branches of the peroneal artery alone (Fig. 16-2). Cutaneous vessels located in the middle third and proximal part of the lateral leg may be musculocutaneous perforators passing through the soleus, flexor hallucis longus, and/or tibialis posterior muscles. The fibular flap harvested with inclusion of a cuff of these muscles to capture these musculocutaneous perforators is called the *fibular osseocutaneous* or *osseomyocutaneous flap*. However, this technique is unreliable, because these musculocutaneous perforators do not necessarily originate from the peroneal artery.

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Fig. 16-2  An elevated fibular osseoseptocutaneous flap. There is no need to include muscles between the skin paddle and the fibula. Adequate blood to the skin paddle is supplied by septocutaneous branches of the peroneal artery alone.
Previous reports suggest that the skin island harvested in this manner is reliable in only 91% of patients. Furthermore, inclusion of large muscle cuffs increases donor site morbidity.

The blood supply to fibular osseoseptocutaneous flaps is well studied. The inclusion of muscle cuffs is unnecessary. Vessels supplying the skin paddle located at the junction of the middle and the distal third of the fibular posterior margin can be mapped with handheld Doppler imaging and dissected along either the short intermuscular septum or an intramuscular course. In our experience, the skin paddle of the fibular osseoseptocutaneous flap can provide more than 98% reliability.

**ADVANTAGES**

Many features make the fibular osseoseptocutaneous flap appealing as a donor site, including the following:

- The remote location of the flap from the head and neck facilitates simultaneous harvesting while the ablative procedure is ongoing, thus reducing operative time. The flap can be conveniently dissected with the patient in the supine position.
- The flap can provide up to 26 cm of strong corticocancellous bone with more than 12 mm of bone height to allow osseointegrated teeth implantation.
- The large diameter of the peroneal vessels and long vascular pedicle allow reliable anastomoses with ipsilateral neck vessels, and, when these are not available, with contralateral neck vessels, without the need for vein grafts.
- The skin paddle can be harvested as large as 24 by 12 cm and is less tethered by bone, which makes it suitable for reconstruction of associated soft tissue defects.
- The rich periosteal blood supply of the fibula allows it to tolerate multiple osteotomies (Fig. 16-3).
- Donor site morbidity is not significant if the flap is harvested properly.

Fig. 16-3  Multiple osteotomies from the fibula for reconstruction of the anterior and bilateral ramus defect of the mandible. A, Osteotomized fibular segments aligned. B, Osteotomized fibular segments fixed to a reconstruction plate.
DISADVANTAGES
The fibular osseoseptocutaneous flap has the following disadvantages compared with other sources of vascularized bone:

- The height of the anterior mandible after reconstruction is only about half that of the dentulous mandible if a single barrel of fibula is used. This shortcoming may not be present when iliac crest or scapular bone flaps are used. However, the design of a double-barreled fibula flap can overcome this problem\textsuperscript{15} (Fig. 16-4). Secondary vertical distraction osteogenesis can also be performed to increase the height of the reconstructed mandible\textsuperscript{16} (see Chapter 35).

- Accurate shaping of the fibula according to the native mandibular defect for bony healing, dental occlusion, and facial contouring can be time consuming. Templates or stereolithographic models provide ideal methods for mandible reconstruction (Fig. 16-5).\textsuperscript{17,18}

PREOPERATIVE ASSESSMENT OF THE DONOR SITE
The vascular supply to the leg and foot depends on adequate flow from the anterior tibial, posterior tibial, and peroneal arteries. It is essential to sacrifice the peroneal artery when harvesting the fibular osseoseptocutaneous flap. Thus, after transferring
the fibula, the leg and foot depend on the remaining anterior and posterior tibial arteries. The possibility of a patient having donor site morbidity or even losing a foot because of inadequate vascular supply following fibular flap harvest has been discussed in the literature. Preoperative assessment of the dorsalis pedis and posterior tibial artery pulsations is critically important before free fibula transfer. If the foot pulses are not palpable, confirmatory ultrasonography of these arteries using a Doppler pencil probe should be performed. In our prospective study, it was determined that routine preoperative angiography of the donor leg before fibula transplantation was not justified. It did not add relevant new information about donor leg vascularity, provided that the pedal pulses were palpable. The only two conditions that may require a preoperative donor leg angiography are abnormal pedal pulses or significant, previous lower leg trauma. This study supports physical examination alone as adequate to determine lower-extremity circulation in most cases.

**Flap Design**

Arterial pulses along the posterior border of the fibula bone are identified with a Doppler pencil probe. The skin paddle is centered at the junction of the middle and lower third of the leg, along the posterior margin of the fibula, corresponding to a line drawn from the fibula head to the posterior edge of the lateral malleolus (Fig. 16-6). One sizable septocutaneous vessel can reliably supply circulation to a 24 by 12 cm skin paddle designed with this method. Planning should include discussion with ablative surgeons regarding the extent of tumor resection and the size, shape, and volume of the defect.

Sensory reinnervation of the skin paddle is possible, and function may be improved if the LSCN is included in the harvested fibular osseoseptocutaneous flap. In adults, up to 26 cm of vascularized fibular bone can be harvested, preserving 6 cm proximally at the fibular head and 6 cm distally at the malleolus to avoid ankle instability. The location of the proximal osteotomy is based on the length of bone and vascular pedicle (peroneal vessels) needed. The dissection of the peroneal vessels is greatly facilitated by performing the proximal osteotomy at a higher level.
OPERATIVE TECHNIQUES
Identifying Septocutaneous Vessels

The procedure is performed under tourniquet control with the patient in the supine position and the donor knee flexed. For less experienced surgeons harvesting the fibular osseoseptocutaneous flap, incomplete exsanguination may facilitate the identification of smaller vessels or perforators to the skin paddle. However, for experienced surgeons, complete exsanguination produces a bloodless and clear field. The skin incision begins at the anterior border of the designed skin flap. The skin flap is elevated initially in the suprafascial plane. The deep fascia is cut after passing the posterior margin of the peroneus longus tendon. This avoids damaging the superficial peroneal nerve located subfascially between the peroneus longus and extensor digitorum longus muscles. By palpating the posterior margin of the fibula, the intermuscular space (posterior crura) between the peroneus longus and soleus muscles can be located. The septocutaneous vessels in the distal third can be seen in the posterior intermuscular crural septum, between the peroneus longus and soleus muscles. A posterior skin incision is made along the posterior margin of the skin paddle. Elevating and undermining the posterior skin anteriorly should help avoid injury to the lesser saphenous vein, sural nerve, and perforators coming from the soleus muscle to the skin (Fig. 16-7).

Elevation of the Skin Flap

Once sizable septocutaneous vessels are identified in the posterior crural septum, musculocutaneous perforators can be ligated to expedite skin flap elevation. If the septocutaneous vessel within the posterior crural septum is small, musculocutaneous perforators coming through the soleus muscle must be mobilized with intramuscular dissection. The dissection of musculocutaneous perforators can be a little tedious.
but is not difficult, because there is always an enveloping fascia separating the neurovascular bundle from the muscle fibers. The intramuscular dissection of the neurovascular bundle is initially carried for only a short distance (2 cm) to allow temporary application of vascular clamps. If circulation to the skin flap remains adequate, those musculocutaneous perforators are ligated without further dissection. However, if septocutaneous vessels are absent, complete intramuscular dissection of the myocutaneous perforator becomes necessary.

**Dissection of the Muscles From the Fibula**

After dissection and evaluation of the vessels leading to the skin flap, the flap is turned back to expose the anterolateral aspect of the fibula. The peroneus longus and brevis muscles in the lateral compartment and the extensor brevis, extensor digitorum longus, and extensor hallucis muscles in the anterior compartment are divided from the fibula, leaving only minimal muscle cuffs attached to the bone. The anterior tibial neurovascular bundle is identified on the anterolateral aspect of the fibula, inspected, and protected.

**Proximal and Distal Osteotomy of the Fibula**

Both ends of the fibula are osteotomized. The maximum length of bone should be harvested, preserving the necessary bone (approximately 6 cm proximally and 6 cm distally). This maximizes pedicle length by providing adequate access for the pedicle to be traced to its origin at the tibioperoneal trunk. Excess bone can be discarded later, during flap inset, to increase pedicle length.

**Dividing the Interosseous Membrane and Ligating the Peroneal Vessel**

Once osteotomies are completed, outward traction and lateral rotation of the fibula bone with bone holders facilitate further dissection. The interosseous membrane is incised to expose the posterior tibial muscle in the posterior compartment. The distal run-off of the peroneal vessel is identified, ligated, and divided.

**Dissecting the Tibialis Posterior and the Flexor Hallucis Longus Muscles**

The tibialis posterior muscle is dissected away from the anterior surface of the peroneal vessel, which is further isolated proximally to its bifurcation with the posterior tibial vessel. All branches from the peroneal vessel in its proximal course should be ligated or cauterized. Finally, the flexor hallucis longus muscle attachment is stripped from the fibular osseoseptocutaneous flap, with particular care not to injure the septocutaneous vessels to the skin flap, because some of these vessels may have a short intramuscular course inside the muscle. At this point, the entire fibular osseoseptocutaneous flap is isolated and connected to the lower leg only by its vascular pedicle.
The tourniquet is deflated to verify adequate circulation to the entire flap. The vascular pedicle is left intact until the recipient site is well prepared to minimize ischemic time.

**Reattaching the Flexor Hallucis Longus Muscle**

The flexor hallucis longus, the largest and most powerful muscle in the posterior compartment, is completely detached from the fibula during harvest of the fibular osseoseptocutaneous flap. This muscle should be carefully reattached to the interosseous membrane and posterior tibial muscles with proper tension to preserve great toe flexion (Fig. 16-8).

![Fig. 16-8](image_url)  
**Fig. 16-8** Complete fibular osseoseptocutaneous flap elevation with the vascular pedicle intact.  
*A,* The flexor hallucis longus muscle (arrow) is dissected from the fibula.  
*B,* The flexor hallucis longus muscle (arrow) is reattached to the posterior tibial muscle and interosseous membrane to preserve the flexion function of the great toe interphalangeal joint.
Wound Closure
The donor site can be primarily closed if it is 3 cm wide or less; a skin graft closure should be performed for donor sites exceeding 3 cm. The donor leg is splinted to stabilize the ankle joint for 1 month.

Potential Morbidity of the Donor Site
The fibula is the origin and insertion of many muscles to the leg and foot; therefore detachment and/or injuries to these muscles during fibula harvest may affect the function of the donor leg. Although rare, extensive muscle necrosis or compartment syndrome can occur because of devascularization or tight closure of the wound, or both. However, overall, donor site morbidity from the harvest of the unilateral free fibular osseoseptocutaneous flap has been minimal. Most patients had few subjective symptoms. The most common problems were pain after prolonged walking (14%), slight difficulty in squatting (28%), and minimal paresthesia. The flexor hallucis longus muscle is most commonly affected by either extensive devascularization or extensive detachment from the fibula during flap harvest. Damage to this muscle can present as interphalangeal joint flexion deformity or the inability to actively flex the interphalangeal joint of the great toe. The functional deficits could often only be revealed under the most unfavorable sensory feedback conditions (Figs. 16-9 and 16-10). If bilateral fibular osseoseptocutaneous flaps are harvested, the functional deficit should be greater. However, in our experience with bilateral fibular osseoseptocutaneous flap harvests, only a few patients reported significant pain, paresthesia, walking and activity restriction, or gait alteration.

Fig. 16-9 The appearance and function of the leg donor site after harvest of the fibular osseoseptocutaneous flap, with toe flexion and extension.
CONCLUSION

The fibular donor site has many advantages. The fibula provides enough length to reconstruct segmental mandibular defects. The straight quality of the bone, together with its adequate height and thickness, constitutes ideal bone stock for precisely shaping a new mandible. Unlike the ilium, the fibula has no nuances of shape that limit the contouring process. Also unlike most other donor sites, the periosteal blood supply is segmental. Osteotomies can be planned wherever necessary and can be placed as close as 3 cm apart without concern for bone viability. The vascular pedicle has sufficient length for most situations and has a large diameter. The soleus muscle is conveniently located along the posterior border of the bone and can be incorporated to obliterate appropriately sized adjacent soft tissue defects. A large skin paddle can be harvested for more complex defects. Of all potential osseous donor sites, the fibula is the most convenient, because it is located farthest from the head and neck area. The free fibular osseoseptocutaneous flap is the flap of choice for most mandibular and many long bone defects. The inclusion of a skin paddle can serve as a sentinel monitor of bone viability, to facilitate recipient wound closure, and/or to reconstruct adjacent soft tissue defects of appropriate size and volume.
CRITICAL POINTS

Must Know
- It is essential to understand the anatomy of the leg, including the muscles and the three major neuromuscular structures.
- The blood supply to the fibula bone and skin paddle on the lateral aspect of the leg must be understood.

Should Know
- The vasculature of the leg and foot should be evaluated preoperatively.
- Surgeons should be able to design a fibular osseoseptocutaneous flap, especially the skin paddle on the lateral aspect of the leg.
- An understanding of the techniques of fibular osseoseptocutaneous flap harvest is critical.
- Proper management of the donor site is essential to minimize morbidity.
- Advantages and disadvantages of the fibular osseoseptocutaneous flap should be compared with those of other donor sites.
- Causes of potential donor site morbidity should be understood and avoided if possible, and discussed with each patient preoperatively.

Synopsis
- The harvest of the fibular osseoseptocutaneous flap is a technically demanding procedure. However, special characteristics of this flap make it ideal for mandible and long bone reconstruction.
- A thorough understanding of the anatomy of the leg and vascular supply to the fibula and skin paddle, proper preoperative evaluation of the donor leg, adequate surgical planning, meticulous execution of flap harvest, and carefully performed osteotomies, contouring, fixation, and flap inset are all critical to a successful mandible and maxilla reconstruction.

References
   This report is the first successful transfer of a composite fibular graft integrated with an appropriate soft tissue flap repair by microvascular anastomoses. A new method of free vascularized bone grafting was developed to salvage two legs, which would otherwise have been amputated.
   The fibula was first introduced as a donor site for free flap mandible reconstruction. It has the advantages of consistent shape, ample length, distant location to allow a two-team approach, and low donor site morbidity. The aesthetic result of mandible reconstruction is excellent in most patients.


   This study demonstrates the importance of thorough clinical evaluation before harvesting fibular osteoseptocutaneous flaps. Preoperative angiography of the injured lower limbs did not provide relevant additional information in this series. Routine recipient site angiography before microsurgical reconstruction, therefore, seems unjustified.


The scapular flap is one of multiple flaps that can be raised on the subscapular axis. Others include the cutaneous axillary (lateral thoracic), serratus anterior, and latis-simus dorsi/thoracodorsal artery perforator flaps. In head and neck reconstruction, it is most often transferred as a microvascular free flap, but as a pedicled flap it is still theoretically capable of reaching the posterior scalp and the lateral face. For practical purposes it is still best to think of it as a free flap. The scapular flap is based on the cutaneous branch of the CSA, a branch of the subscapular artery. The CSA passes posteriorly through the triangular space between the subscapularis and teres minor muscles above, the teres major muscle below, and the long head of the triceps...
muscle laterally. It gives off a number of muscular and osseous branches deep to the teres minor muscle, after which the cutaneous portion continues posteriorly and divides into branches supplying the cutaneous territory of the CSA on the dorsal trunk. The transverse and vertical branches supply the transverse and vertical components of the cutaneous territory, representing the scapular and parascapular flaps, respectively. The transverse branch supplies the classical scapular flap and was originally named the cutaneous scapular artery. It turns medially over the lateral border of the scapula and runs directly transversely, superficial to the deep fascia over the teres minor and infraspinatus muscles, finally breaking up into a fan of smaller vessels (Fig. 17-1).

The theoretical potential of the scapular flap, based on the circumflex scapular pedicle, was first suggested by Saijo1 in 1978. The earliest descriptions of the flap are attributed to dos Santos2 and Gilbert and Téot,3 with the first clinical case performed in 1979.4 Further reports soon followed as the usefulness of this flap was realized.5-8 The potential of another vertical branch of the cutaneous portion of the CSA was recognized with the description of the parascapular flap by Nassif et al.9 This branch proceeds along the lateral border of the scapula and beyond the scapular tip. The evolution of this flap continued with the description of the osseocutaneous scapular flap by Swartz et al10 in 1986. The free ascending scapular flap was later described11; it was based on an anatomically consistent ascending division of the cutaneous

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**Fig. 17-1** The blood supply of the scapular system.
branch of the CSA. Furthermore, the inframammary extended circumflex scapular flap was described; it was based on the consistent presence of one or more anterior divisions of the cutaneous branch of the CSA.

**INDICATIONS**

- Facial skeletal and soft tissue reconstruction, including full-thickness defects
- Facial skeletal and soft tissue contouring
- Face and neck resurfacing of burn defects
- Pharyngolaryngeal reconstruction
- Scalp reconstruction

Scapular and parascapular flaps and combinations of flaps on the subscapular axis are useful for adding soft tissue bulk and bone to the face in cases of facial contour deficiency of varying causes, such as hemifacial microsomia, oblique facial cleft, Treacher Collins syndrome, Romberg’s hemifacial atrophy, neoplasm, postradiation defects, trauma, tumor excision, facial lipodystrophy, and silicone granuloma. These flaps are also useful for full-thickness composite reconstruction of the face, including the mandible and maxilla in sandwich procedures. The thin blade of the scapula also helps provide optimal tissue quality for palate and orbital floor reconstruction and obliteration of the maxillary sinus.

Because of its thinness, consistency, and color, the scapular flap is also favored for forehead reconstruction (Fig. 17-2), facial burn reconstruction (Fig. 17-3), and the release of neck burn contractures. Reconstruction of the entire neck as an aesthetic unit has been recommended. The scapular and parascapular flaps are also considered useful for scalp coverage.

**Fig. 17-2** A. This patient had recurrent squamous cell carcinoma of the forehead with an area of osteoradionecrosis. B and C. A scapular flap was used to reconstruct the defect.
Other uses for the scapular flap include reconstruction of the bony orbit, such as after excision of a retinoblastoma, and reconstruction of complex pharyngolaryngectomy defects, including those of the cricoid cartilage.

For some authors the parascapular flap is the preferred flap for major head and neck reconstruction, because it may be used for craniofacial defects, oropharyngeal soft tissue defects, and combined mandibular and soft tissue defects including noma. The tubed parascapular flap has also been used in total esophageal reconstruction.
ADVANTAGES
The scapular flap has many advantages. It is thin\textsuperscript{3,8} and relatively hairless.\textsuperscript{5,62} It has a constant and easily dissected pedicle with good length and vessel caliber. Primary closure of the donor site with flap widths of 12 cm\textsuperscript{63} has been described (15 cm for a parascapular flap\textsuperscript{64}).

One of the greatest advantage of this flap is the ability to harvest composite tissues in combination with other flaps.\textsuperscript{10,65} The independent vascular pedicles of the cutaneous and osseous portions of the flap make it the preferred method of reconstructing mandibular defects for some authors.\textsuperscript{33} These independent pedicles also allow freedom of orientation of the various tissue components thereby improving three-dimensional spatial relationships in complex composite defects in the head and neck.\textsuperscript{10,66} The various Y-shaped configurations around the subscapular arterial system also allow easy use of the scapular flap as a flow-through flap\textsuperscript{67} (Fig. 17-4). The lateral scapular osseous component of the flap can be fixed with plates and screws and has sufficient thickness for the placement of dental implants.\textsuperscript{68,69}

Fig. 17-4 A composite flap can be designed to incorporate scapular tip and a segment of latissimus dorsi muscle, as well as either scapular or parascapular skin paddles.
**DISADVANTAGES**

The main disadvantage of the scapular flap is the necessity of repositioning patients intraoperatively for the flap harvest and inset.\(^4^0\) However, supine harvesting has been reported,\(^7^0\) as well as a pull-through technique to reduce the number of intraoperative patient position changes.\(^7^1,7^2\) Although donor site morbidity is low, rotator cuff muscle weakness is a potential problem and may confound shoulder dysfunction with an ipsilateral radical neck dissection.\(^6^2\) Other cited disadvantages include the loss of sensation in the flap\(^7^3\) and scar stretch. Other reported complications include atelectasis and pneumonia after harvesting a vascularized scapular flap\(^7^4\) and brachial plexopathy caused by arm abduction during a parascapular flap harvest.\(^7^5\)

**ANATOMY**

The subscapular artery has two divisions: the CSA and the thoracodorsal artery; however, the CSA occasionally arises directly from the axillary artery.\(^6,6^7\) The CSA passes posteriorly through the triangular space between subscapularis, teres major, and the long head of the triceps, giving off muscular (subscapularis, supraspinatus, infraspinatus, teres major, and teres minor) and osseous branches deep to the teres minor muscle. It continues posteriorly between the teres minor muscle above and the teres major muscle below and trifurcates into transverse, descending, and ascending\(^1^1,1^2\) cutaneous branches, which run on the dorsal thoracic fascia. The pedicle length of flaps harvested on the CSA depends on how proximal the dissection is continued. The mean distance from the flap to the origin of the cutaneous portion of the CSA was 4.3 cm in one anatomic study.\(^6\) If the flap is extended to include the subscapular artery, the pedicle length is approximately 14 cm. In addition, all flaps based on the branches of the subscapular artery could be raised. These include the cutaneous axillary (lateral thoracic), serratus anterior, and latissimus dorsi flaps. The cutaneous axillary flap is supplied by the cutaneous branch of the thoracodorsal artery, the serratus anterior flap is supplied by the serratus branch of the thoracodorsal artery, and the latissimus dorsi flap is supplied by the thoracodorsal artery. The only structure separating the scapular flap from the rest of the pedicle is the teres major muscle, which must be detached if multiple flaps have to be harvested on the subscapular pedicle. Such a multiple-territory free tissue transfer has been used clinically for coverage of an extensive scalp defect.\(^6^5\)

The tip of the scapula is supplied by the angular branch of the thoracodorsal artery. This branch of the thoracodorsal artery arises just proximal or just distal to the serratus branch of the thoracodorsal artery (see Fig. 17-1). It arborizes to the periosseum 6 to 9 cm from the bony branch of the CSA. The addition of this vascular pedicle to scapular bone allows the formation two separate bone flaps\(^6^8,7^6\) with one microanastomosis and provides a longer arc of rotation between skin supplied by the CSA and bone.\(^7^6\) The mean length of the angular branch and the thoracodorsal artery together was 14.8 cm in one study.\(^7^7\) After adding the subscapular artery, the overall length averaged 16.7 cm.
If the pedicle is dissected further, along the axillary prolongation, the thoracodorsal artery can be seen under the retracted teres major, latissimus dorsi, and serratus anterior muscles. At this point, care should be taken not to damage the nerves to the teres major, latissimus dorsi, and serratus anterior muscles.  

**Key Points**

- The CSA usually arises from the subscapular artery but can arise directly from the axillary artery.
- The scapular flap pedicle has two venae comitantes or one vein.
- The CSA gives off its cutaneous branch as it passes through the triangular space bordered superiorly by the subscapularis and teres minor muscles, inferiorly by the teres major muscle, and laterally by the long head of the triceps muscle.
- The surface mark for the triangular space is the third point of an equilateral triangle (at the lateral scapular border); the other two points are formed by the most prominent part of the scapular spine laterally and the root of the scapular spine medially.
- The skin paddle is innervated segmentally by the posterior primary rami medially and by the lateral cutaneous branches of the intercostal nerves laterally.

**Preoperative Management and Operative Technique**

**Design and Flap Harvest**

**Technical Tips for Flap Harvest**

- The triangular space is identified on the lateral border of the scapula as the third point of an equilateral triangle, with the other two points formed by the most prominent part of the scapular spine and the root of the scapular spine.
- Doppler imaging of the triangular space helps confirm pedicle position.
- Dissection proceeds from medial to lateral.
- An axillary incision facilitates the proximal pedicle dissection if required.
- The contralateral scapula is used for mandible reconstruction.
- The use of a craniotome with a protective footplate makes bone harvesting easier and safer.
The flap can be harvested with the patient in the prone or lateral decubitus position, with the arm abducted. Harvesting of vascularized scapula with the patient supine has also been reported. The origin of the circumflex scapular pedicle through the triangular space at the lateral border of the scapula can be reliably marked, with a patient’s arm in abduction or adduction, as the third point of an equilateral triangle that is also formed by the most prominent part of the scapular spine laterally and the root of the scapular spine.

The scapular flap is centered on the surface markings of the scapula, inferior to the spine (Fig. 17-5). It can be extended medially to the midline and laterally for a few centimeters into the axilla. Flap dimensions of 24 by 12 cm have been reported. The parascapular flap is centered along the lateral border of the scapula.

The flap dissection may be easier and expedited by palpating the triangular space, with deep dissection and delivery of the proximal flap pedicle through a counterincision in the axilla. Harvesting the flap with an axillary extension also facilitates dissection of the pedicle in a similar fashion.

It is standard practice to use the contralateral scapula for mandible reconstruction, because this places the vascular pedicle at the posterior aspect of the defect to allow optimal pedicle orientation.

Harvesting scapular bone can be made safer by using a craniotome with a protective footplate to protect the pedicle, subscapularis muscle, and underlying chest wall. It is also possible to harvest the scapula with an oscillating or reciprocating saw.
Coleman and Sultan describe harvesting the bipedicled osseocutaneous flap. After identifying the CSA in the triangular space, the plane between the latissimus dorsi and the teres major muscles is opened to expose the angular branch. With the CSA and the angular branch protected, the origin of the teres major muscle is detached from the scapula, and the muscle is retracted laterally to expose the lateral border of the scapula and thoracodorsal artery. The thoracodorsal and circumflex scapular vessels are dissected retrograde to the subscapular vessels to ensure that there is a common origin; they are also followed anterograde to the scapular border. The insertions of the serratus anterior and subscapularis muscles are detached from the tip and undersurface of the scapula, respectively, mobilizing the entire lateral border of the scapula. More commonly the lateral border is harvested as a unipedicled bone flap incorporating the overlying skin paddle (Fig. 17-6). The osseous branch from the CSA to the lateral border is usually very short and comes off the CSA just lateral to the bone, running directly into it. Here there may also be several veins, and this part of the dissection can be difficult. One of the advantages of this flap is that the osseous branch is given off several centimeters before the CSA ultimately supplies the skin. This allows independent movement between the bony segment and the skin paddle and can be very advantageous, depending on the reconstruction performed. One disadvantage of the osseocutaneous scapular flap is that the remaining pedicle (that is, the pedicle proximal to the osseous branch run-off) is relatively short.

![Image](image_url)

**Fig. 17-6** This harvested flap shows the skin paddle, bone, and pedicle.

### Pitfalls

- The CSA can be a direct branch off the axillary artery.
- Nerves to the teres major, latissimus dorsi, and serratus anterior muscles can be damaged during proximal dissection of the pedicle.
Donor Site Management

Technical Tips for Donor Site Closure

- When harvesting scapular bone, the serratus and teres muscles are reinserted through drill holes in the remaining part of the bone.

When harvesting the lateral part of the scapula, shoulder stability must be ensured and functional deficits of a winged scapula minimized. These are achieved by preserving the tip of the inferior angle or, if detached, reinserting the serratus and teres muscles through the drill holes in the remaining scapula. However, depending on the length of bone harvested, the serratus and teres muscles do not always need to be detached. For purposes of hemostasis, it is important to suture the infraspinatus muscle to the subscapularis muscle along the lateral border of the scapula. Doing so covers the osteotomized bone.

When used in a pediatric population, the scapular donor site showed no functional deficit or growth disturbance in one study. This has also been our experience with adult patients.

Pitfall

- Adequate hemostasis must be ensured, particularly from bone. Bone wax is used if necessary.

Modifications

The lateral border of the scapula provides up to 14 cm of thick, straight corticocancellous bone that can be osteotomized where needed. This is sufficient for reconstructing a complete hemimandible or an angle-to-angle defect. The osseous component of the flap can be fixed with plates and screws and has sufficient thickness for the placement of dental implants. Up to 16 cm can be harvested when the V-shaped portion of the scapula is used. This osseous unit is designed along the lateral border, inferior angle, and medial border. The inferior angle of the scapula is said to provide good reconstruction of the mental protuberance. The medial border of the scapula, however, is unlikely to be of sufficient thickness to allow placement of osseointegrated dental implants.
The bicipital flap has been described, in which two contiguous transverse scapular flaps are harvested as a bipedicled free flap with a maximum potential size of 50 by 10 cm, allowing primary closure of the donor site. The extended free scapular flap has been described to be reliable when extended across the midline of the back, despite publication to the contrary. The flap can also be extended laterally into the axilla as far as the anterior axillary line, increasing the length of the flap by 30%. This can also be done bilaterally if a bicipital flap is harvested.

Several authors have described tissue expansion of this flap. Horseshoe-shaped expansion is recommended, because it improves venous drainage of this flap when it is expanded. The bipedicled scapular-parascapular flap provides a large surface area for possible composite facial-scalp defects, and when preexpanded and it can provide sufficient tissue for total face and nose reconstruction.

The free medial scapular osseofasciocutaneous flap has also been described. The overlying fasciocutaneous part of the flap provides vascularity to the bone. Its main advantage is effective lengthening of the vascular pedicle to the bone by at least 6 cm. However, as mentioned previously, this bone may not be suitable for osseointegrated implants. The ascending scapular flap has been described; it is based on an anatomically consistent ascending branch of the CSA.

The inframammary extended circumflex scapular flap is a modification designed to improve the scar that results from flaps based on the circumflex scapular vessels. The CSA consistently gives off one or more cutaneous branches, which course across the anterior chest.

The scapular-parascapular flaps can be harvested with customized extensions of dorsal thoracic fascia. When used to correct facial contour deformities, these can be folded into variable thicknesses to provide subtleness to the contour correction. The CSA perforator flap has been described. The perforator for this flap arises from the CSA or its descending branch within 1.5 cm of its point of branching.

**CONCLUSION**

The superiority of the scapular flap in head and neck reconstruction comes from the potential to harvest a composite of tissues with independent skin paddles of optimal thickness, in addition to adequate bone stock. It can be conjoined with several adjacent flaps on the subscapular axis and modified in multiple ways to allow tailoring for a diverse array of reconstructive needs. The scapular flap maintains an important role in the reconstruction of many anatomic sites.
CRITICAL POINTS

**Must Know**
- The contralateral scapula should be used to reconstruct the mandible.
- The bone harvest can be up to 14 cm, while preserving bony branches of the CSA.

**Should Know**
- Patients usually need one or more position changes intraoperatively.
- The teres and serratus muscles are reinserted in the remaining scapula following the bone harvest.

**Synopsis**
- The scapular flap in head and neck reconstruction has great potential for harvesting adequate bone stock and a composite of tissues with independent skin paddles of desired thicknesses.
- Besides versatility in reconstructive needs, the scapular flap can also be conjoined with several adjacent flaps on the subscapular axis.

**References**


   The author describes the scapular flap based on the posterior cutaneous branch of the inferior scapular artery. This flap has been successfully used in four clinical cases and is very useful in the treatment of small defects of the ankle or lower leg.


The vascular anatomy of the cutaneous branches of the CSA and their communications with perforators supplying adjacent territories are described, based on dissections of 20 scapular regions.


In thirty-six adult dissections (14 cadaver and 22 operative), the angular branch of the thoracodorsal artery is consistently present as a vascular pedicle to the inferior pole of the scapula. The addition of this vascular pedicle to scapular bone allows two separate bone flaps with one microanastomosis and provides a longer arc of rotation between the skin supplied by the CSA and the bone. Donor site morbidity was no greater than with a standard scapular flap.


The scapular flap network is unsurpassed in versatility in its application to patients with head and neck reconstructive problems. Every microsurgeon with the usual complicated head and neck reconstructive problems in their patients would benefit from familiarity with this important donor site, with its long history of safe application in microvascular surgery.


This is the first report evaluating the donor site morbidity of parascapular flaps. Limitations in shoulder function are low if the correct operative technique with refixation of the musculature is maintained.
The latissimus dorsi is the largest muscle in the body and has long been used in all regions for closure of large defects, whether as a muscle flap or as a myocutaneous flap. Its use in the head and neck has been well documented. It was originally described as a pedicled flap, and as such it can comfortably reach the head and neck region on its pedicle, and the arc of rotation can be significantly increased if the humeral insertion is divided and the flap is brought up anteriorly. However, more recently, it is more commonly used as a free flap in the head and neck. Because of its size, it is an ideal flap for reconstruction of large scalp defects. The choice of whether a skin paddle is included depends on the defect to be reconstructed and the bulk required. Even though it is an older flap, it still plays a major role in my practice, with scalp reconstruction being its most common indication.
ANATOMY

- Type V muscle
- Subscapular system → thoracodorsal artery
- Long thoracic nerve

The latissimus dorsi is a large, fan-shaped muscle in the back. The latissimus dorsi is very expendable; although it is a very powerful muscle, its main function is extension and adduction of the shoulder, two actions that are also achieved by other muscles. The presence of an intact and functioning latissimus muscle is of vital importance for only a small number of activities. According to the classification of blood supply by Mathes and Nahai, it is a type V muscle with a single dominant pedicle (the thoracodorsal artery) and multiple segmental lumbar pedicles. The thoracodorsal pedicle is invariably used for head and neck reconstruction. The thoracodorsal artery is part of the subscapular system. The subscapular artery arises from the axillary artery. It gives off a circumflex scapular artery (the basis of the scapular system flaps, scapular and parascapular) and continues as the thoracodorsal artery. A branch to the serratus anterior is given off at a variable distance before the thoracodorsal artery itself enters the deep surface of the latissimus muscle (Fig. 18-1). The long thoracic nerve (the nerve to the latissimus dorsi) runs with the pedicle. When transferring the flap as a pedicled flap, it is important to divide the nerve to avoid unwanted muscle contractions.

![Fig. 18-1](image_url) The subscapular system of vessels.
**Preoperative Management**

No specific preoperative steps apply when using the latissimus dorsi muscle other than standard preoperative preparation. The vascular pedicle is reliable and predictable. If this flap is being used for scalp reconstruction, it is important to counsel the patient on the initial postoperative appearance. The flap will look bulky and the skin graft will be the wrong color, but ultimately the muscle atrophies to a thickness very similar to that of the scalp, and the skin graft fades to an acceptable color.

**Surgical Technique**

- The skin paddle is placed more proximally to capture the optimal perforators.
- It is important to stay above the serratus.
- All branches of the subscapular system are identified before dividing them.
- Meticulous hemostasis is required to minimize the risk of seroma.

Harvest of the muscle requires that the patient be in the lateral decubitus or prone position (Fig. 18-2). I find it easiest to free drape the arm so that it is easy to move during dissection. The arm can rest on a Mayo stand, allowing its height and position to be adjusted.

Fig. 18-2  Patient positioning. It is easiest to free drape the arm with a patient in the lateral decubitus position. The arm can rest on a Mayo stand, allowing easy manipulation during dissection.
The muscle is approached through an oblique incision in the back. If a skin paddle is being harvested with the flap, the skin paddle placement needs to be determined at this point. Ideally, the paddle should be placed more proximally on the muscle, where there is a greater density of muscular perforators supplying the overlying skin (Fig. 18-3). The skin paddle is incised and islanded. The skin flaps are elevated off the muscle so that the shape, size, and configuration of the muscle can be appreciated. There are many variations to the approach, depending on the indication and the concern about donor scarring. In most head and neck patients, the scarring is less of an issue than it might be in, for example, postmastectomy breast reconstruction patients.

The surface of the muscle is exposed, and the muscle is elevated. The anterior border of the muscle is identified, and access to the submuscular plane is gained by elevating the anterior border. The amount of muscle needed for the reconstruction is determined, the muscle is divided distally, and dissection proceeds from distal to proximal. Care must be taken to avoid elevating the serratus anterior muscle as the dissection proceeds from caudad to cephalad. It is very easy to dissect into the area under the serratus. Being cognizant of this and vigilant to identify the inferior border of the serratus usually helps avoid this problem (Fig. 18-4). As the dissection proceeds, the anatomy of the pedicle can be appreciated. The pedicle is typically on the undersurface of the muscle and buried in fat, which can be dissected to reveal the pedicle. This is an important step in identifying the anatomy of the vascular pedicle. The branch to the serratus is divided first to ensure that the continuation of the pedicle running up toward the axilla can be appreciated.
Once the pedicle anatomy is fully exposed, the proximal insertion of the muscle into the humerus can be divided. This makes it much easier to complete the pedicle dissection. The extent of dissection depends on the length required and the caliber of the vessels. Once adequate length and caliber have been attained, the pedicle is divided and the flap transferred. For the latissimus to reach the head and neck as a pedicled flap, the flap generally needs to be brought out through the anterior axilla and pedicled up under the upper chest skin, over the clavicle, and into the neck (Fig. 18-5).
There is some controversy about how to best deal with the donor defect. Obviously, the defect can be closed with relative ease even when a large skin paddle is harvested with the flap. The issue, however, is that these patients almost always develop seromas. I always warn patients that they will develop one. Various techniques have been suggested to reduce this risk.7-9 These have included the use of quilting sutures, Tisseele, and various other maneuvers. I have tried and abandoned all of these techniques, and I simply close the wound over one or two suction drains.

APPLICATIONS

The latissimus dorsi was, at one time, a workhorse in head and neck reconstruction. Although it still has a place in this area, it has been superseded by other flaps for many applications. Because of its size, it is ideal for covering large areas. In my practice, the most common application for the latissimus dorsi in the head and neck is for reconstruction of the scalp. Following are several advantages for using it in this location:

1. It is flat and broad.
2. It has a reasonably long vascular pedicle and can easily reach the superficial temporal vessels.
3. Predictable muscle atrophy obviates the need for revision debulking.
4. When the muscle atrophies, it is very thin and easily mimics the native scalp.
5. When covered with a nonmeshed skin graft, the aesthetic appearance is very satisfactory.
For scalp reconstruction, the muscle is best transferred as a muscle flap. Using a skin paddle tends to produce a flap that is too bulky, whereas covering the muscle with a nonmeshed split-thickness skin graft gives an excellent cosmetic result (Fig. 18-6). The patient must be warned that the initial appearance will be ugly. The flap will appear too bulky and the purplish color of the skin graft will look terrible (see Fig. 18-6, C). However, with some patience, the graft color fades and the bulk of the muscle atrophies, yielding a very acceptable cosmetic appearance. Of course, the flap is non–hair-bearing. For most men, this is not an issue. For women, a wig fits comfortably over the latissimus reconstruction (see Fig. 18-6, E).

Fig. 18-6  A, This patient had dermatofibrosarcoma of the scalp. B, The excision extended from the occiput to the nasion and from ear to ear. Reconstruction involved bilateral latissimus flaps and a nonmeshed split-thickness skin graft. C, The patient is shown 3 weeks postoperatively. The flaps are bulky and the graft is purple. D and E, She is shown 1 year postoperatively, without and with a wig. No revisions were performed.
The latissimus muscle has also been used in facial reanimation surgery. Its attraction in this setting is the feasibility for one-stage reconstruction, as proposed by Harii et al\textsuperscript{10} and Watanabe et al.\textsuperscript{11} The long thoracic nerve lives up to its name in being long enough to reach the contralateral facial nerve, thus avoiding the need for cross-facial nerve grafting.

Also, the versatility of the flap can be enhanced by separating its components, depending on the indication and the defect to be reconstructed. The thoracodorsal perforator flap is supplied by the first dorsal perforator coming from the thoracodorsal system. This allows the skin to be harvested as a cutaneous flap only. Alternatively, the skin paddle and muscle can be separated to produce a flap with different components that can be used to reconstruct different elements of the defect (see Fig. 18-5). The thoracodorsal perforator has a reasonably predictable location\textsuperscript{12} that allows harvest.

**COMPLICATIONS**

When the latissimus dorsi is being used as a free flap, the standard risks of free tissue transfer apply. There is a low but undeniable risk of flap failure; however, these risks apply to any free tissue transfer and are not unique to the latissimus. Various modifications have been proposed to minimize donor morbidity. I have already alluded to the various techniques proposed to minimize donor site seroma. Selective muscle harvest has also been proposed as a means to minimize donor morbidity.\textsuperscript{13}

**CONCLUSION**

The latissimus dorsi muscle is a very useful part of our armamentarium as a pedicled flap that can reach as far as the face, though the indications for this application are limited. As a free flap, it can cover large areas and is particularly useful for scalp reconstruction. The donor deficit is very acceptable. Although the incidence of seroma formation in the donor site is high, it remains a useful flap.
CRITICAL POINTS

Must Know
• The arterial supply is through the thoracodorsal artery.
• The skin paddle is most reliable when harvested proximally.
• The skin paddle may be independently dissected using the thoracodorsal artery perforator.

Should Know
• The musculocutaneous flap may be bulky.
• The scar may stretch with musculocutaneous harvest.
• A donor site seroma is extremely common.

Synopsis
• The latissimus dorsi is a large muscle that is ideal for constructing large areas. It has a long pedicle with a large caliber.
• The donor site has minimal long-term morbidity.
• The skin and muscle components have versatile harvesting options.

References

Latissimus dorsi flap breast reconstruction is associated with a high incidence of donor site seromas, despite the use of surgical drains. The aim of this study was to evaluate the use of donor site quilting sutures and drains on the incidence, volume, and frequency of seroma aspiration. Quilting significantly reduced overall seroma volumes after latissimus dorsi breast reconstruction, including extended latissimus dorsi, and is recommended in combination with surgical drains.


The anatomic topography of the perforators that pierce the latissimus dorsi muscle fascia determines the location and direction of the skin paddle and thus the ultimate design of the thoracodorsal artery perforator flap. The full scope of the thoracodorsal artery perforator topography has not been provided in detail, and the usefulness of perforators from the transverse branch has not been described. The topographic results could be used as a reference in perforator localization for safe and efficient harvesting of the thoracodorsal artery perforator flap.

HIGHLIGHTS

- The gracilis muscle flap is a useful reconstructive tool for closing small to moderate-sized defects.
- The flap can also be used as a functioning muscle unit.
- The flap’s anatomy is constant and predictable.
- Donor site morbidity is minimal.
- The flap has a wide range of applications in the head and neck, including defect coverage, lower lip reconstruction, and functioning transfers for facial reanimation and tongue reconstruction.

The gracilis muscle is the smallest of the adductor muscle group. It is versatile and has long been used for reconstructing small to moderate defects all over the body. It has also recently found a new role in postmastectomy breast reconstruction using a transverse skin paddle known as the transverse upper gracilis (TUG) or the transverse myocutaneous gracilis (TMG) flap. It has some unique applications in the head and neck.

ANATOMY

General
The gracilis is a long, thin muscle on the medial aspect of the thigh (Fig. 19-1). Its origin is the medial margin of the body and the inferior ramus of the pubis. It is the most superficial of the adductor muscles and runs vertically downward to insert into the medial margin of the tibial tuberosity, beneath the sartorius tendon. It is thin
and flat, broad proximally, but narrowed and tapered distally. It is 4 to 7 cm wide, 27 to 33 cm long, 2 to 3 cm thick, and the length of its tendon is about 10 cm. The gracilis muscle serves as an accessory adductor of the thigh, a flexor, and an internal rotator of the hip (Box 19-1).

**Fig. 19-1** The anatomy of the gracilis muscle flap. The gracilis muscle is the most superficial of the adductor muscles, lying mediodorsal to the adductor longus muscle.

**Box 19-1 Important Anatomic Relationships**

- The gracilis muscle is the most medial and superficial muscle of the adductor muscle group.
- The proximal two thirds of the gracilis muscle are directly beneath the deep fascia.
- In the distal third, the sartorius muscle is interposed between the gracilis muscle and deep fascia.
- The gracilis tendon lies posterior to the sartorius tendon and anterior to the semitendinosus muscle.
Blood Supply
Classification
According to the classification of vascular anatomy proposed by Mathes and Nahai,\textsuperscript{1} the gracilis is a type II muscle flap. It has one or more large (major) vascular pedicles entering in close proximity to the muscle origin or insertion and small (minor) vascular pedicles entering the muscle belly distally (Fig. 19-2). The gracilis muscle has one proximal dominant and one or two distal minor pedicles.

The dominant nutrient vessels usually arise from the profunda femoris (deep femoral) vessels. However, they occasionally arise from the medial circumflex femoral vessels. This ascending branch passes between the adductor longus anteriorly and adductor magnus posteriorly, giving off branches to these muscles. The pedicle enters the gracilis muscle usually 10 ± 2 cm from its origin.
and about 1 to 2 cm from the upper muscle edge. The arterial pedicle immediately branches into four or five major branches, which pass longitudinally in the muscle, parallel to the muscle fibers.

The arterial pedicle is 1 to 2 mm in diameter and 7 to 12 cm long. The two veins that commonly run with the principal artery have a mean diameter of 1.4 mm. The proximal portion of the muscle near its origin is usually supplied by a small branch of the medial circumflex femoral artery. In addition, the distal portion of the muscle is supplied by one to three small arterial branches of the superficial femoral artery. These branches vary in location and size.

The gracilis muscle has at least one and, on average, four perforator vessels from the main pedicle. Most are musculocutaneous perforators, but occasionally septocutaneous perforator vessels run along the anterior aspect of the muscle toward the skin. These originate from the main pedicle just before it enters the muscle. These perforators are generally found within a 6 cm segment of the muscle, centered on the entrance point of the main pedicle. The skin supplied by these perforators generally overlies the proximal half of the muscle. The more distal skin segment is mainly supplied by the minor vascular pedicles coming from the superficial femoral artery and is not reliable. Therefore the skin island of the flap is located at the proximal muscle portion and can be oriented either longitudinally or transversely relative to the axis of the gracilis muscle.

**Innervation**

The gracilis muscle is innervated by the obturator nerve (see Fig. 19-2). This nerve descends through the obturator foramen and divides into an anterior and posterior branch under the pectineus muscle. The anterior branch has a mean diameter of 2.7 mm and runs distally between the adductor longus and adductor magnus muscles. It provides motor branches to these muscles before dividing into a motor branch and sensory branch in the vicinity of the main vascular pedicle. The motor branch enters the muscle 1 to 2.5 cm proximal to the vascular pedicle in the proximal third of the gracilis muscle. The vascular pedicle enters the muscle at a right angle, whereas the nerve enters at a 45-degree angle. This anatomic relationship is constant and is a very useful anatomic landmark for identifying the gracilis muscle, especially in obese patients. The motor branch splits within the muscle and runs longitudinally in two or three major branches parallel to the arterial branches and muscle fibers. The sensory branch, however, runs distally and passes across the middle third of the gracilis muscle to innervate the skin at the medial side of the thigh.

**Surgical Options**

The gracilis flap can be transferred alone as a muscle flap or with skin as a musculocutaneous flap. With the associated subcutaneous fat it can provide moderate bulk. It can also be harvested as a functional muscle flap by preserving the motor nerve.
**Muscle Design**

Depending on the requirements of the recipient site, the muscle can be completely or partially harvested. Based on the major vascular pedicle alone, the entire gracilis muscle can safely be transferred if the minor distal pedicles are very small and inadequate. However, if these minor pedicles are substantial, the vascularity of the distal muscular portion may be questionable after the minor pedicles are ligated. This should be assessed intraoperatively and, if the distal vascularity is questionable, the distal third of the muscle should be discarded. The proximal two thirds of the gracilis muscle are always reliable. In clinical practice, it is rarely necessary to harvest the entire muscle, except in cases of functional extremity reconstruction.

One characteristic of this muscle flap is the longitudinal pattern of the neurovascular supply. Because of this anatomic feature, the width of the muscle can be increased approximately 2.5-fold by performing intramuscular dissection and splitting the epimysium and perimysium longitudinally. This makes it an excellent choice when a thin flap is required for covering areas such as the scalp or frontal area in head and neck surgery.6

**Skin Island Design**

The dimensions of the skin island must be determined by each patient’s reconstructive requirements but should enable direct closure of the donor defect (Fig. 19-3). The maximum dimension that can be harvested depends mainly on the laxity of the skin.

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Fig. 19-3  The skin island design of the gracilis muscle flap. The skin island of the myocutaneous gracilis flap is centered over the point where the main pedicle enters the muscle and can be planned either transverse or longitudinal to the axis of the gracilis.
The musculocutaneous and septocutaneous perforators of the main vascular pedicle supply the proximal and middle third of the skin overlying the gracilis muscle. The skin over the distal third of the muscle does not receive sufficient blood supply from the main pedicle but is supplied by perforators from the distal minor pedicles coming from the superficial femoral artery. Furthermore, the perforators of the main pedicle have a pronounced tendency to branch transversely. This enables a transverse, elliptical design of the skin island in the proximal part of the thigh.

The axis of the skin island is centered over the point where the main vascular pedicle enters the muscle and can run either longitudinally or transversely relative to the axis of the gracilis. The axis of the muscle is marked with the patient in a supine position and the thigh abducted. A line is drawn between the posterior border of the proximal tendon of the adductor longus muscle and the tendons at the medial margin of the tibial tuberosity.

The mean dimension of the transverse skin island that can be reliably harvested is about 15 by 8 cm. Depending on the number of perforators, larger skin islands up to 30 by 10 cm can be also transferred. However, the elliptical dimension should always allow for tension-free primary closure of the donor site.

The key to safely elevating a longitudinally designed skin island musculocutaneous flap is to accurately outline the skin island directly over the upper two thirds of the muscle. Longitudinal skin island dimensions of up to 15 by 8 cm can be harvested.5,7,8

**Additional Options**

Motor and sensory innervation of the flap is preserved to achieve a functional flap by including the anterior branch of the obturator nerve. The sensation of the musculocutaneous flap is not always good, but reasonable pressure and touch sensibility are generally obtainable. By performing neurovascular repair, functional free-muscle transplantation can restore function in regions where muscles or their nerve supplies have been damaged. In 1976, Harii et al3 reported the first clinical functioning free gracilis muscle transfer to restore facial expression. The work in this field has led to exciting advancements regarding the capability of functioning muscles to restore facial expression, functional deficits of the extremities, and the detrusor function of the urinary bladder. In clinical practice, the gracilis muscle is the most popular choice for functioning transfer because of its anatomic configuration as a strap muscle, providing a great range of movement. The long muscle fibers, general muscle shape, and reliable blood and nerve supply make the gracilis muscle the first choice for facial reanimation and functioning extremity reconstruction (see Chapter 27).

A particular characteristic of this muscle flap is the longitudinally orientated pattern of its neurovascular supply. This makes it an excellent choice for longitudinal subdi-
vision of the muscle. These subunits can be used as functioning subunits or as separate segments to cover multiple or complex defects.4

Depending on the recipient site requirements, additional fat can be included as vascularized tissue. The longitudinal skin island can therefore be combined with transversely harvested fat tissue. The musculocutaneous gracilis free flap with increased volume can be ideally used as a filling flap for three-dimensional defect reconstruction.

**INDICATIONS AND CONTRAINDICATIONS**

**Indications**

Because the gracilis flap is versatile and can be harvested as a pure muscle, musculocutaneous, nonfunctional, or functional flap, it can be used for several indications in head and neck reconstruction.

**Defect Coverage**

The muscle or musculocutaneous gracilis flap can be very appropriate for covering various defects in the head and neck region, because they do not require a long vascular pedicle (Figs. 19-4 through 19-6). These defects may result from tumor resection, congenital anomalies, vascular malformation, trauma, or deep burn injuries.

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**Fig. 19-4**  
A, This 58-year-old woman developed a wound-healing problem with local infection and exposure of bone cement, skin necrosis, and cerebrospinal fluid leakage after undergoing meningioma extirpation.  
B, The 5-day postoperative result after radical resection of the necrotic tissue, complete removal of the bone cement, closure of the dural leak, and final reconstruction with a free gracilis muscle flap.  
C, The 1-year postoperative result.
Fig. 16-5  This 61-year-old woman had a solitary metastasis of a breast carcinoma in a scar on the forehead that was caused by trauma about 4 years previously. The tumor cells infiltrated the frontal bone. A, Postoperative view after the frontal bone was resected and the defect was reconstructed with Palacos by neurosurgeons. B, The soft tissue of the forehead was radically resected because of the metastasis according to the aesthetic unit of the forehead. The harvested gracilis muscle flap is shown placed into the defect, and there is a marked discrepancy between the regular muscle width and the defect that must be reconstructed. C, After expansion of the muscle flap through intramuscular dissection, the flap met the requirements for defect coverage. The flap was subsequently covered with a split-thickness skin graft. D, At the 6-week follow-up, the patient has an aesthetic contour reconstruction of the forehead unit.
Chapter 19  Gracilis Muscle Flap

The volume and the size of the gracilis flap can be adapted to the requirements of the recipient site. This flap is ideal for small or moderate-sized defects. Because the pedicle is relatively short, the ideal defect location is close to the temporal, facial, or thyroid vessels, which can be used as recipient vessels. For the forehead and scalp region a more planar than volumetric reconstruction is required. We have already described the technique of intramuscular dissection that allows splitting of the epimysium and perimysium. This procedure significantly increases the size of the flap and tends to flatten the muscle belly to facilitate an excellent contour reconstruction (see Fig. 19-5). The thickness of the flap is the most important consideration in determining the aesthetic result. The combination of a pure gracilis muscle flap with a skin graft is generally thin enough to obviate the need for secondary procedures. Where bulk is required, however, a musculocutaneous gracilis free flap is preferable.

Fig. 19-6  A, This 57-year-old man had radiation-induced skin damage on his neck after extirpation of a soft tissue sarcoma and radiation therapy. B, The harvested musculocutaneous gracilis flap with a transverse skin island. C and D, The 6-month postoperative result after radical resection of the radiation-damaged tissue and reconstruction.
Functional Gracilis Flap

Facial movement is achieved by the synchronous interaction of many muscles. Furthermore, facial movement is a vital component of verbal and, more important, nonverbal communication. One of the major advantages of the gracilis muscle is that the nerve supply can be preserved and easily transferred. This makes it an attractive option for functional muscle transfer to restore the missing muscle function of the face, at least in part, and it offers different options for dynamic reconstruction.

The functioning free gracilis muscle transfer provides efficient dynamic facial reanimation and therefore deserves a permanent place in the spectrum of procedures to treat the irreversibly paralyzed face.3,9,10

Reconstruction of the Lips

The lips are a highly visible feature of the face and serve important and diverse functions (Figs. 19-7 and 19-8). Therefore reconstructed lips should be sensate to retain sphincter function, oppose vermilion to vermilion in a watertight seal, allow sufficient opening for food and dentures, and to provide an acceptable aesthetic appearance. Lower lip reconstruction is more significant, because oral competence depends greatly on the lower lip having good muscular function and adequate height and sensation. The classic guidelines of lip reconstruction include repair with like tissue and the concept of subunits. A combination of local, regional, and/or free flaps is suitable for lip reconstruction, depending on the defect. According to the reconstructive requirements of the lower lip, local flaps seem to be the best option in elderly patients with limited-sized, full-thickness defects. However, extensive local flaps may be unsuitable when a subtotal or total lower lip resection is performed. This is true especially in larger defects extending to the chin area and in younger patients who do not have enough tissue laxity and may be discouraged by multiple perioral scars.

Fig. 19-7  A, This 43-year-old woman had a congenital vascular malformation of the lower lip and left cheek.
Fig. 19-7, cont'd  B, The intraoperative view after radical resection of the vascular malformation. C, The free gracilis muscle flap (17 by 7 cm) was inset with resting tension for a functioning reconstruction of the lower lip. The motor nerve of the gracilis muscle was coapted to the marginal branch of the left facial nerve. D, The 1-year postoperative result. A superiorly pedicled facial artery musculomucosal flap was raised from both sides for vermilion reconstruction. E, Mouth opening. F, A strong symmetric voluntary contraction of the lower lip is evident as the patient “blows out” her cheeks.
Fig. 19-8  A, An intraoperative view after radical resection of a sclerosing basosquamous cancer of the lower lip. The resection involved the entire lower lip and chin area, sparing only the right commissure. B, The inset of the free gracilis muscle flap (9 by 6 cm) with a resting tension for functional reconstruction of the lower lip. The motor nerve of the gracilis muscle was coapted to the marginal branch of the left facial nerve. Additionally, the mental nerve was divided at the end and inserted into the gracilis muscle to achieve neurotization. C, The resting position of the reconstructed lower lip is shown 1 year postoperatively. A superiorly pedicled facial artery musculomucosal flap was used for vermillion reconstruction. D, Mouth opening. E, The “kissing” movement of the lips, showing symmetric lower lip contraction.
In these situations, the combination of the gracilis flap with a superior pedicled facial artery mucosal flap and skin graft allows excellent functional and aesthetic reconstruction of the lower lip, with only one surgical procedure and minimal donor site morbidity. Dynamic sphincter capacity is obtained through coaptation between the motor branch of the gracilis muscle and the marginal mandibular branch of the facial nerve. Two mental nerves are implanted into the free gracilis muscle to achieve protective sensibility. The facial artery musculomucosal flap replaces the vermilion and the inner side mucosa. The external surface of the gracilis is covered by a good color-matched skin graft from the scalp.

This kind of reconstruction presents the best possible functioning and aesthetic full-thickness lower lip repair. Other free flaps, such as the radial forearm flap, do not have their own motility, their color match is not ideal, and their donor site defect is more extensive.11

Reconstruction of the Tongue

The tongue is a complex structure, essential for swallowing, speech, and airway protection. A total glossectomy requires reconstruction with a free flap that provides functional bulk to maintain palatoglossal contact, pharyngeal elevation, and sensory innervation. Palatoglossal contact maintains intelligible speech, whereas pharyngeal elevation provides airway protection and creates a pharyngeal suction pump that facilitates swallowing.

The functional gracilis muscle with a transverse cutaneous paddle meets all of these demands. The muscle is oriented transversely to form a sling, with its center fixed at the mandibular body and both ends attached laterally to the mandibular arch. Accordingly, gracilis muscle contraction causes elevation of the neotongue, the hyoid bone, and the pharynx.

The skin flap, however, which is orientated perpendicular to the muscle, is designed to close the intraoral defect and is folded to produce a neotongue with sufficient bulk to allow palatoglossal contact. Recipient vessels are mainly branches of the external carotid artery (that is, lingual or superior thyroid arteries) and branches of the external jugular vein. The hypoglossal nerve stump is preserved for coaptation with the obturator nerve of the gracilis to achieve motor reinnervation of the myocutaneous flap.12

Contraindications

The gracilis flap has a relatively short vascular pedicle and therefore is not indicated in severely irradiated patients in whom there may be a limited number of recipient vessels. In this situation, it is better to harvest a muscle flap with a long pedicle, such as the rectus abdominis muscle flap, the latissimus dorsi muscle flap, the anterolateral thigh flap, or the extended lateral arm flap.
If bony reconstruction is required, the gracilis flap is not appropriate, because it cannot be harvested as a composite flap to include a bone segment. With regard to size, the gracilis flap is generally not an appropriate choice for the reconstruction of huge, composite three-dimensional defects.

The vascular pedicle of the gracilis flap may be atherosclerotic in patients with severe atherosclerosis, especially of the lower extremity. In these patients, it is better to take a muscle flap from the upper part of the body.

It is difficult to plan and harvest a skin island in obese patients because of the mobility and thickness of the skin territory at the medial thigh. In these patients, it is better to apply a pure muscle flap in combination with a skin graft to avoid the bulky myocutaneous flap.

**Preoperative Management**

Preoperatively, surgeons must ensure that there has not been any previous trauma or surgical intervention at the donor site that could endanger the neurovascular supply of the gracilis muscle. Because the pedicle has an anatomically consistent course, preoperative detection using a handheld Doppler unit is usually unnecessary. The key to safe elevation of the musculocutaneous gracilis flap is to accurately outline the skin island directly over the muscle. The precise outlining of the island is hindered with patients in the lithotomy position, especially in obese patients. Therefore planning is performed with patients standing, using the landmarks and surface markings outlined at the beginning of this chapter.

There is no patient age limitation for harvesting this flap. In elderly or paralyzed patients, the reduced muscle volume has to be considered. If a patient's operability is ensured and there is no evidence of vasculopathy that would prevent microsurgical intervention, then there are no contraindications for the surgery.

**Operative Technique**

The axis of the gracilis is drawn while patients are standing. This is particularly important if a skin flap is to be harvested with the muscle but is less important if muscle only will be harvested. Patients are placed in a supine position with the knee and hip flexed and the thigh abducted. The incision is made over the proximal 10 cm, about 2 to 3 cm posterior to the line between the posterior border of the proximal tendon of the adductor longus muscle and the medial margin of the tibial tuberosity.

The proximal incision exposes the deep fascia over the adductor longus and gracilis muscles. The fascia is divided to reveal the muscular interspace. By retracting the adductor longus muscle laterally, careful dissection of the intermuscular connective tissue allows the dominant pedicle to be identified, usually at its predicted position.
The anterior branch of the obturator nerve is always predicted to be 1 to 3 cm proximal to the vascular pedicle (Figs. 19-9 and 19-10). This branch is the best point of reference for confirming that the gracilis muscle has been identified. After the gracilis muscle is identified, the surrounding tissue proximal and distal to the pedicle can be separated by blunt dissection. This creates adequate space for further dissection of the pedicle laterally on the anterior surface of the adductor magnus toward its origin.

![Diagram of muscle anatomy](image)

**Fig. 19-9** Exposure of the dominant pedicle and the anterior branch of the obturator nerve, which indicates that the gracilis muscle is identified.

![Image of dissection](image)

**Fig. 19-10** The approach to the main vascular pedicle. By retracting the adductor longus muscle (green arrow), the main pedicle (grey arrow) of the gracilis muscle (black arrows) is exposed, running between adductor longus and adductor magnus muscles (blue arrow). The anterior branch of the obturator nerve (white arrows) is determined to be 1 to 3 cm proximal to the vascular pedicle.
After the neurovascular structures are completely dissected, the gracilis muscle can be transected distally at different levels, depending on the reconstructive requirements. During this maneuver, it is important to identify and ligate the minor pedicles at the distal third of the muscle to avoid bleeding. After the muscle is completely dissected, its musculotendinous origin is detached proximally. It is better to leave a 1 to 2 cm cuff of gracilis muscle attached to the origin to avoid significant postoperative pain at the pelvic periosteal level. When harvest of the entire muscle is required, the distal musculotendinous portion of the muscle must be exposed through a second skin incision at the distal medial thigh. At that level, the gracilis muscle lies between the sartorius muscle anteriorly and the semimembranosus muscle posteriorly and can be identified by applying traction on the proximal muscle belly. This is an important anatomic point for surgical dissection. Before cutting the tendon, it is firmly retracted to palpate the pull on the gracilis muscle proximally.

For a musculocutaneous flap harvest, the skin island is outlined with the patient standing. The first incision is made along the anterior margin of the skin paddle. Flap dissection proceeds from anterior to posterior in a subfascial plane until the intermuscular septum between the adductor longus and gracilis muscles is encountered. The greater saphenous vein is ligated proximally and distally and included in the flap only if the skin island exceeds 20 cm transversely, otherwise the great saphenous vein should be dissected from the skin island and kept intact. After the major pedicle is exposed and dissected, the posterior incision along the skin flap margin is made to include the deep fascia of the thigh. Dissection then proceeds anteriorly to the posterior border of the gracilis muscle to complete the flap harvest.

**Technical Tips and Tricks**

**Harvest of the Skin Island**

The longitudinal and transverse skin islands of the musculocutaneous gracilis flap are based on musculocutaneous and septocutaneous perforators. A large septocutaneous perforator is often seen running between the gracilis and adductor longus muscles at the level where the dominant pedicle enters the gracilis muscle on its medial, deep surface. This perforator must be included in the myocutaneous flap.

The incision in the subcutaneous tissue should always be performed away from the muscle to securely preserve the perforators of the flap. In addition, it is advisable to suture the skin island temporarily to the muscle to prevent avulsion of the skin island or damage to the perforators.
Flattening the Muscle

The technique used to flatten the muscle and enlarge its surface was previously described (see p. 351). Once the muscle is flattened and expanded, it is important to maintain this expansion by insetting the muscle under some tension and covering it with a split-thickness skin graft⁶ (Fig. 19-11; see also Fig. 19-5).

Prolongation of the Vascular Pedicle

Access to the vascular pedicle of the gracilis flap can be optimized by initial retraction of the adductor longus muscle posteromedially. After the anterior border of the adductor longus muscle is identified, the deep fascia is opened and the muscle is retracted downward to reveal the branching of the vascular pedicle from the deep femoral artery. Once the pedicle is identified, dissection proceeds medially by tunneling under the adductor longus muscle. The adductor longus muscle is retracted laterally as described previously, and dissection proceeds in the usual manner. This technique offers an optimized access to the origin of the vascular pedicle and therefore simplifies its complete dissection.
Coverage of the Muscular Gracilis Flap With a Full-Thickness Skin Graft

When a short segment of muscle is transferred, a nice option is to cover the muscle with a thin, full-thickness skin graft harvested from the donor site. This avoids an additional donor site of a split-thickness skin graft. The elliptical skin graft is planned over the incision line, according to the dimensions of a longitudinal skin island. Before the muscle is dissected, the skin graft can be directly harvested from the superficial layer, making a subsequent defatting superfluous. Afterward, the subcutaneous fatty tissue underneath the skin graft must be resected to the level of the deep fascia. At the end of the gracilis transfer, the donor site can be closed primarily, and the perforated skin graft can be fixed onto the muscle. It is very important to harvest a thin skin graft to permit its secure vascularization.

Pitfalls

It can be difficult to identify the gracilis muscle in obese or significantly atrophic patients, because it may be difficult to distinguish from the adductor longus, adductor magnus, or sartorius muscle. The anatomic relationship between the nerve and major vascular pedicle of the gracilis muscle is constant and can be used for orientation. The anterior branch of the obturator nerve is always located 1 to 3 cm proximal to the vascular pedicle and represents the best point of reference to confirm that the gracilis muscle has been correctly identified. The finding can be confirmed by simple stimulation of the nerve (see Fig. 19-10).

Donor Site Management

Meticulous hemostasis is essential before the donor site is closed. When the distal third of the gracilis muscle is also harvested, it must be confirmed that the minor pedicles arising from the superficial femoral artery are ligated. Closed suction drainage is necessary. Direct closure of the donor site is generally possible, even in the case of a musculocutaneous design.

Complications

Sensory Disturbances of the Medial Thigh

Injury to the cutaneous branch of the obturator nerve leads to significant paresthesia in the distal medial thigh and is one of the most common long-term complications associated with the gracilis muscle harvest. This cutaneous branch arises from the anterior branch of the obturator nerve in the vicinity of the vascular pedicle, passes deep to the adductor longus muscle, and crosses the gracilis muscle at its central portion. Injury to this cutaneous branch can be avoided in many cases by meticulous dissection of this nerve near the major pedicle of the gracilis flap.13
Contour Deformity of the Thigh

Contour deformity of the medial thigh occurs to a greater or lesser degree in patients with a myocutaneous gracilis flap according to the specific skin island. To improve the aesthetic outcome at the donor site, the gracilis flap should not include a skin island if its only purpose is for postoperative monitoring of the flap (Fig. 19-12).

![Fig. 19-12](image)

After harvesting a free musculocutaneous gracilis flap with a transverse skin island, there is a minimal contour deformity of the thigh.

Decreased Strength of Hip Adduction

Harvest of the gracilis muscle causes a permanent decrease in the strength of hip adduction that is generally not noticed by patients.

Lymphedema

Lymphedema of the leg can occur after harvesting a large transverse skin island, especially if the skin island is transversely extended more than 30 cm and includes the saphenous vein as well as the deep fascia to increase its vascularity. The transection of lymphatic vessels in this region causes long-lasting secretion, seroma formation, and lymphedema of the leg in extreme cases.

Postoperative Management

Standard postoperative monitoring, as performed for all free flaps, is required (see Chapter 8). Standard fluid resuscitation, deep venous thrombosis prophylaxis, and the administration of antibiotic agents are based on the nature of each case and the surgeon’s preference.
CRITICAL POINTS

Must Know

- The gracilis muscle is the most medial and superficial muscle of the adductor muscle group. The axis of the muscle is on the line between the posterior border of the proximal tendon of the adductor longus muscle and the medial margin of the tibial tuberosity.
- The relationship of the obturator nerve to its dominant vascular pedicle is the key to identifying the gracilis muscle from the other medial thigh musculature.
- The skin paddle may be oriented transversely or vertically.
- The distal third of the longitudinally oriented skin island is generally unreliable, because it is supplied by perforators from the secondary pedicles.
- The distal third of the muscle may be unreliable, particularly if the secondary pedicles are big.

Should Know

- The neurovascular axis of the gracilis muscle is longitudinal.
- The gracilis muscle can be split longitudinally to provide separate slips of muscle to use either in functional transfer or to close complex defects.
- The gracilis muscle can be flattened and its surface enlarged by splitting the epimysium longitudinally.

Synopsis

- The gracilis flap is a versatile flap that can be used in a multitude of clinical settings.
- The gracilis muscle is expendable, without discernible loss of adductor function, and the final scar is generally inconspicuous. Furthermore, the harvest of the gracilis flap does not require repositioning patients intraoperatively.
- The main restrictions associated with the gracilis flap are its size and the length of its pedicle. The gracilis flap is limited to small and medium-sized defects.

References


   The authors describe five patterns of muscle circulation, based on studies of the vascular anatomy of muscle. The clinical and experimental correlation of this classification is determined by the predictive value of the vascular pattern of each muscle currently used in reconstructive surgery. These patterns include the arc of rotation, skin territory, distally based flaps, microvascular composite tissue transplantation, and design of muscle-delay experimental models. This classification is designed to assist surgeons in choosing and designing the muscle and musculocutaneous flap for use in reconstructive surgery.


   A clinical operative technique for free muscle transplantation using microneurovascular anastomoses is presented. Two cases of free transfer of the gracilis muscle for dynamic reconstruction of facial paralysis are described, including a follow-up study with electromyography, light microscopy, and electron microscopy. The authors suggest that this new technique will have a wide range of applications in reconstructive surgery.


   The authors perform a comprehensive study of the intramuscular neurovascular anatomy in 14 human cadavers as it relates to segmental neurovascular functioning muscle transfer. The distal portion of the muscle was supplied by one to three small arterial branches of the superficial femoral artery. Venous drainage was through paired veins comitantes. The motor nerve arises from the obturator nerve and enters the muscle in association with the major vascular pedicle. The nerve then splits within the muscle and runs longitudinally in two or three major branches within the muscle, parallel to the arterial branches and muscle fibers. The neurovascular anatomy of the gracilis muscle was found to be remarkably consistent from specimen to specimen, varying only in the length of the muscle and tendon, and in the number of minor pedicles supplying the distal portion of the muscle. This study confirms the suitability of the gracilis muscle for segmental functional muscle transfer.


   The authors provide a detailed anatomic description of the gracilis vessels based on their findings in 32 human cadaver thighs. Methylene blue and colored fluid latex were selectively injected in the principal pedicle of the gracilis muscle to facilitate measurement of the perforator vessels and associated cutaneous paddle. The contour and anatomic location of the paddles were digitized to obtain precise data that could be used to model a standard theoretical skin paddle. The quantitative values for the skin paddle and its relationship to the perforator arteries may be of significant interest to surgeons who aim to harvest a composite musculocutaneous gracilis flap, to improve its reliability by reducing the risk of cutaneous necrosis.


   The gracilis muscle is one of the most extensively used muscles for free tissue transplantation. Its advantages are low donor site morbidity with a concealed scar, a constant anatomy with large-diameter vessels, and its potential as a neurosensory flap and a large skin paddle. However, its size is limited, and thus the muscle is used only for small to medium-sized defects. A novel technique is presented by which the muscle can be enlarged three to four times over the regular muscle width. This can be achieved by microscopically aided intramuscular dissection of connective tissue with preservation of the intrinsic vessels of the muscle. With this technique, the application of the versatile gracilis muscle in reconstructive surgery can be further expanded.


   The authors examine the blood supply to the skin overlying the gracilis muscle through detailed anatomic study and latex injection of 24 cadaver legs. This information led to a “new” transverse design of the gracilis musculocutaneous flap in which the vascular perforators are invariably included in the cutaneous portion of the flap. In contrast, because of skin mobility, the traditional design may allow elevation outside the skin territory of the muscle perforators.
In the past several years, perforator flaps have come into widespread use for head and neck reconstruction. The swell of anatomic study and clinical application has steadily overcome the inertia of adopting this relatively new treatment method into standard practice in a growing number of centers worldwide. The willingness of surgeons to tackle the learning curve of performing an intramuscular dissection has opened up an entirely new area of potential reconstructive options that are particularly desirable in the head and neck.

Traditional musculocutaneous flaps are appropriate in many clinical scenarios, but they have significant limitations. The excess muscle bulk may be a disadvantage when resurfacing crowded areas such as the oral cavity. Although the denervated muscle
undergoes some degree of atrophy, the final volume is unpredictable. Perforator flaps supply a lean and predictable volume of soft tissue and reduce the burden on the donor site. Muscle function, sensation, and cosmesis are preserved, and patients may have a less painful and potentially shorter recovery period. A number of creative innovations have also allowed for custom-designed flap reconstruction. Multiple structural components can be restored by including chimeric tissues such as muscle, fascia, or bone to obtain a like-with-like replacement. If the skin paddle contains two widely separated perforators, the flap may be divided into separate skin islands (or two separate free flaps) to allow greater flexibility in resurfacing a complex defect. This renaissance in applied anatomy has enabled plastic surgeons to achieve more elegant reconstructive solutions in a single stage with a single pedicle.

**HISTORICAL CONTEXT**

The development of perforator flaps is rooted in a precise understanding of the cutaneous blood supply. The fundamental question asked by generations of anatomists and surgeons is: How exactly does the underlying blood supply reach the skin? Although it would be logical to assume that anatomic discovery preceded clinical application, a brief review of history reveals otherwise. The evolution of our understanding and practice is not a linear progression, but a constellation of progress, misdirection, and rediscovery influenced by scientific observation, dogma, personalities, and fashion. For example, Esser\(^2\) applied the clinical concept of an axial patterned flap (later described by McGregor and Morgan in 1973\(^3\)) during World War I. His “arterialized” island flap was performed long before accurate studies of cutaneous vascular anatomy were available. Although Manchot\(^4,5\) published the first comprehensive study of the cutaneous blood supply in 1889, its accuracy was limited by the techniques available at the time. Esser’s insight of incorporating a vascular pedicle into a flap would ultimately become a central concept in plastic surgery, but this idea remained dormant for decades. Likewise, the tubed pedicled flap, described by Filatov\(^6\) and popularized by Gillies,\(^7\) came to define the state-of-the-art in plastic surgery. This technique helped innumerable patients who were otherwise without hope, but tubed pedicled flaps were devoid of any underlying anatomic rationale. Flap viability relied on length/width ratios and careful technique. In 1936, Salmon\(^8,9\) published a detailed catalogue of cutaneous vascular territories using lead oxide and gelatin injection coupled with radiographic studies. This painstaking accomplishment illustrated the basis of many potential axial-based flaps that would be described decades later. Despite this valuable work and its vast clinical implications, random pattern flaps continued to dominate plastic surgery for several decades.

The concept of including a vascular pedicle or muscle carrier in the skin flap to increase the amount of tissue that can be reliably transferred gradually gained momentum in the latter half of the twentieth century. Some examples include the groin flap described by Shaw\(^10\) in 1944, the deltopectoral flap described by Bakamjian\(^11\) in 1965, and the compound pectoral flap described by Hueston and McConchie\(^12\) in
1968. The 1970s marked tremendous growth in the development of musculocutaneous flaps following the work of Orticochea and McCraw and Dibbell. A wealth of anatomic studies ensued, culminating in the classification and compendium of muscle and musculocutaneous flaps published by Mathes and Nahai. The discovery of fasciocutaneous flaps followed, as Ponten observed that including the fascia imparted greater perfusion to cutaneous flaps in the lower extremity. These findings stimulated detailed analysis and classification by Cormack and Lamberty, with further contributions by Nakajima et al. This period of anatomic discovery prompted a renewed appreciation for the relevance of Salmon’s original work published decades earlier. Taylor and Palmer elaborated on these studies with an impressively detailed archive of the vascular territories, with modern clinical application and the introduction of the angiosome concept. The angiosome was a three-dimensional extrapolation of the angiotome, described by Behan and Wilson as the cutaneous territory supplied by a named vessel.

These profound advances in the understanding of the cutaneous circulation coincided with the dawn of microsurgery. In 1971, Antia and Buch accomplished an incredible feat: the transfer of a superficial epigastric artery–based free “dermo-fat graft” to the face, without the use of an operating microscope. Taylor and Daniel coined the term free flap and pioneered this new entity that provided surgeons with entirely new reconstructive options.

As instruments, needles, and surgical technique improved, anastomotic success gradually became expected. Reducing donor site morbidity was the next challenge facing microsurgeons and raised the question of whether the underlying muscle and its associated functional morbidity could be spared. This would require an additional level of complexity in safely extracting the cutaneous perforator from the seemingly inseparable muscle within which it was invested. The successful use of retrograde intramuscular dissection was first applied to procedures such as toe-to-hand transfer and the lateral arm flap, performed by our team and other pioneers in the field. In 1989, Koshima and Soeda applied the concept of intramuscular dissection to harvesting an abdominal skin flap based on a perforating branch of the deep inferior epigastric artery, leaving the rectus abdominis muscle intact. This publication increased the awareness of the clinical applications of intramuscular dissection techniques and helped to ultimately debunk the outdated notion that inclusion of the underlying muscle is critical to maintaining the circulation of the overlying skin. This departure from previously accepted convention paved the way for notable pioneers in perforator flap surgery such as Allen et al and Blondeel, who popularized its use in breast reconstruction.

Koshima et al and Kimata et al published early applications of perforator flaps in head and neck reconstruction. Realizing this potential, Wei et al demonstrated the reliability of the anterolateral thigh (ALT) flap on a large scale, ultimately establishing this perforator flap as the new first choice in head and neck reconstruction at
their institution. Most recently, the concept of free-style flaps, as reported by Wei and Mardini,30 further liberates surgeons from thinking in terms of conventional flap markings. Variability in perforator anatomy is accepted as a rule, and as long as a reasonably sized perforator is identified, local surrounding tissue may be harvested instead of adhering to traditional skin territories. Our technical ability has now caught up with our understanding of the anatomy. Current fashion in plastic surgery is favorably aligned with perforator flaps and the associated reduction in donor site morbidity.

**DEFINITION**

A concise definition of what constitutes a perforator flap is important for clear communication among surgeons. Yet despite much discussion, there is no universally adopted definition.31-35 The term *perforator flap* came into vogue in the 1990s following pioneering efforts in the concept of intramuscular dissection by Koshima and Soeda,24 Allen et al,25 and Blondeel.26 This tedious and delicate dissection technique provided an entirely new generation of flaps. For this reason, Wei et al34 define any cutaneous flap that requires an intramuscular dissection as a perforator flap. Flaps based on septocutaneous vessels or direct cutaneous vessels are excluded, because the technical demands of the harvest are significantly different.

Hallock33 proposed a broader definition of perforator flaps, defining them as any cutaneous flap supplied by a vessel that pierces the deep fascia. He distinguished between *direct perforators*, which pierce only the deep fascia without coursing through a deeper structure, and *indirect perforators*, which penetrate muscle, septum, bone, or other tissue in addition to the deep fascia before supplying the skin. For example, a groin flap is based on a direct cutaneous perforator according to this definition, and septocutaneous and musculocutaneous ALT flaps are grouped together as indirect perforator flaps. Blondeel et al31 take Hallock’s classification a step further and divide the indirect perforator class into two smaller categories: muscle perforator and septal perforator flaps. This definition makes the important distinction between the surgical technique required to perform an intramuscular dissection and that required to elevate a septocutaneous flap. However, in daily practice, most surgeons simply use the term *perforator* instead of *septal perforator* or *muscle perforator*, which can lead to confusion when comparing procedures. For example, a septocutaneous ALT flap involves a different operative technique than an ALT flap that requires a tedious intramuscular dissection. Surgeons may refer to both these entities as *perforator flaps*, thus blurring the definition when making comparisons.

Both the semantics and the historical context may become confusing when broadly applying the term *perforator flap*. If all cutaneous flaps are designated as perforator flaps, then the word *perforator* loses its significance, and the term could be eliminated when discussing skin flaps. Historically, the term *perforator flap* came into common
use following the application of intramuscular dissection; applying this term to the previous generation of free flaps may seem anachronistic. For example, the radial forearm flap would be reclassified as a perforator flap, despite its being in use long before the term perforator was applied. Although this subject remains controversial, it is important to clearly communicate the technical details when comparing procedures to facilitate clear discussion.

Establishing a standardized system for naming perforator flaps has not generated much debate, but flap names and definitions are by no means uniform in daily practice. Many perforator flaps have been described, and many different names are often assigned to the same flap. Recognizing the need for precise nomenclature in this field, Geddes et al\(^3\) proposed a standard system: source vessel–muscle being perforated. For example, the ALT flap is designated as LCFAP-vl (lateral circumflex femoral artery perforator–vastus lateralis). Most surgeons still refer to this flap as an ALT flap, but this concise classification scheme is particularly useful for describing new or less-well-known perforator flaps.

**ALT Flap as a Model for Design and Harvest**

The ALT flap is a useful model for illustrating general principles of perforator flap design and harvest. Initially described by Song et al in 1984\(^3\) as a septocutaneous flap, the ALT flap is typically supplied by the descending branch of the lateral circumflex femoral artery. However, musculocutaneous perforators are the dominant supply to this flap, which broadens its application. This flap has become a workhorse in head and neck reconstruction across many centers in Asia and abroad for patients with a thin subcutaneous layer. Its rising popularity stems from a greater understanding of the vascular anatomy and increased comfort in performing an intramuscular dissection. The ALT flap has a reliable track record and provides a large volume of tissue with a long pedicle and generous lumen diameter, resulting in minimal donor site morbidity. Details of the flap harvest are described in Chapter 13.

**Preoperative Management**

Thoughtfulness in flap design is critical in achieving success with perforator flaps. The missing components of the defect are evaluated to estimate the recipient site’s three-dimensional tissue requirements. A simple pinch test on the anterolateral thigh skin can determine if this donor site provides an appropriate thickness for resurfacing or volume replacement.

Flap design begins with identifying the relevant anatomic landmarks so that the relative location of the cutaneous perforators can be marked. The perforators are localized using a handheld Doppler probe, and a skin island is patterned around them. In most cases, these landmarks are valid; however, it is worthwhile to actively consider...
the underlying anatomic relationships when marking the flap to avoid problems caused by differences in body habitus and anatomy among patients. For example, the standard marking used for the ALT flap is a line drawn from the anterior superior iliac spine to the superolateral corner of the patella, with the patient supine. Based on previous anatomic study, the most likely location of a perforator is within a 3 cm radius of the midpoint of this line. This line corresponds to the septum between the vastus lateralis and the rectus femoris muscles. It may be useful to confirm the underlying anatomy by palpation, noting that to guarantee the inclusion of any perforator through the vastus lateralis muscle, the medial-most margin of the skin paddle should lie over the rectus femoris muscle (Fig. 20-1). While patients are in a supine position, particularly those with a bulky thigh, muscles may hang more laterally while the bony landmarks remain immobile, and the line between them may not closely correspond to the intermuscular septum. In this case, reliance on the bony landmarks may result in a skin paddle that is not centered over the desired perforators.

![Fig. 20-1 Preoperative markings for an ALT flap. ASIS, Anterior superior iliac spine.](image)

Although the handheld Doppler device may not always be reliable, particularly in obese patients, it is a useful tool in skin paddle design. At least three perforators are identified, and the dominant perforator is distinguished by marking a larger dot on the skin. Occasionally, an unusually loud signal may not indicate a perforator, but rather the source vessel, especially in thin patients. Alternatively, there may be no audible perforator. The most common cause is hypotension caused by anesthesia, which should be addressed with the anesthesiologist. If a patient is normotensive and there is still no Doppler signal, the perforators may be small, or, on rare occasions, absent. Even in this scenario we typically proceed with the plan based on landmarks and intraoperative exploration for perforators. The cutaneous blood supply
must come from somewhere, and the free-style principle is applied, which is discussed later. Alternatively, color flow Doppler and CT angiography provide greater sensitivity and specificity in localizing perforators, but they require additional time and cost. As these and other new technologies gain wider acceptance and become more cost effective, the small but always present degree of uncertainty regarding the adequacy of the perforators will diminish.

Once the perforators are localized, the skin paddle is typically designed with the dominant perforator at the center of the flap, although this is not always necessary. In cases in which maximizing pedicle length is desired, a skin paddle with a peripherally oriented perforator may be preferable. There are two differing philosophies regarding skin paddle design in immediate head and neck reconstruction: (1) using a two-team approach in which the flap harvest and ablative procedures are performed simultaneously or (2) creating a template of the defect following ablation and then custom designing the skin paddle directly on the donor site. Both approaches are reasonable, and each has advantages and disadvantages. For example, if a patient is in poor health and reducing the anesthesia time is a central concern, then a two-team approach may be more appropriate. In this case, the surgeon may as well harvest the maximum amount of tissue that allows easy primary closure. In our experience using the ALT flap, a skin paddle dimension of 8 by 22 cm suits this purpose. There are a number of benefits to this approach, including extra volume that compensates for shrinkage following radiation therapy, a standardized flap elevation that allows a reliable training model for residents, a skin paddle that may be reoriented during inset without having already committed to deepithelialization or flap shape, and reduced anesthesia time. The main benefits of waiting for the resection to be complete and then making a template of the skin paddle are 100% assurance of the defect size and a customized inset, but of course this comes at the cost of a longer period of anesthesia. If, for some reason, the precut skin paddle does not allow a desirable pedicle orientation or if some other event requires reorienting the skin paddle, the inset may be compromised.

**Operative Technique**

A safe and systematic approach to flap elevation is essential to a reliable and efficient harvest. Millard’s principle of always maintaining a lifeboat is particularly true for perforator flaps. The first means of providing a lifeboat is to incise only one side of the skin paddle until the perforators are identified. With an ALT flap, this is typically the medial border. If a perforator cannot be identified, the skin incision can be extended, or dissection can proceed in the opposed direction, consistent with the free-style concept. Incising the entire skin island at the start of the case preempts the possibility of altering the size or orientation of the skin paddle to accommodate a perforator peripheral to the flap.
As perforators are encountered during the course of flap elevation, the next critical step is to decide which perforators to sacrifice (Fig. 20-2). Although perforators typically include both arterial and venous components, careful inspection is important, because the artery or vein may be deficient or even absent in some patients. A perforator should not be sacrificed until another perforator of larger caliber is encountered. If there is an additional perforator that may act as a lifeboat, it should be preserved until the main perforator dissection is complete, in case there is inadvertent injury to the pedicle. Including two perforators is desirable, especially when harvesting a large flap or when flap thinning is planned. This augments the perfusion and provides a self-contained lifeboat if one of the perforators is injured.

Fig. 20-2  A, Exposure of perforators through a suprafascial approach with preservation of the lateral femoral cutaneous nerve (arrows). B, Complete exposure of the perforators (arrows) after splitting the deep fascia.

Once the dominant perforator is identified, the larger source vessel is exposed (Fig. 20-3). The septum between the rectus femoris and vastus lateralis muscles is opened, revealing the descending branch at the base, overlying the vastus intermedius muscle. Exposing the feeding vessel before performing the perforator dissection is useful in a number of ways. If the patient had a previous surgery or injury, it allows the surgeon to identify an unusable pedicle early in the dissection and convert to a different flap. Additionally, visualization of the target anatomy facilitates perforator dissection, allowing a combined retrograde and antegrade approach.
At this point, the perforators are unroofed with meticulous hemostasis and minimal manipulation of the vessels (Fig. 20-4). Gentle tissue handling is critical to maintain consistent success. Any degree of vessel injury risks vasospasm and prothrombotic cascades, rapidly degrading the reliability of the pedicle. Dissection is carried out by spreading parallel to the perforator to avoid injury. Resistance is usually caused by the presence of a vascular branch or nerve and requires close inspection or ligation. A motor nerve can usually be teased away from the pedicle, or, if it is entwined between the artery and vein, the nerve can be divided and repaired primarily following flap harvest if necessary. All vascular branches are carefully divided ideally 3 to 4 mm away from the pedicle. If bleeding occurs after bipolar cautery or hemoclip placement, the extra room allows the surgeon to stop the bleeding without occluding the perforator. Although tedious, maintaining a bloodless field provides an unobstructed view of the anatomy and helps avoid further bleeding, which may occur when disrupting branches hidden in a small pool of blood. Direct manipulation of the vessel is avoided; instead of retracting the pedicle with forceps, small double hooks are used to retract the surrounding muscle. Liberal irrigation with a vasodilating agent prevents desiccation of the perforator and may reduce the likelihood of vasospasm.

Fig. 20-3 Exposure of the descending branch of the lateral circumflex femoral artery. Following identification of the perforators, the avascular plane between the rectus femoris and vastus lateralis muscles is opened to reveal this presumed source vessel (arrow).

Fig. 20-4 Unroofing the perforators. The muscle is retracted using small hooks, rather than using direct manipulation of the vessel. Only the anterior portion of the muscle is initially opened to efficiently delineate the origin of the vessel.
Once the perforators are unroofed and traced to the source vessel, the intact borders of the skin paddle may be incised (Fig. 20-5). Circumferential dissection of the pedicle is performed carefully, because at this point the perforators are particularly vulnerable to occult traction injury. The color of the flap and any dermal bleeding are noted frequently throughout the dissection to ensure that the perforators are adequate and patent. When dividing the pedicle, we find it useful to place a clip on the artery and leave the veins unclipped for clear identification and communication within the surgical team, particularly if different surgeons are performing the anastomosis and flap harvest. The flap is harvested only after the recipient vessels are completely dissected and hemostasis is achieved.

Fig. 20-5 The posterior border of the skin paddle is incised, and a retrograde intramuscular dissection is performed. In this case, the perforator originated from the descending branch.

**COMMONLY USED PERFORATOR FLAPS**

Several perforator flaps have come into popular use: the anterolateral thigh (ALT or LCFAP-vl) flap, deep inferior epigastric artery perforator or deep inferior epigastric artery perforator–rectus abdominis (DIEP or DIEAP-ra) flap, thoracodorsal artery perforator–latissimus dorsi (TDAP-ld) flap, and superior gluteal artery perforator (SGAP) flap. The DIEP, TDAP, and SGAP flaps primarily have been used in breast reconstruction, but they may also be applied to head and neck reconstruction (Figs. 20-6 through 20-8). Most of these flaps have reliable pedicles, with the SGAP’s pedicle being somewhat more diminutive. However, they differ in terms of donor site, tissue bulk, and convenience of harvest.
Fig. 20-6  A, Preoperative markings for a deep inferior epigastric artery perforator flap for post-mastectomy reconstruction of the diseased left breast. B, The DIEP flap was harvested. C, The postoperative result. D, The donor site.

Fig. 20-7  A, A thoracodorsal artery perforator flap. The preoperative markings delineate the posterior axillary fold and perforator, which were identified using a handheld Doppler unit. B, The flap was harvested based on a thoracodorsal musculocutaneous perforator.
The ALT flap has become a popular choice in head and neck reconstruction, because it is well suited to the needs of both the surgeon and patient (Figs. 20-9 through 20-11). The TDAP and SGAP flaps require a timely position change, precluding the option of a simultaneous flap harvest and tumor extirpation. The ALT flap is situated at a comfortable distance from the ablative surgeon’s field. The anterolateral thigh skin is typically thin in Asian patients, which is a desirable quality for most head and neck defects.

Fig. 20-8  A, Preoperative markings for a superior gluteal artery perforator flap. B, Exposure of the perforator. C, Hyperpigmented donor site scar in an Asian patient.

Fig. 20-9  An ALT flap. A, This through-and-through buccal defect included the oral commissures and required internal lining, volume restoration, and external skin resurfacing. B, The ALT flap was harvested.
Fig. 20-9, cont'd  C, The postoperative result following the first stage of reconstruction. D, The postoperative result following commissuroplasty and partial excision of the external skin paddle.

Fig. 20-10  A, This patient had a partial glossectomy defect that was reconstructed with an ALT flap. B, The postoperative result shows satisfactory contour and function.

Fig. 20-11  A, An ALT flap was used to repair this buccal defect. B, The postoperative result shows adequate resurfacing and unrestricted mouth opening.
Alternatively, the medial sural artery perforator flap and peroneal artery perforator flap are reliable sources for thin, pliable tissue with minimal donor site morbidity, with the exception of a prominent scar on the lower leg (Figs. 20-12 and 20-13).\textsuperscript{31,42}

**Fig. 20-12**  
A, A medial sural artery perforator flap. A handheld Doppler unit was used to localize the perforators traversing the medial gastrocnemius muscle. B, The flap was elevated and the donor site was closed primarily. C, The harvested flap with medial sural pedicle (arrow).

**Fig. 20-13**  
A, A peroneal artery perforator flap was designed in the proximal third of this patient’s leg, along the posterior margin of the fibula. B, Although it is shown here as a local flap, it can be reliably harvested as a free flap. Perforators may course through the peroneus, gastrocnemius, or soleus muscle.
Because many head and neck cancer patients are smokers with impaired lung function, postoperative deep breathing and pulmonary hygiene are important for avoiding pneumonia. An abdominal donor site created by the DIEP flap places a painful incision on the abdomen and may cause splinting and shallow breathing during the early recovery period. It is our observation that placing the donor site on an extremity rather than the trunk allows an easier recovery period.

Recently, the general philosophy regarding perforator flaps has evolved into the free-style concept (Fig. 20-14). Variable perforator anatomy is assumed, and a donor site is chosen based on the requirements of the defect. As long as there is an audible perforator signal using a handheld Doppler unit, a flap can be harvested on this basis. Because a retrograde dissection will ultimately lead to an adequately sized source vessel, surgeons are not limited by conventional flap markings.

**Fig. 20-14** A free-style flap. A, The preoperative markings were made using Doppler imaging. B, An incision was made on one side of the skin paddle to expose the perforators, and the flap was elevated. C, The flap is shown following harvest. The minimum pedicle length of a free-style flap in the thigh may be estimated by drawing a line from the perforator signal to the superficial femoral artery.
COMMON PITFALLS AND COMPLICATIONS

The initial critique regarding perforator flaps is usually the requirement for a tedious intramuscular dissection and the vulnerability of the pedicle to vasospasm. After overcoming the initial learning curve, the intramuscular dissection becomes safe and less time consuming. Pitfalls may occur at a number of points during the course of the procedure. Preoperative identification of the perforators using a handheld Doppler probe or other means helps identify the danger zones during the initial dissection. Once the skin is incised, the primary surgeon and assistant should be aware of the location of the pedicle at all times to avoid inadvertent injury. During dissection, manipulation of the main perforator, inadequate irrigation of the vessels, and poor hemostasis increase the chances of vasospasm and thrombosis. Once the initial perforator dissection is complete, the skin paddle is released. The exact location of the perforator is constantly confirmed to avoid injury when incising the posterior border of the flap. When the skin paddle is completely free, gentle handling is important to avoid occult traction injury to the perforator. The prevention of shearing injuries during flap inset can be challenging in the confines of the head and neck. When passing the vessel through a subcutaneous tunnel, the use of a large Penrose drain that is filleted open, along with copious irrigation, is a safe method of delivering the pedicle to the recipient vessels. Redundancy in the pedicle length, especially in the vein, is checked before anastomosis. Hemostasis at the recipient site and on the pedicle is critical, because even a small hematoma may cause pedicle compression or a later infection, which may trigger coagulation cascades and late thrombosis.

OPTIMIZING OUTCOMES: TIPS AND TRICKS

- Perforators are mapped preoperatively using handheld Doppler imaging or other appropriate means.
- Only one side of the skin paddle is incised until perforators are identified.
- A perforator should not be sacrificed until a larger one is located.
- A secondary perforator is not sacrificed until the dominant perforator is completely dissected.
- Two perforators are included when possible.
- A bloodless field must be maintained.
- Direct manipulation of the perforator should be avoided.
- The pedicle orientation is always be double checked to avoid twisting and kinking.
- The most robust portion of the flap is inset into the most dependent and hidden part of the defect.
CONCLUSION

Perforator flaps are well suited to the complex demands of head and neck reconstruction. The once-perceived barrier of performing an intramuscular dissection is gradually fading, and more elegant reconstructive options are available with reduced donor site morbidity. The most recent concept of free-style flaps allows greater flexibility in approaching flap harvest and serves as a lifeboat when the originally planned skin paddle fails to yield significantly sized perforators. The demand for meticulous technique in perforator flap dissection will likely become valuable in future applications for supermicrosurgery.

CRITICAL POINTS

Must Know
- An understanding of what constitutes a true perforator flap is important for clear communication.
- The principles of vascular anatomy and perforator flap design and harvest must be known.
- The surgeon must comprehend the details of meticulous intramuscular dissection technique.
- Doppler imaging is useful for identifying perforators.

Should Know
- Knowing the history and evolution of perforator flaps contributes to a better understanding of these flaps.
- The concept of free-style flaps helps liberate surgeons from thinking in terms of conventional flap markings.
- The final decision on skin paddle dimensions should not be made until the perforators are identified.
- Flaps can be thinned and contoured, provided that care is taken to protect the perforator.

Synopsis
- Perforator flaps provide a reliable and versatile means of reconstructing complex defects while minimizing donor site morbidity.
- Increasing familiarity with intramuscular dissection and the free-style concept allows for greater freedom in choosing the optimum donor flap for the specific needs of the patient.
References


The authors present the first two cases involving the muscle-sparing harvest of lower abdominal tissue based on perforators of the deep inferior epigastric artery. This work demonstrates that a large volume of tissue can be supplied by a relatively small perforator and introduces the successful application of intramuscular dissection.


In this series of 38 ALT flap procedures, 26.3% were septocutaneous and 73.7% were musculocutaneous. The authors’ harvesting strategy was to simultaneously dissect the pedicle while the ablative team performed the tumor resection. Once the tumor was removed, the skin paddle was designed and the flap harvest was completed. This study demonstrates the versatility and reliability of the ALT flap in head and neck reconstruction.


This publication reviews the Chang Gung group’s vast experience with the ALT flap. At the time of publication, the ALT flap had yet to be widely accepted because of concerns regarding the variability in anatomy. In this series of 672 ALT flaps, only six patients (0.89%) had no cutaneous vessels to this flap. Notably, these six cases were performed early in this study, and the authors suspect that there were probably cutaneous vessels present but they were likely inadvertently divided because of inexperience. This study confirmed the reliability of the ALT flap and further clarified its anatomy: 87.1% of the cutaneous vessels were musculocutaneous perforators and 12.9% were septocutaneous vessels. The complete flap survival rate was 95.68%, with 12 complete failures and 17 partial failures. The authors highlight the wide application of this flap in head and neck, breast, chest, and extremity reconstruction with a multitude of options: chimeric flaps, flow-through flaps, multiple skin paddles, and primarily thinned flaps.


The free-style flap concept is introduced, broadening the approach to perforator flap harvest in general. As long as an audible Doppler signal is identified, a viable flap can be based on nearly any perforator using a retrograde approach to the dissection. Variability in anatomy is not considered an obstacle, because a retrograde approach will eventually lead to an adequately sized pedicle. The authors present their series of 13 free-style flaps harvested in a suprafascial plane, with a 100% success rate. Benefits include the ability to harvest tissue nearly anywhere in the body to suit the needs of the defect and the preferences of the surgeon. Disadvantages are the unknown pedicle length and the limited preoperative planning imposed by the accuracy of the Doppler technology. However, the minimal pedicle length can be estimated by the distance from the planned skin paddle directly to the closest vessel of origin that cannot be sacrificed. For example, in the thigh this would be the superficial femoral artery. This publication adds an additional degree of freedom in thinking about and executing perforator flap harvest in the setting of diverse vascular anatomy.


Addressing the confusion caused by inconsistent nomenclature, a standard format for describing cutaneous flaps and musculocutaneous perforator flaps is presented. This system includes the name of the source vessel and the name of the muscle through which the perforator traverses. For example, a DIEP flap would be formally referred to as a DIEAP-ra. The “AP” in DIEAP signifies that this is a true musculocutaneous perforator flap, and “-ra” denotes the vessel’s passage through the rectus abdominis muscle. For septocutaneous flaps, “-s” is placed after the source vessel abbreviation to distinguish this entity from a musculocutaneous perforator flap. For example, LCFAP-s indicates an ALT flap based on a septocutaneous vessel.


The introduction of supramicrosurgery,\textsuperscript{1,2} which allows the anastomosis of smaller-caliber vessels and microvascular dissection of vessels ranging from 0.8 to 0.5 mm in diameter, has led to the development of new reconstructive techniques. The result has been improved success with replantations of or within the distal phalanx of the fingers,\textsuperscript{3,4} vascularized toenail for fingernail loss,\textsuperscript{5} vascularized distal interphalangeal

\section*{Highlights}

- With the development of supramicrosurgery, flap perforators can be dissected directly and anastomosed to small recipient vessels (less than 1 mm diameter).
- New applications of this technique are used for crushed fingertip replantations with venule grafts, toetip transfers for fingertip reconstructions, and lymphaticovenular anastomoses under local anesthesia for extremity lymphedema.
- In head and neck reconstruction, partial ear transfers are useful for tracheal and eyelid defects, and free perforator-to-perforator flaps are used for facial defects. These flaps include deep inferior epigastric artery perforator (DIEP) flaps, gluteal artery perforator (GAP) flaps, thoracodorsal artery perforator (TAP) flaps, anterolateral thigh (ALT) flaps, and tensor fascia lata (TFL) perforator flaps with a short pedicle.
- These flaps are mainly indicated for head and neck and extremity reconstructions.
- Tiny funicular sutures are useful for vascularized nerve flaps or local nerve flap transfers.
(DIP) joints, and toetip transfers for fingertip reconstructions. In addition, many new free tissue transfers have been developed, including vascularized appendix transfer for urethral reconstruction; partial auricular transfer for alar defects; upper eyelid loss; vascularized nerve grafts with perforators; toe web transfers for oral commissure defects; and lymphaticovenular anastomosis for obstructive lymphedema in the extremities. Branches of the temporal artery, facial artery, and frontal artery have been used as recipient vessels for some of these flaps in the head and neck. Vein grafts from the volar aspect of the wrist and the dorsum of the foot are other frequently used options. With the use of supramicrosurgery techniques, many new flaps and true perforators will hopefully become available in the future.

The advantages of true perforator flaps are the simplicity of the operation, the short time required for flap elevation, and versatility in donor site selection. Flaps can often be raised from concealed areas. Flap dissection is minimally invasive and the operations are very simple. Donor site morbidity can be minimized. Disadvantages are the anatomic variability and the need for supramicrosurgical dissection and anastomotic techniques.

**CLASSIFICATION OF PERFORATOR FLAPS**

We have classified perforator flaps into the categories listed in Box 21-1.

**Box 21-1  Classification of Perforator Flaps**

<table>
<thead>
<tr>
<th>Long vascular pedicled perforator flaps</th>
<th>True perforator flaps that only include the perforators</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DIEP flaps</td>
<td>• DIEP/PUP flaps</td>
</tr>
<tr>
<td>• ALT and AMT flaps</td>
<td>• ALT flaps</td>
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<tr>
<td>• TAP flaps</td>
<td>• AMT flaps</td>
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<td></td>
<td>• TFLP flaps</td>
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<tr>
<td>Short-pedicled perforator flaps</td>
<td>• TAP flaps</td>
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<tr>
<td>including a short segment of large</td>
<td>• DP flaps</td>
</tr>
<tr>
<td>vessels</td>
<td>• Paraspinal perforator flaps</td>
</tr>
<tr>
<td>• DIEP or PUP flaps</td>
<td>• GAP flaps</td>
</tr>
<tr>
<td>• ALT flaps</td>
<td>• Posterior tibial perforator flaps</td>
</tr>
<tr>
<td>• AMT flaps</td>
<td>• Medial plantar perforator flap</td>
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<td>• TFLP flaps</td>
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<td>• TAP flaps</td>
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<td>• SCIP flaps</td>
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<td>• Radial artery perforator flaps</td>
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<td>• Snuff box flaps</td>
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<tr>
<td>• Medial plantar flaps</td>
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</table>

AL; Anterolateral thigh; AMT; anteromedial thigh; DIEP; deep inferior epigastric artery perforator; DP; deltopectoral; GAP; gluteal artery perforator; PUP; paraumbilical perforator; SCIP; superficial circumflex iliac perforator; TAP; thoracodorsal artery perforator; TFLP; tensor fascia lata perforator.
INDICATIONS AND CONTRAINDICATIONS
Using supramicrosurgical techniques, new short-pedicled perforator flaps have been developed. These flaps are indicated for head and neck and extremity reconstructions, because there are many recipient perforators that are the same size as the flap perforators. In addition, tiny funicular sutures are useful for vascularized nerve flaps or for local nerve flap transfers. By free perforator-to-perforator flaps we mean true perforator flaps whose harvest does not include the parent vessel and whose vessels are less than 1 mm. To revascularize these flaps, the vessels are anastomosed to equally small perforators. True perforator flaps that have been reported include the paraumbilical (or DIEP) perforator adiposal flap and the DIEP flap for breast reconstruction. This flap can also be used for facial augmentation. Other true perforator flaps include the TAP flap used for extremity reconstruction, the ALT perforator flap for extremities, the TFL perforator flap for hand reconstruction, the medial thigh perforator flap for foot reconstruction, the GAP adiposal flap for facial augmentation, the posterior tibial perforator flap for hand coverage, and the medial plantar perforator flap for finger pulp coverage.

True perforator flaps are indicated for cases in which small recipient vessels can be found adjacent to the defect. In cases without small recipient perforators, flaps with longer and larger pedicles should be selected and anastomosed to the large recipient vessels available at the reconstructive site. Using perforators in a scarred area after radiation therapy or neck dissection must be avoided.

PREOPERATIVE MANAGEMENT
Preoperative information on the vascular anatomy of the donor and recipient sites is very important. Preoperative Doppler examinations and three-dimensional or CT angiograms are usually performed to confirm the existence of the perforators.

OPERATIVE TECHNIQUE
As a representative flap, a lower abdominal flap based on the DIEP is described in this section. The major perforators from the deep inferior epigastric artery (DIEA) are anatomically located around the umbilicus. The size of these perforators can be very large (up to 1.0 mm). The vessels that we work with typically range from 0.5 to 0.8 mm. These can be anastomosed to recipient vessels of similar size. Other vessels available in this area include the ascending branch of superficial circumflex iliac artery (SCIA), the superficial inferior epigastric artery (SIEA), and the SEV. Each perforator is usually compensative; that is, one is dominant (hypertrophic) and the other
is hypoplastic. This concept can be adapted to the ascending branch of the SCIA and SIEA\(^27\) (Figs. 21-1\(^{18}\) and 21-2).

**Fig. 21-1** A thin DIEP flap. The major perforators from the DIEA are anatomically located around the umbilicus. The flap can be thinned by removing fatty tissue in one stage.

**Fig. 21-2** The classification of free perforator flaps. **A**, A long-pedicled perforator flap. **B**, A short, T-shaped, segmental pedicled flap, which is useful as a flow-through flap. **C**, A true perforator flap.

### Preparation of the Recipient Site and Vessels

An intraoral incision through the upper buccal sulcus and a short submandibular incision are made. A small anterior branch of the facial artery, angular vein, or labial artery is exposed for use as a recipient vessel. In some cases of temporal depression, the frontal branch of superficial temporal artery (STA) is visualized through a preauricular incision.

Lower abdominal adiposal flap elevation begins with an incision through the inguinal ligament. The ascending branch of the SCIA, SIEA, SEV, or DIEP can be found in this area. As already mentioned, each perforator is usually compensative, one is dominant (hypertrophic) and the other is hypoplastic. This is often seen with the ascending branch of the SCIA (dominant) and SIEA (hypoplastic). The largest perforator is selected.

Complete hemostasis using bipolar cautery is essential, because any blood staining makes the dissection difficult and the vessels hard to see. SCIA or SIEA pedicle vessels are transected at the level of the inguinal ligament. The DIEP is transected above deep fascia, or within the rectus abdominis muscle in the case of a short, segmental, T-shaped pedicle.
The pedicle vessels are anastomosed using 11-0 or 12-0 sutures under the microscope. Using other branches, multiple vascular anastomoses with double or triple arterial and venous anastomoses are possible and often recommended.

Skin closure is performed without compression on the anastomosed vessels (sometimes a skin graft is required or, occasionally, the wound is left partly open), with drainage at the anastomosed area.

**Technical Tips and Tricks**

The theory of compensative vascular anatomy is important in flap elevation. Meticulous hemostasis with bipolar cautery helps prevent bleeding during flap elevation. Preservation of a tissue envelope around the pedicle perforator is essential. The perforator itself is never dissected. The smaller branch (less than 0.8 mm) of the main recipient artery (for example, the anterior branch of the facial artery or the frontal branch of the STA) is often more appropriate than the main artery as a recipient, because the size match with the flap pedicle vessels is better. In addition, we frequently use vein grafts, flow-through vascular anastomoses using a T-shaped pedicle vessel, duplicated vascular anastomoses, and postoperative vasodilating drugs such as prostaglandin E1 (PGE1) to optimize results.

**Pitfalls**

Vascular anomalies are unavoidable. In cases without pedicle perforators, other adjacent perforators always exist. Sometimes these vessels appear extremely small, often because of spasm. Vasodilating drugs may allow better appreciation of the true size.

**Complications**

Vascular spasm, thrombosis, and partial necrosis are common complications. These are best avoided by using atraumatic vascular dissection, loupes, complete hemostasis with bipolar cautery, and the administration of intraoperative and postoperative PGE1. Other technical tricks to maximize flow include flow-through vascular anastomoses and multiple vascular anastomoses using a single vascular source with its branches, or end-to-side anastomoses. In cases with a vessel size discrepancy, vein grafts or end-to-side anastomoses are recommended. Drainage and noncompressive dressings are essential to prevent venous occlusion and hematoma at the site of the anastomosis.

**Optimizing Outcomes**

Less-invasive flap transfer is possible, with perforator-to-perforator flaps leading to improved outcomes. Free adiposal flaps such as DIEP, TAP, GAP, SIEA, and SCIP flaps are useful for facial and temporal augmentation. Eyelids and circumferential tracheal losses are repaired with partial auricular flap transfers. Also, vascularized nerve flaps and funicular nerve sutures and transfers are very useful for nerve repair.
RESULTS
Scalp Defect With a True DIEP Adiposal Flap

This 42-year-old woman had malignant melanoma (Fig. 21-3, A). It was widely resected to include periosteum. The defect was resurfaced with a true thinned DIEP flap using only a DIEP (Fig. 21-3, B and C). The small pedicle perforators (0.8 mm) were anastomosed to the distal level of the superficial temporal vessels. Fatty tissue was removed in one stage (Fig. 21-3, D). There is no flap necrosis postoperatively (Fig. 21-3, E).

Fig. 21-3  A, A malignant melanoma with the outline of the planned resection. B and C, The design and elevation of a true thinned DIEP flap with only a short perforator. The recipient vessel was the distal level of the STA. D, Fatty tissue removed in one stage. E, There is no postoperative flap necrosis.
Cheek Augmentation With a Free SCIP-SIEA Adiposal Flap

An adenoid cystic carcinoma was resected in this 53-year-old woman. However, severe contracture of the right buccal mucosa and right maxillary loss resulted in depression of the right cheek (Fig. 21-4, A and B).27 A free lower abdominal adiposal flap was planned, because the prepared subcutaneous pocket was surrounded with severe fibrosis (Fig. 21-4, C). The flap was transferred with a short length of SCIA, SIEA, and SEV. A preauricular branch and frontal branch of the STA (0.8 mm each) were anastomosed to the SIEA and SCIA. The SEV of the flap was joined to the superficial temporal vein (STV) (Fig. 21-4, D). Postoperatively, there is no flap atrophy or necrosis (Fig. 21-4, E and F).

Fig. 21-4  Facial augmentation with a free SCIP-SIEA adiposal flap. A, This 53-year-old woman presented with adenoid cystic carcinoma. She lost the right malar bone and had severe contracture of the right buccal mucosa. B, A three-dimensional CT scan of the defect. The unusual appearance of the area around the teeth is an imaging artifact. C and D, A free adiposal flap was transferred with a short length of SCIA, SIEA, and SEV. The preauricular branch and frontal branch of the STA (each 0.8 mm in diameter) were joined to the SIEA and SCIA. The SEV of the flap was joined to the STV. E and F, The patient is seen 16 months postoperatively. There is no flap atrophy.
Tracheal Reconstruction With an Auricular Conchal Flap

A 59-year-old man lost his cervical trachea in an injury (Fig. 21-5, A and B). The tracheal cannula could not be removed, because the loss was circumferential. A free vascularized full-thickness conchal flap of 5 by 5 cm was transferred with a short segment of the superficial temporal vessels (Fig. 21-5, C and D). Although the flap showed temporary congestion, it survived completely. One month after surgery, the cannula was removed without any stenosis of the trachea (Fig. 21-5, E and F).

Fig. 21-5  A and B, This patient had tracheal loss after trauma. The tracheal cannula could not be removed because of total circumferential loss of the trachea, as seen in the MRI scan. C and D, A free vascularized full-thickness conchal flap with a short segment of the superficial temporal vessels was transferred. E and F, The cannula was removed 1 month after surgery. No tracheal stenosis was observed.
Upper Eyelid Reconstruction With Auricular Chondrocutaneous Flap

A skin cancer of the right upper eyelid in a 66-year-old man was widely resected (Fig. 21-6, A). An island pinna flap with a reverse arterial flow and normograde venous flow of the STA was harvested (Fig. 21-6, B). After flap transfer, the proximal end of the STV was anastomosed to a subcutaneous vein at the lateral canthal area. Buccal mucosa was grafted on the inner side of the flap. The levator muscle was sutured to the auricular cartilage within the flap.

Fig. 21-6  A, This 66-year-old man had skin cancer in the upper right eyelid. Subtotal eyelid resection was performed with an auricular chondrocutaneous flap. B and C, An island pinna flap (P) was designed with a reverse arterial flow and normograde venous flow of the STA. After flap transfer, the proximal end of the superficial STV (S) was anastomosed to the subcutaneous vein (Z) at the lateral canthal area. Buccal mucosa was grafted on the inner surface of the flap. The remaining levator muscle was sutured to the auricular cartilage (C) in the flap.
Postoperatively, there is no flap congestion or corneal ulcer (Fig. 21-7). The patient can completely close and open the right eyelid.13

**POSTOPERATIVE MANAGEMENT**

We generally use PGE1. These flaps are very susceptible to compression, so it is important to go to some lengths to avoid it. Compressive dressings or bandages in particular should be avoided, if possible. Compression is a concern at the time of wound closure. A split-thickness skin graft is used, or the wound is temporarily left open or covered with a synthetic skin substitute. It is essential to perform early reexploration when vascular occlusion is suspected.
CRITICAL POINTS

**Must Know**
- Microvascular surgeons must have training in supramicrosurgical nerve and vascular dissection.
- A superior technique for supramicrosurgical anastomosis and funicular suture is essential.

**Should Know**
- Microvascular surgeons should know the microanatomy of perforator flaps and be aware of variations and anomalies of perforators, the compensative theory on the anatomy of perforators,\(^{27}\) and the vascular supply of the peripheral nerves.

**Synopsis**
- With continued development of supramicrosurgical techniques, many new flaps with true perforators have been described. These flaps and vascularized tissues may be transferred with minimal skin incisions and, in some cases, using only local anesthesia.

A part of this work was reported at the First International Course on Perforator Flaps in Gent in June 1997, the First and Second Congresses of the World Society of Reconstructive Microsurgery in Taipei and Heidelberg in October/November 2001 and June 2003, respectively, and the Thirteenth Congress of the International Plastic Reconstructive and Aesthetic Surgery in Sydney in August 2003.

### References

   *This work reports on the first documented use of supramicrosurgery.*


   *This article presents the first use of a free vascularized appendix transfer. For urethral reconstruction in cases with poorly vascularized tissue and for total penile creation, a new technique involving a free vascularized appendix transfer combined with a radial forearm osseocutaneous flap was successfully used in two cases.*

The authors present the first use of the free retroauricular flap with two new one-stage methods for resurfacing a part of the face: (1) the microvascular transfer of a free retroauricular flap and (2) an island flap from the galea covered by a full-thickness skin graft from the retroauricular region. Both procedures provided good color match, without leaving a readily visible donor scar.


This article presents one of the first lymphaticovenous anastomosis for lymphedema. Microlymphatic surgery appears to have a worthwhile clinical application in the treatment of secondary obstructive lymphedema. The authors prefer three or more lymphaticovenous anastomoses at or above the elbow; otherwise, ablative procedures are recommended. In the selected cases, two advantages of anastomoses over surgical reduction procedures are: (1) the incidence of postoperative cellulitis is significantly less and (2) the microlymphatic techniques are applicable to upper and lower limbs and could perhaps be extended to localized cases of obstructive lymphedema after trauma and for congenital constriction bands.


This article presents the first internationally used classification of free perforator flaps. New flow-through perforator flaps with a large-diameter, short vascular pedicle are proposed because of their clinical significance and high success rate with reconstruction of the lower legs. Of 13 consecutive cases, the authors describe two cases of successful transfer of a new short-pedicled anterolateral or anteromedial thigh flow-through flap for coverage of soft tissue defects in the legs.


This article presents the first use of a true DIEP adipofascial flap. Scarpa’s fascia is a prominent superficial fascial system of the body. It consists of a single, wide membrane between the superficial fatty layer and deep fatty layer in the lower abdominal wall. The authors describe a case with a wide scalp defect resulting from a resection of a dermatofibrosarcoma, and reconstruction of the defect with Scarpa’s adipofascial flap (that is, a combined parauvibilical perforator–based adipofascial flap–groin adipofascial flap).


This article presents the first description of a true medial plantar perforator flap. This perforator flap has no fascial component and is nourished only by perforators of the medial plantar vessel and a cutaneous vein or a small segment of the medial plantar vessel. The advantages of this flap are minimal donor site morbidity, minimal damage to the posterior tibial and medial plantar systems, no need for deep dissection, the ability to thin the flap by primary removal of excess fatty tissue, the use of a large cutaneous vein as a venous drainage system, a good color and texture match for finger pulp repair, a short time for flap elevation, possible application as a flow-through flap, and a concealed donor scar.


This article describes new anatomic findings on the SIEA system and the clinical application of the intraorally transferred SIEA adiposal flap for facial augmentation. The author found that hypoplasity of the SIEA system can be compensated for by the dominant, ascending branch of the SCIA system.

CHAPTER 22

Free-Style Free Flap

Chin-Ho Wong, Fu-Chan Wei

HIGHLIGHTS

- The surgical approach for the free-style free flap allows a free flap to be harvested, based only on skin vessels that are localized using handheld Doppler sonography.
- The skin vessel is isolated and mobilized in a retrograde manner, often necessitating intramuscular dissection to achieve an adequate pedicle length and caliber.
- The source artery can be variable and may not necessarily need to be isolated as long as the pedicle length and size are adequate.
- Free-style free flaps give surgeons unparalleled freedom and versatility in the choice of donor sites.
- This flap can also be used when anatomic anomalies can be handled safely and with confidence by completely mobilizing the pedicle to clearly evaluate its anatomy.
- The concepts and technique used for free-style free flaps can be used to elevate free-style island pedicle flaps.

The development of perforator flaps in the 1990s caused a fundamental shift in the conventional concepts of harvesting flaps. The intramuscular dissection of musculocutaneous perforators to completely skeletonize vessels from their source to the skin is central to the practice of perforator flap surgery. Although this approach was initially received with great reservation and caution by many microsurgeons, it has subsequently proved viable and safe when performed properly. The development of many flaps that are commonly used today, notably the deep inferior epigastric artery (DIEA) perforator flap and the anterolateral thigh (ALT) perforator flap, attests to the reliability and superiority of this technique compared with
those of conventional musculocutaneous flaps. Microsurgeons in many centers around the world are now trained in the use of perforator flap–type surgeries, significantly enhancing the technical prowess of the microsurgical community at large.

The concept of free-style free flap surgery evolved from this burgeoning application of perforator flaps. The surgical approach for free-style free flaps involves harvesting a cutaneous flap unit from any region of the body, with the requisite condition that a sizable skin vessel can be located using handheld Doppler flowmetry. This method is called free-style, because unlike conventional flap harvest, it is not strictly based on a particular, named pedicle but is harvested by retrograde dissection of the selected skin vessel until a sufficient pedicle length and caliber are achieved. The actual source vessel of the skin vessel need not be isolated and can vary. These unique features give this type of flap unparalleled versatility and freedom in donor site selection and advance microsurgery a step closer to the reconstructive ideal of replacing “like for like.”

**INDICATIONS AND CONTRAINDICATIONS**

The specific defect requirements and the donor site considerations help determine the type of flap to use. If a free-style flap is selected, the risk of harvesting flaps in a free-style manner versus the benefit of reduced donor site morbidity must be considered. Although free-style free flaps are generally considered more technically challenging than conventional flaps, the risk of failure decreases with a surgeon’s experience and comfort performing the technique. As with all new techniques, the indications slowly expand with this experience. In our practice, free-style free flaps are also indicated and are particularly useful in patients who have undergone multiple free flap procedures, exhausting the usual donor sites.

Contraindications for the use of free-style flaps include large defects, complex defects, and the requirement for a long pedicle. Doppler sonography can be used to reliably predict the adequacy of skin vessels 0.5 mm or larger; however, sonography cannot predict the size or even the presence of sizable branches that supply muscle or bone directly. Therefore the use of free-style free flaps is not advised in large defects needing bone or muscle as components of the reconstruction. Also, in complex defects such as those needing two separate skin islands, there is no guarantee that vessels in proximity to each other have a common source vessel. This anatomy is in contrast to that of well-studied flaps, such as the ALT perforator flap, in which cutaneous vessels on the lateral thigh usually converge on the descending branch of the lateral circumflex femoral artery. Cases needing a long pedicle are a relative contraindication. Although vein grafts can be used to overcome the problem of inadequate pedicle length, it is best to avoid such maneuvers to decrease the complexity of the reconstruction. Specific cases may present relative contraindications, such as a failed free flap.
PREOPERATIVE MANAGEMENT

The preoperative preparation and counseling for patients scheduled for a free-style free flap procedure is the same as those for a patient undergoing free flap surgery. Imaging such as color duplex scanning and multidetector-row helical computed tomography (MDCT) is useful, particularly during a surgeon's initial experience with these flaps. However, they are costly and time consuming. Color duplex imaging allows direct evaluation of the caliber and hemodynamic characteristics of skin vessels, with a high sensitivity and 100% positive predictive value.\(^\text{14,15}\) However, this modality is expensive, time consuming, and most important, operator dependent. MDCT has a high sensitivity and specificity for locating sizable perforators, but its use exposes patients to significant doses of radiation.\(^\text{17}\) We do not routinely use these modalities in our preoperative preparations.

OPERATIVE TECHNIQUE

We examine the defect and determine the required flap size, thickness, color, texture, and pliability, as well as the approximate pedicle length and diameter, then select the donor region according to these requirements. The area is assessed using a handheld Doppler unit. All skin vessels in the area are marked with appropriately sized dots. The operator carefully notes the quality of the Doppler sounds detected, paying particular attention to the location of loud, high-pitched, and pulsatile signals. These are preferentially marked with larger dots. At this point, the approximate pedicle length that can be obtained with the free-style free flap is estimated by measuring the distance from the selected skin vessel to the main vessel supplying the region—the vessel that cannot be sacrificed. In the thigh area, for example, this is the superficial femoral artery, and the pedicle length extends from the point on the skin to the surface marking of this vessel. This is only an approximation, because not all pedicles run in a straight line and some have inherent redundancy after being completely mobilized. The skin vessels that best meet these requirements according to their Doppler imaging quality and the pedicle length are selected. The flap is designed based on these skin vessels.

Dissection is performed under loupe magnification (2.5× to 3.5×). Only one border of the proposed design should be incised initially for exploration. This affords the flexibility to alter the flap design if necessary, based on intraoperative findings. The flaps are dissected either suprafascially or subfascially; the former is preferred, because it minimizes donor site morbidity by preserving fascia and cutaneous nerves that run immediately above the fascia. Sizable subcutaneous veins should also be preserved and included with the flap. These can be traced proximally for a certain distance; this step may be invaluable for augmenting venous outflow if congestion occurs after revascularization. It is important to maintain meticulous hemostasis, because excessive bleeding and subsequent staining of the tissues interfere with clear visualization and accurate, timely identification of small vessels. After sizable cutaneous vessels are found, the deep fascia is cut around the selected vessel to start mobilizing it. This may entail intramuscular dissection for musculocutaneous per-
forators, or it may be relatively straightforward in the case of septocutaneous or direct cutaneous vessels. Other cutaneous vessels may be in the vicinity of the selected vessel. These should not be ligated until the selected vessel has been completely mobilized, because these may be needed if the selected vessel is inadvertently injured during dissection. Also, if a large flap is needed, more than one skin vessel may be required to nourish the flap. Retrograde mobilization of the pedicle is continued until a sufficient length and/or size is obtained. At this point, the adequacy of the pedicle and reach of the flap are assessed. The final step involves islanding the flap. This step is the last opportunity to tailor the flap to fit the defect. The pedicle is traced to its parent vessel, which cannot be sacrificed. In the thigh region, this is the superficial femoral artery. The pedicle length and diameter are now fixed. If more pedicle length is needed, two maneuvers can increase the effective length of the pedicle. First, the skin vessel is usually placed in the center of the flap in the initial design. Extending the skin incision distally places the skin vessel eccentrically at the tip of the flap and recruits more tissue distally, thereby increasing the reach of the flap and the effective length of the pedicle. The proximal portion of the skin is not needed and returned to the donor site (Fig. 22-1). Second, two or more skin vessels are usually incorporated with the initial flap harvest. Including multiple skin vessels has the effect of tethering the pedicle down to the flap.

Fig. 22-1  Increasing the effective length of the pedicle. The initial incision is made from A to B (the dashed line indicates the initially planned flap). If the pedicle length is insufficient, the flap can be shifted distally, placing the skin vessel eccentrically within the flap. The incision is extended to C, and part of the proximal incision that is not used is resutured. This maneuver shifts the skin flap distally, effectively increasing the reach of the pedicle.
If the flap is deemed adequately nourished by a single perforator, ligating smaller skin vessels or less important vessels increases the pedicle length (Fig. 22-2). These maneuvers can, at best, modestly increase the pedicle length. If the length is still not sufficient, the backup plan should be used (see Complications). Once all of these considerations are addressed, the flap is completely islanded, and the pedicle is divided. Fig. 22-3 shows a clinical case of a free-style free flap harvested from the lateral leg.

**Fig. 22-2** The configuration of a skin flap with two preserved cutaneous vessels. Having multiple vessels has the effect of tethering the pedicle down to the flap. By ligating the proximal vessel (B), the redundancy in the pedicle between the proximal and distal vessel (A) can be used to increase the reach of the pedicle.

**Fig. 22-3** A, Skin markings for a planned free-style free flap from the lateral leg. B, Three cutaneous vessels (arrows) were identified. C, After the intramuscular dissection, two of the perforators were noted to converge, and this was traced further proximally to obtain an adequate pedicle length. The third vessel was ligated. D, A free-style lateral leg flap was harvested.
**Complications**

The use of free-style flaps minimizes donor site morbidity, but complications may occur. For example, the flap may not meet the reconstructive needs for a variety of reasons, including failure to locate a sizable skin vessel, injury to the delicate vessel during dissection, and inadequate length and/or size of the selected skin vessel. Because of these potential complications, a backup plan is always required when performing free-style free flap procedures. By preserving cutaneous nerves and fascia during the harvest, the potential donor site morbidity is negligible if the originally chosen flap is abandoned. Fig. 22-4 shows skin markings for a surgical plan with a backup flap. Preoperatively, this patient’s medial thigh was evaluated and the location of all cutaneous vessels marked. At the same time, the skin markings and cutaneous vessel locations for the ALT perforator flap (an area with which we are familiar) were indicated as a backup flap. The initial incision was made at the common border of these two flaps to provide the flexibility of switching from the medial thigh free-style free flap to the ALT flap and to minimize unnecessary incisions. The flap was elevated in a lateral to medial direction. If no suitable skin vessels had been found, the dissection could have been shifted toward the lateral side to harvest the backup ALT flap.

![Fig. 22-4](image-url)

*Fig. 22-4  A, Perforators on the medial thigh were localized using a handheld Doppler probe. The conventional ALT flap was also marked as a backup flap. B, The flap was elevated suprafascially until the cutaneous perforators were visualized (arrows). C, The deep fascia was opened to begin retrograde dissection of the selected vessels (arrows). In this case, two were septocutaneous vessels and the third was a musculocutaneous perforator with a short intramuscular course. D, All three vessels were preserved and traced to the descending branch of the medial circumflex femoral artery, which was the flap pedicle.*
Table 22-1  Technical Pearls for Using the Free-Style Free Flap

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locating the skin vessels</td>
<td>Skin vessels with a loud, high-pitched, and pulsatile Doppler signal should be used.</td>
</tr>
<tr>
<td>Selecting the skin vessel and skin markings</td>
<td>These markings are used to determine the length of the pedicle. To maximize the chance of harvesting a flap with a long pedicle, the design should be based on skin vessels located farthest from the major regional vessels, which cannot be sacrificed. The approximate length of the pedicle is at least the distance from marking of this skin vessel to the marking of the major vessel; all intervening vessels can be sacrificed if needed.</td>
</tr>
<tr>
<td>Defining flap dimensions</td>
<td>The maximum flap dimensions that a single vessel can support are variable and dependent on the selected vessel. In general, if the skin flap is large and the reliability of the pedicle is doubtful, it may be necessary to incorporate more than one skin vessel in the design.</td>
</tr>
<tr>
<td>Placing the first incision</td>
<td>The first incision is placed at a site that shares a common border with the backup flap.</td>
</tr>
<tr>
<td>Determining venous drainage</td>
<td>Doppler flowmetry is fairly accurate in detecting a sizable arterial component of the skin vessel. However, the vein may be inherently inadequate to drain the flap. In addition, veins are more susceptible to inadvertent injury during dissection. Preserving a superficial subcutaneous vein is a good practice if venous congestion occurs after revascularization, because it provides an additional outlet for venous blood.</td>
</tr>
<tr>
<td>Increasing the effective length of the pedicle</td>
<td>The effect length of the pedicle can be increased in two complementary ways. First, the incision is extended distally to recruit more skin and the proximal part remains with the donor site. This maneuver places the skin vessel in an eccentric location within the flap. The reliability of the skin should be checked intraoperatively. Second, in a flap with more than one skin vessel harvested, the proximal vessel or vessels can be ligated to minimize the tethering effects of these proximal vessels.</td>
</tr>
<tr>
<td>Islanding the skin paddle</td>
<td>The islanding of the paddle is the final step in which the adequacy of the design is determined. At this point, adequate pedicle length and caliber must be ensured. Otherwise, the backup flap must be used.</td>
</tr>
</tbody>
</table>
The free-style free flap concept was developed to allow surgeons to reliably raise flaps of various designs, even in unfamiliar anatomic locations. However, after gaining experience and becoming accustomed to the anatomic variations in these areas, the flaps can be more reliably and predictably harvested. Furthermore, by applying the free-style free flap concepts and techniques in initial cases, the transition period from working in unfamiliar areas to working in familiar ones is shortened. As a result, the learning curve for surgeons attempting this new procedure is also shortened, and this is the true value of the free-style free flap concept.

The maximum dimensions of a flap that can be harvested based on a single perforator are a matter of some debate. Koshima\(^1\) noted that the skin paddle of an ALT flap, based on a single dominant skin perforator, could be up to 35 cm long and 25 cm wide. However, these dimensions depend on many factors, such as the size of the perforator and its location within the flap. In our practice, the skin dimensions of a free-style flap are limited to 8 by 20 cm.\(^1\)\(^2\) If a larger flap is needed, two or more skin vessels may need to be incorporated into the flap. In free-style flaps, adjacent skin vessels may not have a common source vessel, necessitating multiple anastomoses if two or more skin vessels are needed to supply or drain the flap.

To obtain optimal aesthetic and functional results in some locations (such as the intraoral and the dorsal foot areas), the flap may need to be thinned.\(^1\)\(^9\)\(^,\)\(^2\)\(^0\) Kimura et al\(^2\)\(^1\) describe thinning an ALT flap, with a radius of 9 cm around the perforator to a thickness of 3 to 4 mm by preserving a 2 cm cuff of tissue around the perforator. Although this may be a reasonable estimation in some cases, intraoperative thinning should be conservative in free-style flaps. Further thinning can always be performed as a secondary procedure, if needed, to ensure the safety of the flap.

The free-style free flap technique is a valuable component of any surgeon’s armamentarium when confronted with anatomic variations while harvesting conventional flaps. For instance, if sizable perforators are absent in the lateral thigh when attempting to harvest the ALT flap, the free-style concept can reliably be applied to harvest a backup flap near the incision.\(^8\)\(^,\)\(^2\)\(^2\)\(^,\)\(^2\)\(^3\) Sizable vessels can be dissected medially, proximally, or distally in a free-style manner. When harvesting flaps, free-style free flap techniques can safely be used to provide viable flap options in any region of the body with unfamiliar anatomic variations.

The application of free-style free flap techniques has sparked a renewed, creative use of various local flaps for coverage of difficult defects. Based on this flap concept, perforators located in the vicinity of the defect are located using Doppler imaging and flaps can be raised based on these perforators by retrograde dissection. These free-style local flaps can be advanced or rotated into the defects.\(^2\)\(^4\)\(^-\)\(^2\)\(^6\) This application of the free-style free flap concept for local flaps is reliable and versatile, and it provides an alternative solution to many difficult problems in reconstructive microsurgery.
**CRITICAL POINTS**

**Must Know**
- Handheld Doppler sonography is used to locate vessels of adequate caliber.
- Perforator flap concepts must be understood.
- The skin vessel is isolated and mobilized using a retrograde intramuscular dissection technique.
- In the event that a flap does not meet a patient’s reconstructive needs, it is essential to have a regional backup option.

**Should Know**
- The caliber of the vessels may be small (less than 0.8 mm) and the quality (especially of veins) may be fragile. Therefore surgeons should have good experience with supermicrosurgical techniques and all necessary instruments at his or her disposal.
- The free-style free flap concept can also be used to design local flaps based on skin vessels in the vicinity of the defect.

**Synopsis**
- Harvesting flaps in a free-style manner is growing in popularity and has wide clinical applications.
- The free-style free flap can be used if anatomic anomalies are found when harvesting conventional flaps. In these situations, the flap harvest can be safely and reliably completed, despite these anatomic variations, because the pedicle is followed in a retrograde manner.
- The free-style flap can also be used in rare instances in which all the conventional flaps have been exhausted in patients who have undergone multiple free flap procedures. As long as a good Doppler signal is detected, a free flap may potentially be harvested.

**References**


This paper describes the technique of retrograde dissection of the pedicle of the toe. Using this technique, the toe can be reliably harvested, regardless of any anatomic variations. In some variants, the pedicle traverses the intrinsic muscles of the foot, necessitating intramuscular dissection of the pedicle. From this experience, the technique of intramuscular dissection was developed into what is routinely used in perforator flap surgery today.

We prefer to restrict the use of the word “perforator” to refer to musculocutaneous vessels, because this implies intramuscular dissection to mobilize the pedicle. Other vessels, such as direct cutaneous or septocutaneous vessels, are thus named to avoid confusion. In this chapter, a Doppler signal detected on the skin is described as emanating from a skin vessel until the exact anatomic feature of the vessel is known.


This is the first article describing the free-style free flap technique and its role in microsurgery. The early experiences with the use of this technique, mainly in the thigh in 13 patients, were favorable. Flaps were used for head and neck reconstructions. There were no flap failures and no instances in which the authors had to resort to a backup flap.


The authors’ extensive experience with perforator flaps in the thigh allowed them to perform several free-style free flaps successfully using two methods. The first method requires preoperative Doppler mapping of all skin vessels. In the second method, an anterior midline incision is made, and the thigh is explored for sizable vessels. Flaps are designed after the vessels are selected. Free-style flaps are successfully raised without resorting to the backup plan using either method.


PART FOUR

RECONSTRUCTION BY REGION
The techniques used for scalp and dural reconstruction vary with the cause, location, size, and components of the defect and the quality of the surrounding tissues.

The reconstruction of scalp and/or dural defects with free tissue transfer should be considered if adequate coverage cannot be achieved using local tissues or if the defect results from conditions such as a frontal sinus fistula, osteomyelitis, implant exposure, or osteoradionecrosis.

Popular options for microsurgical reconstruction of scalp defects include the radial forearm flap, anterolateral thigh (ALT) flap, scapular/parascapular flap, latissimus dorsi flap, rectus abdominis flap, and serratus anterior flap.

Dural reconstruction should be watertight. The fascial component of a fasciocutaneous flap is particularly useful.

The superficial temporal artery and vein are the most commonly used recipient vessels. Although some authors prefer end-to-side anastomosis of the pedicle to the external carotid artery and internal jugular vein, we are conservative with this approach, because all neck vessels branching from the external carotid artery can serve as recipient vessels.

Flap losses are most commonly caused by vascular complications, especially venous thrombosis.

The aesthetic problems that occur after free flap reconstruction include the absence of hair-bearing skin, color mismatch, bulkiness, and contour deformity. Secondary revision with tissue expansion and serial excisions can improve the aesthetic result.
A complex scalp defect may result from trauma, tumor excision, tissue necrosis after a burn injury, implant exposure, or radiation therapy. Partial-thickness scalp defects can be managed with skin grafting. Full-thickness defects, however, are subject to bone necrosis and sequestration of the desiccated and exposed calvarium; therefore a more aggressive approach is required to achieve primary wound closure (wound coverage). The reconstruction of these full-thickness defects, especially those involving the skull and dura, presents a great technical challenge. The techniques used for reconstruction may vary with the cause, location, and size of the defect, and the quality of the surrounding tissues. In general, the scalp should be reconstructed with adjacent, hair-bearing scalp whenever possible. However, for large defects in which reconstruction with scalp tissues is not feasible, a nonscalp flap transfer from a distant site is the next option.

If the tissue defect involves the calvarium or dura, vascularized soft tissue coverage must be provided. Many reconstructive methods have been proposed for exposed bone and dura. Immediate coverage can be achieved with local or regional flaps, such as bilobed flaps, pinwheel flaps, temporoparietoooccipital (TPO) flaps,1,2 and the Orticochea three-flap and four-flap technique.3,4 These fasciocutaneous scalp flaps have the advantage of a quick, easy, and safe dissection; however, they may not be able to repair a dural defect, and their volume may not be sufficient to obliterate deep defects. From an aesthetic point of view, local or regional flaps may not be suitable for forehead reconstruction, because they may disrupt the hairline or hair growth pattern.

Several distant pedicled flaps have also been described for repairing extensive scalp defects. The vertical trapezius myocutaneous flap allows one-stage reconstruction for scalp defects located as far as the parietal areas.5 The pectoralis major and latissimus dorsi musculocutaneous flaps are the other options. However, they all have the disadvantage of unreliable distal circulation, which may result in partial flap necrosis and reconstruction failure.

In 1972, McLean and Buncke6 first reported on the use of free tissue transfer for the reconstruction of a large scalp defect; they successfully reconstructed the defect with an omental flap. Since then, many series7-21 have demonstrated the efficacy and safety of this approach.
If a calvarial defect involves the dura mater, reconstruction becomes even more challenging, because a watertight closure is necessary to prevent cerebrospinal fluid (CSF) leak. Although nonvascularized fascia lata may be useful for the repair of clean dural defects, they are not adequate for infected defects. Heller et al,19 Ozkan et al20 and Koshima et al,22 demonstrated that the ALT fasciocutaneous flap provides two vascularized tissue components for the repair of dural and scalp defects in a one-stage operation. The well-vascularized fascial components were used to repair the infected dural defects, and the skin flaps were used for coverage.

ANATOMY

The analysis of the defect and the selection of reconstructive methods require comprehensive understanding of the scalp anatomy and blood supply.

The scalp consists of five distinct layers23:

1. Skin
2. Subcutaneous tissue, which contains hair follicles, blood vessels, and nerves
3. Aponeurosis and muscle (galea aponeurotica)
4. Loose areolar tissue, which allows the scalp to be mobile on the cranium (most scalp flaps are elevated superficial to this layer)
5. Pericranium

The scalp has an extensive circulatory network, which can be divided into four vascular territories.23 Anteriorly, the scalp is supplied by the supraorbital and supratrochlear arteries and the end vessels of the ophthalmic artery from the internal carotid system. Laterally, it is supplied by the superficial temporal artery, which is the longest scalp vessel and supplies the largest area of the scalp. It is one of the terminal branches of the external carotid system. At the anterior pole of the ear, it bifurcates into the frontal and parietal branches. The frontal branch is usually dominant and courses anteriorly, and the parietal branch courses posteriorly.

Posteriorly, the scalp is supplied by two lateral and two medial branches of the occipital artery, which enter the scalp at the supranuchal line and course superiorly. Posterolaterally, it is supplied by the posterior auricular artery and its branches. These vessels are small, short, and tightly adhered to the mastoid process of the temporal bone. The collateral circulation of the scalp is so ample that a single microsurgical arterial anastomosis is sufficient to maintain viability of the entire scalp.24 The relative anatomy and vascular supply of the scalp, skull, and dura mater is shown in Fig. 23-1.
INDICATIONS AND CONTRAINDICATIONS

Complete or near-complete avulsion of the scalp is a good indication for microsurgical replantation. In 1976, Miller et al reported the first successful scalp replantation after traumatic, complete avulsion. The replanted scalp subsequently had normal hair growth and frontalis muscle function. Since then, microsurgical replantation has become the treatment of choice for completely or almost completely avulsed scalps. Cheng et al suggested that scalp replantation be performed unless an artery or vein cannot be identified or if the warm ischemia time exceeds 30 hours.

Indications for Microsurgical Free Tissue Reconstruction

Large Scalp Defects Involving the Calvarium and/or Dura

Although successful reconstruction of large scalp defects involving the calvarium can be achieved using local flaps in some cases, most surgeons now prefer to perform free tissue transfers (Figs. 23-2 and 23-3). When the dura mater is also defective,
the repair becomes even more complicated. Scalp flaps are usually not voluminous enough to fill large or deep defects, and this may result in wound-healing problems or abscess formation. Without a watertight closure of the dural defect, there is a high incidence of CSF leakage and possible meningitis. Some argue that the aesthetic outcomes of free tissue transfer may be inferior to those of local flaps, because the hairline or hair growth pattern is usually disrupted. However, it is undoubtedly the best approach for achieving one-stage reconstruction of composite defects. Reconstruction with free flaps can also be a salvage procedure after failure of locoregional scalp flaps.

Fig. 23-2  A, This 33-year-old woman underwent a brain tumor excision. A large and shallow parietotemporal scalp defect (11 by 7 cm) remained after debridement of parietal osteomyelitis. B, A thinned ALT flap was harvested for reconstruction.

Fig. 23-3  A, This 40-year-old man underwent a craniotomy for treatment of a traumatic brain injury. Two years postoperatively, he developed calvarial osteomyelitis, bone cement exposure, and a nasofrontal sinus fistula. The resulting large and deep frontoparietal defect measured 15 by 8 cm. B and C, He underwent extensive sequestrectomy and reconstruction with a chimeric free ALT skin and vastus lateralis muscle flap for coverage and dead space obliteration.
Soft Tissue Coverage for Large Defects

Myocutaneous or muscle flaps are usually selected for their capacity to resist infection and to supply blood to surrounding tissues that may have been irradiated preoperatively or require postoperative radiation therapy (Figs. 23-4 and 23-5). There is good evidence that free flaps tolerate therapeutic doses of radiation better than local flaps. These flaps are also effective for large defects with allograft exposure and infection.

Fig. 23-4  A, This 39-year-old woman had artificial dural exposure for 3 months after undergoing a craniectomy and surgical treatment of temporal anaplastic oligodendroglioma, followed by adjuvant radiation therapy and chemotherapy. This small and shallow temporal defect resulted.  B and C, The wound was debrided and reconstructed with a radial forearm flap.

Fig. 23-5  A, A small scalp/skull defect with artificial dural exposure occurred in this 23-year-old woman. After debridement and removal of the artificial dura, an ALT fasciocutaneous flap was used for reconstruction.
Compromised Recipient Site

Free flap reconstruction can be used to transfer a large amount of well-vascularized tissues into a recipient site that has been compromised by previous surgery or radiation therapy. Lutz et al, 15 McCombe et al, 17 and Hussussian and Reece 18 have demonstrated the benefits of free flap reconstruction and its success in achieving primary wound healing and local infection control.

Secondary Reconstructions for Cosmetic Improvement

Cranioplasty should be covered completely to avoid implant exposure in the event of wound dehiscence or breakdown of adjacent, compromised scalp. Local flaps usually cannot provide adequate coverage after cranioplasty, and free-flap reconstruction becomes the obvious choice. Free flaps provide well-vascularized tissue to control infection and allow tension-free coverage, which is necessary to avoid implant expo-
sure. Furthermore, composite free flaps such as vascularized ribs can be used to provide a better infection-resistant calvarial reconstruction.

A poor medical status is the only absolute contraindication for microsurgical scalp reconstruction. The main disadvantages of free flap reconstructions are flap bulkiness and the non–hair-bearing nature of the skin paddle. Additional drawbacks include technical difficulties, the lack of nearby recipient vessels, and donor site morbidities associated with microsurgical tissue transfer.

**ANALYSIS AND CLASSIFICATION OF DEFECTS**

When planning a complex scalp and forehead reconstruction, several factors must be considered in the decision-making process. First, free flap reconstruction may be required if local tissue is not sufficient to provide adequate coverage. This is also true if the scalp defect includes a frontal sinus fistula, osteomyelitis, implant exposure, or osteoradionecrosis. In addition to the size, depth, and location of the defect, the duration of treatment and comorbidities must be evaluated. Unlike reconstruction for other anatomic regions, the size of a scalp defect should not be the most important determinant for the treatment selection.

Hussussian and Reece suggested that flaps used for scalp reconstruction after the resection of malignant tumors should be able to withstand postoperative radiation therapy and be reliable enough to allow timely healing so that adjuvant treatment can be started without undue delay. Therefore, free tissue transfer, instead of local flaps, should be considered for patients with irradiated scalp wounds and those who will receive postoperative radiation therapy.

A simple and practical classification of complex scalp defects is helpful in the donor flap selection. Essentially, the flap selection should be based on the length of the vascular pedicle and the amount of tissue required to cover the defect. We suggest initially classifying defects according to the involved components and depth to match some suitable flaps. The final decision is made according to the location, wound conditions, and special considerations.

**Scalp Defect Only**

For defects involving only the scalp, thin cutaneous flaps are our first choice, followed by thin muscle flaps with a skin graft. These defects are usually caused by bone graft or implant exposure without infection, extensive resection of a malignant tumor, or avulsion trauma. Reconstructive considerations should focus on adequate coverage and good contour without bulky deformity. Our preferred flaps are the radial forearm flap, ALT perforator flap, and parascapular or scapular flap. The latissimus dorsi muscle flap with a skin graft is our second choice.
Scalp and Skull Defects
For scalp and skull defects, thickness-matched cutaneous or myocutaneous flaps are the ideal choice. If a bony defect is present, reconstruction of the calvarium should be considered to provide adequate, protective coverage for the intracranial contents and to restore calvarial contour. Cranioplasty by alloplastic calvarial replacement is expedient and does not require an additional donor site. However, when there is an increased risk of infection with alloplastic material, autologous tissue is preferred. Reconstruction using autologous bone is the benchmark for skull defects. This includes split-rib graft, calvarial bone graft, and vascularized rib transfer. Simultaneous scalp and calvarial reconstructions can be achieved in one stage using a latissimus dorsi flap with or without serratus anterior muscle and vascularized rib. If nonvascularized bone graft or alloplastic materials are used, a free flap is only used for coverage, and the decision-making process for the flap is the same as that for scalp defects only.

If intractable infection is present in the recipient site and secondary bone reconstruction is planned, concomitant scalp and skull defects can be temporarily covered with a thick, cutaneous flap. We prefer the ALT fasciocutaneous flap. A rectus abdominis muscle/myocutaneous flap or latissimus dorsi muscle/myocutaneous flap is our second choice. The second stage of reconstruction can be performed several months later with rib graft or alloplastic implants, when the signs of infection have subsided. The cutaneous flap provides a better plane for secondary bony reconstruction than the muscle or myocutaneous flap.

Scalp, Skull, and Dural Defects
For defects involving the scalp, skull, and dura, a thickness-matched fasciocutaneous flap with a well-vascularized fascia large enough to reconstruct the dural defect is our first choice. Thickness-matched flaps for coverage with a fascial graft or alloplastic materials for dural replacement is our second choice. In patients with a dural defect and exposed brain tissue, dural reconstruction should be performed using either alloplastic materials or autogenous tissue. A watertight closure is necessary to prevent CSF leakage and possible meningitis. Nonvascularized fascia lata may be useful to repair clean dural defects, but it is not adequate in the presence of infection. For these patients, dural repair with vascularized fascia is preferred, because it is more resistant to infection. It can be transferred as part of the ALT flap or tensor fascia lata flap. Our preferred flap is the ALT fasciocutaneous flap, which provides two vascularized tissue components for the repair of dural and scalp defects in one stage. Skull reconstruction, if necessary, should be delayed to a second stage when there is no residual infection or dead space.
FLAP OPTIONS

Large Flaps

The dimension of scalp defects is often underestimated. Therefore it is important to assess and measure the defect in a precise manner—creating a soft template to duplicate the defect is useful.

For large defects, the latissimus dorsi flap (either muscle only with skin graft or musculocutaneous) is the most commonly used flap for scalp reconstruction. The advantages of the latissimus dorsi muscle flap include a large dimension, suitable thickness, good pliability, good pedicle length and vessel caliber, and acceptable donor site morbidities. Furthermore, it can include rib or be combined with a serratus myocutaneous flap to form a composite tissue flap for composite bone and soft tissue defects. A vascularized rib transfer, rather than a costochondral graft, is preferred if there are signs of infection or radiation damage at the recipient area. Cosmesis after this reconstruction is usually satisfactory.

Nevertheless, there are several drawbacks of using a latissimus dorsi muscle flap with a skin graft. First, the absence of a skin paddle makes perioperative flap monitoring difficult. Second, the split-thickness graft may not be durable and stable enough for postoperative radiation treatment. Third, progressive muscle atrophy and fibrosis may lead to delayed reconstruction failure.

Scapular and parascapular flaps have the following advantages: a large hairless skin paddle with reliable circulation, similar in thickness to the scalp, a long and sizable pedicle vessel, and the possibility of primary closure of the donor site. In addition, these two skin paddles may be separated to allow three-dimensional reconstruction of a desirable contour. The main disadvantage of free scapular/parascapular flaps is the need to reposition patients intraoperatively.

The ALT fasciocutaneous flap has become our first choice for coverage of large scalp defects because of its long vascular pedicle, reliable circulation, large skin paddle, and acceptable donor site morbidities. It can be harvested while the patient is in a supine position, and simultaneously while the other team is operating on the recipient site. In addition, it can be thinned extensively and safely to become a thinner cutaneous flap when necessary. The ALT fasciocutaneous flap can also be elevated together with vastus lateralis muscle to obliterate associated dead space. It also provides a vascularized fascia, which is uniquely useful for dural reconstruction to protect the brain.

Other large flaps include the rectus abdominis muscle flap with a skin graft, vertical rectus abdominis myocutaneous (VRAM) flap, transverse rectus abdominis myocutaneous (TRAM) flap, deep inferior epigastric artery perforator (DIEP) flap, and
the omental flap. Although the omentum was the first free tissue used for scalp reconstruction, the additional morbidities associated with laparotomy have limited its use. The rectus abdominis muscle, VRAM, TRAM, and DIEP flaps are all based on the deep inferior epigastric vessels, which provide a long, reliable pedicle. This donor area allows several different designs to match variable recipient defects. However, relative flap bulkiness and possible abdominal wall weakness or even ventral hernia at the donor site are drawbacks.

**Small Flaps**

The radial forearm cutaneous flap is reserved for smaller defects because of its limited dimensions. However, it has a long vascular pedicle and is easy to dissect. This thin and pliable flap is particularly useful for contour restoration of shallow defects. The radial forearm flap is preferred by some to cover forehead defects because of aesthetic considerations. Although it can be doubled in size to meet reconstructive needs using tissue expansion, it requires an additional operative procedure and multiple office visits, resulting in a much longer time to complete the reconstruction.

The ALT flap can also be used to reconstruct small and shallow defects in relatively thin patients when raised in a suprafascial manner and further thinned. Even if the flap is still too thick after reconstruction, it can easily be thinned secondarily.

**Modified Flaps**

**Prefabracticated Flaps**

The color mismatch resulting from distant free tissue transfer in the forehead region is usually conspicuous. A prefabricated and expanded cutaneous flap from the nearby supraclavicular area has been proposed to circumvent this aesthetic concern. However, venous compromise during the early postoperative period has been noted in relatively large-dimension prefabricated flaps. Supplemental venous drainage with medical leeches is usually required. The complexity and staged nature of this reconstruction technique limit its wider application.

**Adipofascial Flap**

Koshima et al described a case in which a wide scalp defect was reconstructed with Scarpa’s adipofascial flap (that is, a combined paraumbilical perforator–based adipofascial flap-groin adipofascial flap). This thin and pliable flap is good for contour restoration. However, a skin graft is necessary. Another disadvantage of this flap is that the territory with a single artery may be smaller than a skin flap with the same artery. Kimata et al also reported a case in which a free adipofascial flap was harvested from the scapular area for scalp reconstruction. Reconstruction with this flap has the potential of providing a better size and thickness match to the scalp defect.
TECHNIQUE

The harvest technique for any of the previously described flaps can be found elsewhere in this book. This section describes techniques that are uniquely applicable to scalp reconstruction.

RECIPIENT VESSELS

The superficial temporal artery and vein are the most commonly used recipient vessels. They are preferred because of their availability, easy dissection, and adequate caliber (about 2 mm in diameter) when traced to the pretragal region. They are usually the closest recipient vessels to scalp defects. However, they are still relatively distant for defects located at the midline or vertex regions. Vein grafts should be used if necessary. An alternative solution to inadequate pedicle length is to design a longer flap and advance its vascular hilum toward the recipient vessels. Occipital and postauricular arteries are sometimes available, but their concomitant veins are usually of insufficient caliber. The external jugular vein is an alternative choice in this situation.

When exploring the recipient vessels, those rendered small or unhealthy as a result of previous procedures or radiation therapy are sometimes encountered. In these situations, we may look for vessels in the neck. Hussussian and Reece\textsuperscript{18} preferred to use the external carotid artery and internal jugular vein with end-to-side anastomoses. However, in our experience, we have not had to use the carotid artery. The use of superficial temporal vessels on the contralateral side is another option. Similarly, the ipsilateral facial artery and vein and the superior thyroid artery and vein are potential recipient vessels.

Adequate preoperative planning can help avoid the use of vein grafts. We suggest preparing the recipient vessels before starting the free flap harvest to ensure a proper flap selection. We can also modify the flap design or harvest a larger flap to extend the pedicle length. A carefully chosen flap with good pedicle length generally makes vein grafts unnecessary.

COMPICATIONS

Major complications related to scalp and dural reconstruction include meningitis, brain abscess (Fig. 23-6), CSF infection, intracranial hemorrhage, cerebrovascular accidents, and pulmonary emboli, which may cause perioperative mortality. All of these complications are highly associated with a patient’s medical status, and they may occur even if a successful reconstruction is achieved. However, survival of the total transferred flap, without CSF leakage and with adequate control of local infection,
can decrease the incidence of these major complications. In 2001, McCombe et al17 reviewed a consecutive series of 32 free flap reconstructions in 29 patients with cutaneous malignancy of the scalp and forehead. The major complication rate was 10%. In their study, substantial morbidity was seen in the older patients, with one death related to thromboembolism and two cerebrovascular accidents. Age has an influence on the perioperative morbidity associated with microvascular transfer. Ioannides et al13 reported on 31 patients with large scalp and cranial defects who underwent reconstruction with a total of 36 free tissue transfer and scalp flaps. Major complications included meningitis leading to death in one patient and complete free flap loss resulting from venous ischemia in another.

![Image](image.png)

**Fig. 23-6** The patient shown in Fig. 23-3 developed seizures and a ventricoperitoneal shunt infection 3 weeks after the free ALT myocutaneous flap transfer. CT imaging of the brain revealed a left frontal abscess (about 2.3 cm in diameter) anterolateral to the frontal horn of the lateral ventricle. The patient's symptoms subsided and she regained consciousness 2 days after the abscess was surgically drained.

Minor complications related to scalp and dural reconstruction include partial flap loss, wound infection or dehiscence, implant exposure, and CSF leakage, any of which may result in reconstruction failure. Partial flap loss worsens the exposure of nonvascularized grafts and the control of local infection. In 2002, Hussussian and Reece18 reported a 59% overall complication rate, with 32% of patients requiring a secondary surgical procedure. Most of the complications involved wound healing. The authors emphasize that meticulous attention to ensure complete flap viability in the operating room and careful postoperative positioning are critical in reducing wound-healing problems. CSF leakage is not a major complication, but it may lead to disastrous meningitis. To avoid CSF leakage and possible meningitis, a watertight dural seal with well-vascularized tissue is preferred, because it can resist local infection.19
Flap losses are mainly attributable to vascular complications, including venous thrombosis, arterial occlusion, pedicle kinking or twisting, and compression of the vascular pedicle by hematoma, inadequate tunnel, or excessively tight wound closure. Vascular complications warrant reexploration to identify and rectify the problems and restore adequate circulation as quickly as possible. Early detection of vascular compromise and reexploration can lead to a higher flap salvage rate.\textsuperscript{32,33,40,41}

In reviewing the literature, we found that venous insufficiency is the main reason for flap loss and reexploration.\textsuperscript{13,15,17,18} In 1998, Lutz et al\textsuperscript{15} reported on 30 free flaps performed in 29 cases of scalp reconstruction. Two complete failures occurred (6.7%), both caused by venous compromise. Another flap required reexploration twice and revision of the venous anastomosis. McCombe et al\textsuperscript{17} reported a 6% flap failure rate and a 15.6% reopen rate. The two flap losses were also attributed to venous thrombosis, and both failed despite reexploration. Three other patients also required reexploration for venous compromise and were salvaged successfully (two with the use of vein grafts).

Comprehensive evaluation of each patient’s medical status preoperatively; adequate debridement, drainage, dead space obliteration, ensuring a watertight dural seal intraoperatively; and close monitoring and intensive care postoperatively are principles that decrease the complication rate.

**OPTIMIZING OUTCOMES**

The main purpose of microsurgical scalp reconstruction is to achieve adequate wound coverage and dead space obliteration. Complete flap survival with infection control is the basic requirement.

As described previously, venous insufficiency is the main cause of flap loss and reexploration.\textsuperscript{13,15,17,18} To decrease these vascular complications, we suggest the following: First, microvascular anastomosis should be tension free, especially for the vein. Second, the tunnel for the pedicle should be able to accommodate the surgeon’s index finger without resistance. Third, a longer skin paddle can be designed to provide defect coverage as well as pedicle protection and tension release. Fourth, adequate drainage is critical to avoid hematoma formation and subsequent infection. Fifth, care must be taken postoperatively to avoid external compression over the vascular pedicle. The effect of gravity can cause movement of a bulky flap, which may subsequently pull or compress the vascular pedicle and lead to vascular insufficiency.

A customized flap design helps to achieve infection control, wound coverage, and an optimal aesthetic outcome. Appropriate donor flap selection can provide more accurate flap volume to the recipient area to minimize a bulky or sunken deformity. For example, a thin and pliable flap can achieve a better contour restoration if the calvarium is intact. However, some residual aesthetic problems still occur after free
flap reconstructions, including the absence of hair-bearing skin, color mismatch, and contour and bulk deformity. Secondary revisions can improve the aesthetic outcome. These include tissue expansion, staged excision, flap thinning/debulking, and onlay skin grafts.

Tissue expansion has been well described for coverage of large scalp defects, and it offers the advantage of reconstruction with hair-bearing skin. Although the presence of high-grade malignancy precludes tissue expansion, tissue expanders can be used before the resection of low-grade scalp tumors such as basal cell carcinomas. The other role of tissue expanders is to replace scar tissue, or even flaps used for primary wound coverage, with local skin to improve the color match, hair pattern, and texture.

Composite tissue allograft (CTA) transplantation holds great promise to achieve functional and aesthetic outcomes. In 1982, Buncke et al reported on the microvascular transplantation of two free scalp flaps between identical twins. Jones et al reported on a rectus abdominis flap allotransplantation for scalp reconstruction in a patient who was already taking immunosuppressive medications for renal transplantation. Because of various ethical issues, the clinical application of CTA is limited at present. However, the refinement of immunosuppressive techniques may popularize the clinical application of CTA in the future.

**CONCLUSION**

Popular options for microsurgical reconstruction of scalp defects include the radial forearm flap, ALT flap, scapular/parascapular flap, latissimus dorsi flap, rectus abdominis flap, and serratus anterior flap. The ALT flap is ideal for scalp coverage reconstruction because of its reliable circulation, large surface area, lower donor site morbidity, and long vascular pedicle. Good contour of the scalp can usually be achieved. This flap also allows a two-team approach whereby flap harvesting and tumor resection or wound debridement can be performed simultaneously. When harvested as a fasciocutaneous flap, the ALT flap is uniquely useful for simultaneous reconstruction of a dural and scalp defect, because it can provide a well-vascularized fascia to replace the missing dura. The superficial temporal artery and vein are the most commonly used recipient vessels. Although some authors prefer to perform end-to-side anastomosis of the pedicle to the external carotid artery and internal jugular vein, we are conservative with this approach, because all neck vessels branching from the external carotid artery can serve as recipient vessels. Flap losses are most commonly caused by vascular complications, especially venous thrombosis. The aesthetic problems after free flap reconstruction include the absence of hair-bearing skin, color mismatch, bulkiness, and contour deformity. Secondary revision with tissue expansion and serial excisions can improve the aesthetic result.
CRITICAL POINTS

Must Know

- Thorough knowledge of scalp anatomy is crucial.
- Knowledge of the indications for microsurgical scalp and/or dural reconstruction is essential.
- An appropriate donor flap selection is a priority.
- Vascular complications should be minimized or, ideally, avoided.

Should Know

- Reconstruction options for scalp and dural defects are chosen based on the cause, site, size, depth, surrounding tissues, aesthetic subunits, and the duration of treatment.
- Available recipient vessels are usually remote. However, the use of vein grafts should be avoided. It is important that the donor flaps selected for scalp reconstruction have a long pedicle.
- Popular options for microsurgical reconstruction of scalp defects include the radial forearm, ALT, scapular/parascapular, latissimus dorsi, rectus abdominis, and serratus anterior flaps.
- The superficial temporal artery and vein are the most commonly used recipient vessels. However, all neck vessels of an appropriate size that can be reached by the vascular pedicle of the flap can serve as the recipient vessels.

Synopsis

- The techniques used for scalp and dural reconstruction vary with the cause, location, size, component or components of the defect, and the quality of the surrounding tissues.
- Free tissue transfer should be considered for the reconstruction of scalp and/or dural defects if adequate coverage cannot be achieved using local tissues, or if the defect results from conditions such as a frontal sinus fistula, osteomyelitis, implant exposure, or osteoradionecrosis.

References

Unlike reconstruction for other anatomic regions, the size of the scalp defect should not be the most important determinant. Surgeons must also consider the duration of treatment, the cause, and each patient’s comorbidities. The authors conclude that free-flap procedures are appropriate for scalp reconstruction in trauma, osteomyelitis, and osteoradionecrosis cases, and following radical resection of malignant tumors.

This study suggests that flaps used for scalp reconstruction after resection of malignant tumors should be able to withstand postoperative radiation therapy and be reliable enough to allow timely healing so that patients can begin adjuvant treatment without undue delay. Therefore, free tissue transfer, instead of local flaps, should be considered for patients with previously irradiated scalp wounds and for those who will receive postoperative radiation therapy. The authors also emphasize that meticulous attention to ensure complete flap viability in the operating room and careful postoperative positioning are critical in reducing wound-healing problems.

Dural repair with vascularized fascia is preferred in infected wounds, because it is more resistant to infection. In this study, the ALT fasciocutaneous flap provided two vascularized tissue components for the repair of dural and scalp defects in a one-stage operation. The well-vascularized fascial components were used to repair the infected dural defects. The skin flaps were used for coverage reconstruction. Skull reconstruction, if necessary, should be delayed to a second stage when there is no residual infection or dead space.


Skull base surgery has advanced significantly in the past two decades with the improvement of diagnostic and surgical technique and the use of a multidisciplinary team. The use of vascularized tissue for reconstruction of skull base defects has contributed significantly to a decrease in perioperative complications and the improvement of patient outcomes. Successful reconstruction in the skull base depends on several key principles to minimize the likelihood of perioperative complications, including a watertight dural seal, a barrier between the aerodigestive tract and dura, and obliteration of dead space. Local flaps are useful for small defects, but larger defects are best treated with free tissue transfers, and the rectus abdominis muscle flap is an excellent choice for these complex defects.
The resection of lesions in the skull base region can result in extensive defects that require complex reconstruction. Because of the anatomic nature of the skull base, postoperative complications may be devastating; therefore reconstruction in this region presents a surgical challenge that requires a comprehensive approach. Historically, surgical treatment of cranial base tumors had a poor prognosis and resulted in poor outcomes. However, because of the advancements of operative techniques, diagnostics, interventional radiology, and the multidisciplinary team approach, successful surgical treatment of most skull base tumors is now possible.

ANATOMY

Key points for the anatomy of the skull base region include the following:
- The intracranial surface is formed by the anterior, middle, and posterior cranial fossae.
- The extracranial surface is formed by the infratemporal fossa, nasopharynx, sphenoid sinus, and orbital roof.
- The skull base is divided into regions I, II, and III.
- Each region has its own incidence, pathology, and prognosis.

The intricate anatomic structures located in the skull base make the management of any lesion in this region difficult. The skull base intracranial surface is formed by the posterior, middle, and anterior cranial fossae. The extracranial surface of the skull base supplies structure to the infratemporal fossa, nasopharynx, sphenoid sinus, and orbital roof. Critical neural and vascular structures traverse this region through numerous foramina and canals. Because of the complex surgical approaches to the skull base, this region has been classified into different regions and zones by several authors. Jackson and Hide\(^1\) introduced their classification system to assist operative reconstruction of the skull base. They divided the region into two main areas: the anterior area, which consists of the anterior cranial fossa, and the posterior area, which is further divided into the posteroanterior, posteroentral, and posteroanteroposterior regions. Jones et al\(^2\) classified the region into the anterior, middle, and posterior regions, which relate to the anterior, middle, and posterior fossae. Irish et al\(^3\) established a classification of three regions based on the tumor growth patterns and anatomic location of tumors that invaded the skull base in 73 patients. They classified region I tumors as lesions arising from the orbit and sinuses, those extending into the anterior cranial fossae, and those originating in the clivus or extending as far posteriorly as the foramen magnum. Region II lesions were classified as tumors originating in the lateral skull base or extending into the middle cranial fossa, involving predominately the infratemporal and pterygopalatine fossae. Lesions in region III may extend to the posterior cranial fossae but primarily occur in the region of the ear.
and parotid or temporal bone. Significant variation in outcome and prognosis occur as a result of the diverse pathologies and locations of patients’ lesions. Therefore the classification of neoplasms in the skull base region is useful to understand and predict outcome and prognosis.

**INDICATIONS**

The indications for skull base surgery depend on the nature of the disease, the location, the extent, and the prognosis of the patient. The decision to offer surgery is generally a multidisciplinary one based on all of these factors. Accurate tissue diagnosis with appropriate imaging can help guide the decision process. If surgery is contemplated, reconstructive plans must be part of the planning process.

**SURGICAL OPTIONS AND APPROACHES**

Complex defects following tumor ablation in the head and neck region often require structural support and soft tissue bulk; however, there are unique challenges and considerations when managing a defect in the skull base region. To minimize the potential for postoperative complications, it is important to ensure a watertight seal, to fill any existing dead space, and to use well-vascularized tissue for coverage (Box 24-1). Numerous reconstructive options have been introduced, including local and regional flaps and free tissue transfers. The selection should be based on several factors, including the size and location of the defect, the involved tissue, and whether the dura has been breached. The use of the classification system described by Irish et al, based on skull base zones (Fig. 24-1), has facilitated our approach for reconstruction in the skull base region (Fig. 24-2).

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**Box 24-1  Reconstructive Approach**

- Not all defects require reconstruction.
- Anterior defects may be reconstructed with local flaps if applicable.
- Principles of skull base reconstruction include:
  - A tight dural seal
  - Isolation of the dura from the aerodigestive tract
  - Dead space obliteration
  - Support of neural structures
Fig. 24-1  Three regions (zones) of the skull base by location and growth patterns of tumors.

Fig. 24-2  An algorithm for the management of skull base defects.
Skull Base Zone I

In the patient series reviewed by Irish et al., tumors were most commonly found exclusively in zone I (44%), and 6% of patients had neoplasms extending into zones I and II. Nouraei et al. reported 53% of their patients had tumors in zone I, and Chang et al. reported 40% of tumors in this region. Zone I, as classified by Irish et al., begins at the anterior midline to the orbital posterior wall and may extend into the foramen magnum. This zone is comparable to the anterior regions outlined by Jackson and Hide and Jones et al. Tumors in this area often begin in the skin of the midface or anterior sinuses and occasionally extend to the cribriform plate, dura, and brain. Patel et al. reported a poor survival rate in patients with intracranial involvement.

Surgery for these tumors requires an approach that provides access to the whole tumor for en bloc resection. The surgical approach selected also depends on the tumor size and pathology. A lateral rhinotomy or maxillotomy approach is commonly used and provides excellent exposure in most cases. However, in some patients it may be necessary to include a partial or total maxillectomy. Lesions that extend into the clivus may require a Le Fort I maxillary osteotomy and/or mandibulotomy combined with a midline split of the hard and soft palate. In some cases, complete exposure of the tumor may require a bicoronal incision with a frontal craniotomy. As with any defect following tumor extirpation, the reconstruction selected is based on the size and position of the defect and the type of tissue required.

A breached dura adds complexity that is unique to skull base reconstructions. Before the introduction of myocutaneous flaps, reconstruction in this region involved nonvascularized grafts such as split-thickness skin grafts or tensor fascia lata grafts. In many cases, these approaches proved unsuccessful. Ketcham et al. reviewed patients who had defects that were reconstructed using nonvascularized grafts and found that approximately 50% of cases acquired a cerebrospinal fluid leak. Reconstruction failures using nonvascularized grafts lead to the use of other techniques for these patients, including vascularized tissues.

Local soft tissue flaps have been described for skull base defects. These include glabellar, forehead, pericranial, and galeal flaps. These flaps provide good vascularized soft tissue coverage for small defects, and the galeal and pericranial flaps may be used for midline defects but are less reliable for more lateral defects. Price et al. reported that, in patients with a pericranial flap who underwent postoperative radiation therapy, radionecrosis of the flap was a significant complication. Myocutaneous flaps provide more soft tissue coverage, and these flaps have been useful, particularly in patients who require postoperative radiation therapy. The temporalis muscle flap is an excellent local myocutaneous flap for small defects and for defects that are more laterally located. However, when this muscle is transposed medially, the distal portion of the flap is more vulnerable to vascular insufficiency and
thus is more likely to lead to flap necrosis and/or wound dehiscence. The temporalis flap also has significant patient morbidity, which is primarily associated with the concave deformity at the donor site.

Local muscle flaps provide adequate tissue for small defects; however, these flaps may be inadequate for larger defects or when more tissue is required to fill dead space in the skull base. Pedicled regional myocutaneous flaps such as the trapezius, latissimus dorsi, and pectoralis major have been used for these types of reconstructions. However, since the introduction of free tissue transfers, pedicled regional muscle flaps have become less useful for primary reconstruction. With the advancement of surgical technique and perioperative management, free tissue transfers are now commonly used for large defects in the skull base in appropriately selected patients. However, for patients in whom free tissue transfer has failed, the pedicled myocutaneous flap is an excellent choice for a revision procedure. The free tissue transfer provides an abundant source of well-vascularized tissue, and it is now accepted as the best reconstructive option for skull base defects. The free flap does not have the attachment of the pedicle; therefore its design and inset depend on the unique requirements of each defect after tumor ablation. It is also possible to use a two-team approach (one team for tumor extirpation and one team for flap elevation), decreasing the risks associated with a longer anesthesia time.

To obtain successful reconstruction of the skull base, there must be no communication between the dura and the aerodigestive tract after tumor extirpation. Myocutaneous flaps are often used to provide a barrier between the dura and the aerodigestive tract, because they provide a large amount of vascularized tissue. These flaps may also assist with infection resistance. The rectus abdominis muscle flap provides a large amount of well-vascularized tissue and is our first choice for reconstruction of large skull base defects.

In zone I, small defects may be reconstructed with a galeofrontalis or pericranial flap and, in some cases, a temporalis muscle flap may be considered. For more extensive defects that require a large amount of vascularized soft tissue, we recommend a rectus abdominis free tissue transfer.

**Skull Base Zone II**

Zone II extends from the posterior border of the petrous temporal bone to the posterior orbital wall, and it is surrounded by the infratemporal and pterygomaxillary fossae and the middle cranial fossae. Many vascular and neural structures cross through this zone to the middle cranial fossa. These include the internal carotid artery and the trigeminal, facial, and auditory nerves. Lesions classified as zone II tumors may originate either within this zone or outside of the zone and extend into the area. Tumors that originate in zone II include nasopharyngeal and glomus jugulare tumors, meningiomas, and chondomas in the clivus, and neoplasms that invade this region include parotid tumors and basal and squamous cell tumors of the external
and middle ear and scalp. Irish et al\(^3\) found that 9% of their patients had tumors contained only in zone II, and 43% had involvement of the dura. Zone II tumors were associated with a poorer prognosis. For lesions in zone II, a hemicoronal incision with a preauricular extension is commonly used for an infratemporal surgical approach to provide good access to the condyle of the mandible and inferior displacement of the zygomatic arch if necessary. Increased exposure is possible with a mandibulectomy or mandibulotomy. A transtemporal approach may also be used with a hemicoronal incision and postauricular extension, which requires transection of the external auditory canal.\(^{26}\) In cases with intradural involvement, a frontotemporal craniotomy may also be necessary.

Following tumor extirpation, the reconstruction that is selected depends on the size and location of the defect and other patient factors (see Fig. 24-2). Smaller defects in zone II may be adequately reconstructed with a local vascularized flap such as the temporalis flap. However, this small flap is insufficient for larger defects. Historically, regional pedicled flaps were used for larger soft tissue reconstructions, including scalp,\(^{15}\) deltopectoral,\(^{27}\) pectoralis major, and trapezius flaps. With the refinement of free tissue transfer, pedicled flaps have been mostly replaced with free flaps for reconstruction of large defects in zone II. The rectus abdominis myocutaneous flap provides a long pedicle, reliable vasculature, and abundant soft tissue for reconstruction. This flap may also be modified to provide muscle extensions, which may be used to obliterate the sphenoid sinus or to provide more coverage in the neck region. Therefore, for larger defects in zone II, our choice is a rectus abdominis free muscle transfer.

**Skull Base Zone III**

Zone III includes part of the posterior aspect of the middle cranial fossa, but it consists primarily of the posterior cranial fossa. Similar to zones I and II, many critical vascular and neural structures traverse zone III, including the internal jugular vein and the accessory, glossopharyngeal, hypoglossal, and vagus nerves. The pathology of tumors in this region varies by report. Jones et al\(^2\) found that zone III tumors were commonly schwannomas and glomus cell tumors, and Irish et al\(^3\) reported that squamous cell tumors were more common. These studies are based in different geographic regions and surgical specialties; therefore this variation in reported tumor pathologies may indicate a difference in referral patterns to different surgical specialties. A transtemporal approach is often used to excise zone III lesions, which may also require bony resection around the carotid artery and sigmoid sinus. Similar to zone II, a small defect may be reconstructed using a local temporalis muscle flap or the temporoparietal fascial flap. In patients who require a radical neck dissection, local muscles may not be available because of inclusion in the resection. Therefore regional flaps may be used. Pedicled flaps such as the trapezius and latissimus dorsi muscle flaps have been described, but these flaps are less commonly used because of the availability and success of free muscle transfers. Therefore it is recommended that large defects in zone III be reconstructed with rectus abdominis free flaps in
appropriately selected patients (Fig. 24-3). If external skin coverage is required, the rectus abdominis skin paddle may be a poor color match. In these cases, the scapular flap or latissimus dorsi myocutaneous free flap may be used and will provide a more optimal skin color match.

![Fig. 24-3](image)

**Fig. 24-3**  A, This CT scan shows a region III squamous cell cancer. B, The area is outlined for resection. C, A rectus abdominis myocutaneous flap reconstruction is shown postoperatively.

**Technical Concerns**

It is important to minimize the risks associated with complications following skull base reconstruction, because any complication may be potentially life threatening. Techniques used to prevent perioperative complications include ensuring a watertight dural seal, obliteration of dead space, use of vascularized soft tissue and bone, and selection of optimal donor vessels where a free tissue transfer is necessary. For patients whose dura has been breached, successful reconstruction requires a watertight dural seal, and this is best achieved with a vascularized graft. Difficulty maintaining a watertight seal is likely related to the downward gravitational pull on the repair site caused by the anatomic position of the skull base. This may cause the graft to separate from the dura and may also create more dead space. To maintain the dural seal, the flap can be secured into position by connecting it to the surrounding bone (Fig. 24-4). The graft may be secured to the bone by drilling holes into the bone, placing the sutures through these holes, pulling the graft into place using the sutures, and securing the seal with fibrin glue. Muscle flaps are ideal for repair in this region because of their capacity to resist infection and because of the large amount of available tissue that can be packed into the dead space if necessary. In addition, a muscle flap can be used to ensure an adequate barrier between the dura and aerodigestive tract if they communicate. Reconstruction of the skull base with a free tissue transfer requires the best possible donor vessels. For most free flap reconstructions in zone I, the superficial temporal vessels are dependable and, therefore, commonly
used. For patients in whom these vessels are not available, the pedicle should be extended into the neck, and the superficial thyroid or facial vessels may be used.

Fig. 24-4  A, Following resection of the temporal bone, sutures are passed through drill holes to support the flap. B, The rectus abdominis muscle flap (white line) is inset and suspended using bone sutures.

Most free flap reconstructions in zones II and III require vessels located in the neck. The donor vessels should be selected based on caliber, pedicle length, and geometry. Because the skull base is located deep in the head and neck region, postoperative clinical perfusion monitoring is not possible. Therefore flap status should be monitored with an implantable Doppler probe.

Because of the increased risk of osteoradionecrosis in patients who undergo postoperative radiation therapy, avascular bone should not be used for reconstruction. In most cases, it is possible to achieve an excellent reconstruction with only soft tissue; however, if bony stability is necessary, vascularized bone or an allograft material such as titanium should be used.

**Complications**

Because of the proximity of the skull base to the central nervous system, particularly the brain stem, any complication arising from the skull base requires prompt treatment. The first strategy is to minimize the risks associated with perioperative complications and select the best possible reconstruction for the surgical defect, patient factors, and comorbidities. The complication rate following skull base reconstruction ranges from 11.5% to 63%, with a general decrease in complications in more recent reports.\(^4\,\text{29}\) This improvement in patient outcome likely relates to improved postoperative patient care, the use of free tissue transfers, and better surgical technique. The occurrence of early complications is often related to inadequate dural repair
and/or communication between the aerodigestive tract and the dura. Early complications include infection, flap compromise, cranial nerve dysfunction, cerebrospinal fluid leak, and intracranial infections. Late complications are usually the result of fibrosis from postoperative radiation, soft tissue atrophy, and/or inadequate structural support. These complications include malocclusion, trismus, diplopia, facial movement dysfunction, and nasal obstruction. These physical deformities and dysfunctions are not life threatening but certainly affect a patient’s satisfaction and health-related quality of life and should be corrected, if possible, to minimize patient morbidity.

CONCLUSION

Skull base surgery has advanced considerably, with the improvement of diagnostic and surgical technique and the involvement of a multidisciplinary team. The use of vascularized tissue for reconstruction of skull base defects has contributed to improvement of patient outcome and a decrease in perioperative complications. Successful reconstruction in the skull base requires a watertight dural seal and obliteration of dead space to minimize the likelihood of any complication following surgery. Local flaps are adequate for small defects, but larger defects are best treated with free tissue transfers, and we recommend the rectus abdominis myocutaneous flap.

CRITICAL POINTS

Must Know
• Skull base defects are unique because of the anatomic location and consequences of complications.
• Bulky flaps are often indicated, because dead space obliteration is important.
• Smaller defects may not need reconstruction.
• Sealing dura from the aerodigestive tract is a prime goal.

Should Know
• Bony reconstruction is frequently not required.
• Pedicled flaps may be sufficient but are often at the limit of their vascularity.
• Small local flaps may be useful for small defects and as adjuncts to other flaps.

Synopsis
• Successful reconstruction of the skull base has allowed a more aggressive approach to these tumors.
• Failure of the reconstruction can be critical, so it is imperative that the most reliable type of reconstruction be chosen.
• Protection of the dura and brain from outside contamination is one of the primary goals of reconstruction.
• Microsurgical reconstruction has made skull base surgery safer. The next frontier is to devise flaps that can be placed endoscopically to repair endoscopically produced defects.
   
   The base of the skull can be divided into three segments, which allows a better understanding of the spread and the symptoms related to tumors in this area. Surgical approach varies based on the location of the tumor. This systematic consideration allows more efficient exploration of this difficult area using a combined plastic and neurosurgical approach. The types of tumors occurring in this area and their prognosis are discussed. A preexisting craniofacial team experienced in the management of congenital craniofacial anomalies is an advantage when this type of procedure is performed.


   The authors review their experience with combined approaches to lesions that transcend the bones of the skull base. Seventy-seven skull base procedures were performed on 73 patients from 1982 to 1992. Overall, 44% of the patients had a postoperative complication. Survival of this heterogeneous group of patients was 79% at 2 years and 71% at 4 years, with patients having region II disease exhibiting a statistically significant poorer prognosis with no survivors at 4 years.


   The authors compare their local, pedicled, and free-flap reconstructions for 90 skull base defects performed over 10 years. They conclude that microvascular free tissue transfer is the safest, most economical procedure for moderate to large composite defects of the cranial base.
   A retrospective chart review was conducted to identify patients with anterior or lateral skull base defects, or both, who underwent microvascular free flap reconstruction. The use of microvascular free tissue transfer for reconstruction of complex skull base defects proved highly successful in the large series presented in this study. The versatility and reliability of free flaps for such reconstruction are discussed, and helpful hints are given to minimize the complication rate.
Facial Soft Tissue Reconstruction

Yoon S. Chun, Julian J. Pribaz

HIGHLIGHTS

- Optimal facial soft tissue reconstruction begins with an accurate assessment of the defect.
- When assessing the facial defect, multilayered facial anatomy must be considered, and the need for cutaneous coverage, three-dimensional volume, and lining must be evaluated.
- Facial soft tissue reconstruction involves careful preservation of the intricate relationship among facial anatomic features—eyes, brows, nose, lips, cheeks, and hair-bearing regions.
- Multiple reconstructive options are available, ranging from local and regional flaps to distant tissue transfers to restore aesthetics and function.
- Although free tissue transfer methods usually do not provide the best color or texture match, they are often used initially to close large defects. Subsequent revisions with local flaps help to achieve the final aesthetic result.
- Successful facial reconstruction frequently involves a staged approach with multiple flap options to achieve appropriate soft tissue replacement and contour.
The soft tissue of the face consists of multilayered tissue anatomy that contributes to its overall form and function. Each layer of tissue performs a specialized role that must be addressed for successful reconstruction. Furthermore, the intricate relationships among facial anatomic structures, including the eyes, eyebrows, forehead, scalp, nose, lips, and cheeks, often make facial soft tissue reconstruction a clinical challenge to restore aesthetics and function.

The head and neck region is a constellation of multiple specialized subunits. Previously published descriptions of the various aesthetic subunits of the face provide guidance in planning facial reconstruction after injuries, tumor resections, and burns. The major subunits are the forehead, nose, cheeks, periorbital region, lips, periauricular region, chin, neck, and scalp. The forehead is best considered as a large, single subunit that extends from the hairline to the eyebrows. Scars oriented along the natural crease lines in the midforehead and lateral forehead or vertically in the midline are well tolerated. Skin grafts should be avoided unless they span the whole subunit, because they are aesthetically unattractive and typically have a poor tissue match.

The cheek represents the largest percentage of facial surface area of any subunit, making appropriate coverage of a defect in this area essential to the restoration of overall facial aesthetics. The ideal classification of the cheek aesthetic subunits remains unresolved (Fig. 25-1). González-Ulloa\(^1\) considers the entire cheek to be a subunit (Fig. 25-1, A). Other authors further subdivide the cheek into multiple smaller subunits. Cabrera and Zide\(^2\) provide the most widely used description of the cheek aesthetic subunit. They divide the cheek into three overlapping zones: the suborbital, preauricular, and buccomandibular zones (Fig. 25-1, B). The suborbital zone is bordered by the nasolabial fold medially, the anterior sideburn laterally, the lower eyelid superiorly, and the gingival sulcus inferiorly. The preauricular zone comprises the lateral cheek component and extends from the malar eminence medially to the junction of the helix and cheek laterally and down to the mandible inferiorly. The buccomandibular zone consists of the lower cheek region inferior to the suborbital zone and anterior to the preauricular zone, including the oral lining. Defects in all three zones can be addressed with the use of local, regional, or distant flaps. Defects of the buccomandibular zone may require reconstruction with a combination of flaps to provide coverage for external skin and the oral lining. These zones may be further subdivided to reflect the different qualities of skin in the different zones and different approaches to reconstruction (for example, suborbital, nasolabial, malar, buccal, parotid-masseteric, sideburn, and beard areas) (Fig. 25-1, C).
The chin abuts the lower lip complex and includes the supramental groove and a variable central dimple. In men it also has a characteristic distribution of hair, which needs to be considered in the overall reconstruction strategy. The neck has thin, pliable skin and extends from the jawline to the clavicles. It is hair bearing in males in its upper half. It is loose and mobile anteriorly, where it overlies the platysma muscle, and it is more firmly adherent laterally and posteriorly, beyond the sternocleidomastoid muscle. It receives a segmental blood supply from the external carotid arterial branches, which is important to consider when designing axial flaps for soft tissue reconstruction (for example, the submental flap).

Fig. 25-1  Zones of the cheek aesthetic subunit. A, González-Ulloa\textsuperscript{1} considers the entire cheek as one subunit. B, Cabrera and Zide\textsuperscript{2} divide the cheek into three aesthetic subunits: 1, suborbital zone, 2, preauricular zone, and 3, buccomandibular zone. C, Further subdivisions reflect the various qualities of skin in the zones and different approaches to reconstruction.
SURGICAL OPTIONS

Soft tissue defects of the face are difficult but common clinical problems with variable severity and multiple causes, including trauma, congenital pathology, neoplasm, and burn injuries. A careful and accurate analysis of the defect is critical in selecting the most appropriate reconstructive solution to restore facial function and aesthetics. Consistent with the basic principle of general reconstructive surgery, facial soft tissue reconstruction strategy involves using all rungs of the “reconstructive ladder,” depending on the size and depth of the soft tissue defect. Small facial skin defects may be closed primarily or may only require skin grafts or local flaps, and more extensive, full-thickness defects may involve complex distant tissue transfers and microsurgical techniques to address the mucosal lining, muscles of facial expression, and external skin coverage. In addition to providing coverage of open defects, it is essential to restore the appropriate contour of facial anatomy, which may require bony and soft tissue reconstruction. Furthermore, it is not uncommon to use a staged approach or multiple flap options to maximize overall success in facial reconstruction. The primary goals in facial soft tissue reconstruction are to obtain appropriate soft tissue replacement and restore contour while minimizing distortion of the critical surrounding anatomy. A meticulous preoperative evaluation must be performed to identify the most appropriate technique for treatment and to minimize the risk of complication.

Current methods of facial soft tissue reconstruction, including restoration of natural facial contour, are presented in this chapter. Flap prefabrication and flap prelamination are two-stage procedures that provide useful adjuncts to reconstructive options for difficult head and neck defects. These recently developed methods are especially useful when available donor sites are limited. Flap prefabrication refers to a technique in which a distally ligated vascular pedicle is transposed into a body of donor tissue. After neovascularization has taken place, the tissue is transferred based on its implanted vascular pedicle during a second-stage procedure. Flap prefabrication has been used most commonly to reconstruct surface defects after burn injuries. Flap prelamination involves creating a multilayered flap for a composite reconstruction by implanting selected tissue layers into an established native vascular bed. The second stage of the procedure entails transferring the composite flap based on the native axial blood supply for reconstruction. Flap prelamination has been most useful in treating complex deformities involving the central third of the face. Flap prefabrication and prelamination techniques and their applications are discussed in more detail in Chapter 41.
INDICATIONS AND CONTRAINDICATIONS

Because of the intricate and aesthetically sensitive nature of facial anatomy, even small defects of the face can lead to significant deformity and distortion of the surrounding anatomy. Most facial soft tissue defects should be optimally reconstructed to preserve and restore previous facial aesthetics. Moreover, existing or anticipated functional deficits following tumor excisions or injury to the face are important indications for reconstructive surgery. These may include improved oral competence, functional mouth opening, eyelid positioning for corneal protection, and facial expression. Medical comorbidities such as diabetes, vascular disease, or poor cardiac function, or a history of smoking, which can all compromise wound healing and ultimate reconstruction outcomes, should be considered carefully before attempting any reconstruction. The appropriate reconstructive technique should be based on the patient’s general health, nutritional status, and overall medical condition, especially when a complex reconstructive method such as a free tissue transfer is considered. Careful preoperative assessment and awareness of appropriate selection criteria minimize the risk of complications and lead to successful reconstruction.

PREOPERATIVE MANAGEMENT AND CONSIDERATIONS

The facial anatomy is richly vascularized, which greatly facilitates a variety of local flap designs and provides excellent recipient vessels for free tissue transfers. Most small lesions of the face can be treated with simple excision and primary closure, without leading to significant aesthetic compromise. However, more extensive defects that require tissue replacement warrant careful preoperative and intraoperative evaluation to choose a reconstructive technique that provides the best aesthetic outcome (Box 25-1).

A comprehensive evaluation and accurate diagnosis of the presenting problem are critical and facilitate planning the ultimate reconstruction. These involve obtaining a complete patient history and examination of the pathology or defect requiring reconstruction. The relevant medical comorbidities, smoking history, preexisting scars from prior facial surgeries, and vascular status are all important parts of the overall evaluation, and this information must be obtained before beginning any reconstruction. An intraoperative assessment of the defect after extirpation helps determine the reconstructive requirements. The primary defect may evolve into a larger, secondary defect following additional debridement or complete tumor excision, and the reconstructive needs may become greater and more complex. Furthermore, when considering a free flap reconstruction, adequate coverage of the vascular pedicle and the primary defect must be ensured.
Box 25-1  Considerations in Flap Selection and Design

**Defect: Accurate Diagnosis**
- Assessment of the defect
  - Surface areas (cutaneous coverage, lining): Two-dimensional pattern
  - Volume (filler, support): Three-dimensional model
- Recipient vessels
  - Outside the zone of injury
  - Adequate caliber
  - Need for vein graft or arteriovenous loop
  - Need for flow-through or tandem flap

**Donor Site: Multiple and Expanding Choices**
- Standard available flaps
- Coverage
  - Skin (consider color, texture, and thickness match)
  - Skin graft
- Filler/support
  - Flap thickness and content
  - Dermis/fat
  - Muscle: Is it functional?
  - Bone, cartilage
- Lining
  - Skin, skin graft
  - Mucosa
  - Muscle that will mucosalize
- Flap pedicle: Length and caliber
- Manipulation of donor tissue
  - Flap delay
  - Preexpansion
  - Compound flap on one pedicle
  - Double pedicle for extensive flap
  - Folded flap
- Staged reconstruction
  - Prelamination
  - Prefabrication
- Residual donor defect
  - Primary closure or skin graft
  - Scar
  - Contour
  - Functional loss
When assessing the missing tissue components of the defect, reconstructive surgeons need to consider the surface area (coverage and lining) and volume (filler and support) of the defect to achieve optimal reconstruction. The use of preoperative and intraoperative models is helpful in making this assessment. Preoperatively, a moulage and plastic model of the face can be helpful in designing the appropriate flap for complex contour deformities. More commonly, modeling is used intraoperatively when an alginate model of the defect can provide an accurate three-dimensional representation. Alginate is a dental compound powder mixed with water to form a paste that is poured into the defect and sets within minutes to provide a three-dimensional model of the defect. Subsequently, an accurate, two-dimensional pattern of the cutaneous surfaces of the defect (with the intervening buried parts, which require de-epithelialization) can be created by wrapping an Esmarch bandage around the model. We have found that this technique facilitates flap design and inset. These techniques are demonstrated in Figs. 25-2 and 25-3.

A, This 5-year-old girl had an extensive bleeding AVM of the right cheek, maxilla, and upper and lower lips. B, A preoperative expansion of the right side of the back was planned for a composite folded flap transfer. Immediate reconstruction was deferred because of massive blood loss during the AVM resection. C, The patient is shown with a contaminated wound 5 days after the AVM resection.
Fig. 25-2, cont’d  
**D,** An intraoperative alginate model of the facial defect was made. **E,** A two-dimensional template was designed by wrapping an Esmarch bandage around the three-dimensional alginate model. **F** and **G,** A tailored and expanded parascapular functional latissimus dorsi flap was elevated as one composite free flap on one vascular pedicle. **H,** A folded parascapular/latissimus dorsi sandwich free flap.
Fig. 25-2, cont’d  I, She is shown immediately after the transfer. J, Flap necrosis from infection 4 days postoperatively. K, A right facial defect developed after debridement and temporary coverage using skin grafts. L, A second reconstruction was attempted using a folded free flap. A tailored, functional rectus abdominis free flap was designed. M, The patient is shown immediately after surgery.

Continued
Fig. 25-2, cont’d  N and O, Two- and 4-year postoperative results. P and Q, An expanded sub-mental flap and cheek flap eventually provided better-matched cutaneous coverage.
Fig. 25-3  A, This 35-year-old man had a left facial contour deformity following a rhabdomyosarcoma excision from the left side of the face, jaw, and neck. B, Preoperative modeling facilitated tailoring of the planned free flap. C, A template of the left facial contour defect was made. D, A parascapular free flap was designed. E and F, He is shown 12 months postoperatively.
In free tissue transfers, the recipient vessels must be carefully selected to ensure adequate caliber and should be ideally located outside the zone of injury. The vascular status is occasionally evaluated using radiographic imaging studies to facilitate free flap design and ensure the presence of appropriate recipient vessels. The potential need for a vein graft for free flap transfer should be determined early and planned before the free flap is detached. If a vein graft is required for arterial and venous systems, an arteriovenous loop can be inserted before the flap is detached. If the reconstruction requires multiple flaps, a flap that allows “flow-through” to carry an additional tandem flap should be considered. The venous drainage of the face does not parallel the arterial system, and there is a significant difference in venous drainage patterns between the central and lateral aspects of the face. The vascular anatomy of the lateral facial region is similar to that of the rest of the body in that the veins run in close proximity to the corresponding arterial inflow. In contrast, the central facial region has no notable veins for anastomosis, which can pose a problem when replanting central facial elements (that is, the nose and lips).

Once the defect and its reconstructive requirements have been fully evaluated, the most appropriate donor site should be selected. The suitability of each donor site is assessed according to the goals of the reconstruction to provide the best match to the missing soft tissue and to maintain or restore function. In addition, the logistics and technical ease anticipated during the operation must be considered to maximize efficiency. For instance, repositioning the patient intraoperatively should be minimized. The flap selection is made based on its ability to provide the best quality coverage and tissue match (that is, color, thickness, and texture). Some of the most important issues to address in selecting the flap for facial reconstruction include the following: the need for innervated flaps; appropriate volume replacement (dermis versus fat); the need for functional muscle or support structures, such as bone or cartilage; the appropriate lining requirement and selection using a skin paddle, skin graft, or mucosal graft; and the appropriate pedicle length and caliber in free tissue transfers.

For more complex facial defects, donor site tissue can be altered for transfer to provide a better, tailored flap while minimizing donor site morbidity. For example, preoperative tissue expansion of the planned donor site may provide additional tissue surface area or a thinner flap, which can allow a better tissue match to the facial defect (see Fig. 25-2). Furthermore, preexpansion can also allow easier closure and result in a better scar at the donor site. Occasionally, compound flaps may be elevated on either a single or double pedicle, depending on the size of the flap needed (see Fig. 25-2). The flap may also be folded to create a laminated structure to repair complex, full-thickness facial defects. However, with more extensive defects, a staged reconstruction may be more feasible. For instance, a flap procedure may be delayed before the ultimate transfer to extend the vascular territory. Furthermore, more recent reconstructive strategies of flap prelamination (for example, a multilayered flap used most commonly in complex central facial defects) and flap prefabrication (used mainly in burn reconstruction when usual donor sites may not be available) may be considered.
Reconstructions that use distant tissue usually require additional secondary reconstructions using local flaps to enhance the aesthetic and functional results. These secondary, adjunctive procedures need to be performed in proper sequence after the primary flap used for the first stage reconstruction has stabilized. Examples of these techniques are presented in Fig. 25-4.

Fig. 25-4 Free parascapular flap. A, This 35-year-old man had unstable left facial skin with recurrent basal cell carcinoma and squamous cell carcinoma after radiation therapy for retinoblastoma. B, A contoured parascapular flap was designed for the left facial reconstruction. C, He is shown early postoperatively. D, Left eyebrow and sideburn reconstruction was performed using a local transposition flap and a V-Y advancement flap. E, The postoperative result shows improved cosmesis.
OPERATIVE TECHNIQUE

Reconstructive surgeons need to be familiar with the full spectrum of reconstructive options to select the method of reconstruction that will provide the best outcome. The optimal reconstructive strategy may involve multiple modalities of treatment and/or multiple-staged procedures. Special care must be taken to ensure availability of back-up reconstructive plans and avoid compromising the final result. The various methods used in soft tissue reconstruction of the head and neck are discussed in this chapter. The ideal reconstructive method or combination of methods depends greatly on careful analysis of the reconstructive requirements of the presenting problem.

Primary Closure

Most small cutaneous malignancies of the face can be treated by resection and primary closure, ideally along relaxed skin tension lines. Some undermining of the surrounding tissue can facilitate tensionless closure for optimal healing.

Skin Grafts

In general, split- or full-thickness skin grafts provide disappointing aesthetic results, despite the ease and simplicity of the procedure. The color, texture, and contour matches are suboptimal and unpredictable, and this reconstructive method frequently leads to a patchlike appearance, especially with small grafts that abut native facial skin. Split-thickness skin grafts eventually contract and can cause malpositioning of surrounding anatomic structures, such as the lower eyelid or the oral commissures. Even full-thickness skin grafts are generally not able to provide sufficient thickness or volume to adequately address the skin and subcutaneous tissue defect created by most resections. Skin grafts also result in a poor color match with the native facial skin and tend to be pale and glossy in appearance. They frequently lead to indentations and create contour irregularity on the face. Therefore the role of skin grafts in facial reconstruction should be minimal beyond temporary coverage of the defect or facilitating closure of the donor site when large flaps are used.

One exception to this principle is facial burn reconstruction. Skin grafts are commonly used for these defects. Sheet grafts that cover an entire aesthetic subunit give the best result, and full-thickness grafts are generally preferred over split-thickness grafts. In head and neck reconstruction, skin grafts harvested from the neck, retroauricular region, and scalp provide the best color match. In addition, the skin graft donor site can be tissue expanded to provide a larger sheet of full-thickness graft. Recently, the use of a very thin scalp split-thickness skin graft was advocated by Walton to improve the color of a distant flap previously placed on the face. The original flap with a poor color match is treated with dermabrasion and overgrafted with the thin scalp graft.
Local Flaps
When using small local flaps to reconstruct small defects not amenable to primary closure, the laxity and vascularity of the surrounding facial skin are often beneficial. Various areas of the cheek provide a generous source of tissue for reconstructing a wide variety of defects, and well-designed local flaps can provide excellent color, texture, and contour matches with the defect.

V-Y Flaps
One of the most versatile local flap options in facial reconstruction is the V-Y advancement flap. The V-Y advancement flap technique is an effective way of closing small defects in the head and neck region. This local flap option transfers an island of skin immediately adjacent to the defect to provide soft tissue coverage based on a subcutaneous vascular pedicle (Fig. 25-5). The length of the flap is designed to be approximately 1.5 to 2 times the diameter of the defect, and the long axis is in the direction of maximal tissue mobility.

Fig. 25-5  V-Y flap. A, The preoperative design of a V-Y advancement flap for coverage of the right suborbital/malar defect after a planned excision of melanoma in situ. B, Flap elevation. C, The immediate postoperative result after the V-Y advancement flap. D, The long-term postoperative result shows no evidence of ectropion.
The cheek is anatomically well suited for this reconstructive option because of its laxity and the abundance of subcutaneous tissue facilitating flap mobility. Modifications of traditional V-Y advancement flaps have also been described for reconstruction of even larger facial defects or those located in areas with less subcutaneous tissue.\textsuperscript{8-10} The extended V-Y flap involves adding an extension limb onto the advancing edge of the traditional V-Y flap and has been used effectively to reconstruct areas with less tissue mobility.\textsuperscript{8} The width of the extended V-Y flap is greater than the width of the defect, and the length of the extension limb is approximately the width of the defect to close the distal portion of the defect as a transposition flap. The flap can be designed with one or two extension limbs (Fig. 25-6). The V-Y advancement flap can generally provide a well-contoured reconstruction with an excellent skin color and texture match for small cheek defects. The flap is very useful in closing hair-bearing defects on the cheek by moving adjacent hair-bearing tissue into the defect. This is best achieved with a simple V-Y flap if possible. For larger defects, extended V-Y flaps may be used, but they have the disadvantage of altering the direction of hair growth, because the extended part of the flap is transposed 90 degrees (Fig. 25-6, E).

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\end{figure}
Fig. 25-6, cont’d  

C, An extended V-Y advancement flap design for coverage of a right temporal scalp defect.  

D and E, The immediate and long-term postoperative results. The direction of hair growth is changed by the extension limb of the flap.
Rhomboid Flaps

Small defects that are not amenable to primary closure can be managed with local flaps such as a rhomboid flap. Rhomboid and modified rhomboid flaps involve simple techniques that use the surrounding soft tissue to provide coverage for small facial defects. There are multiple possible flap designs for any given defect. However, even when care is taken to place the donor scar along relaxed skin tension lines, most scars from rhomboid flaps tend to lie prominently in an unfavorable orientation and may result in a cosmetically poor outcome.

Tissue Expansion

Larger deformities of the face and neck can be reconstructed using tissue expansion alone or in combination with other techniques. By expanding the neighboring facial skin, tissue expansion provides the best color and texture match for facial reconstruction.11-13 Expander selection and the location of the expander and port pockets are important parts of preoperative planning.14 The incisions for expander placement should be minimal in length and located away from the defect or lesion to be excised. When determining the location of the incision, the potential design of the future flap should be considered to ensure flap vascularity and to optimize defect coverage. The expander width and length should be at least as large as the defect, and intraoperative filling of the expander can reduce hematoma and seroma formation.14 Expanders are typically filled once a week for 6 to 8 weeks and are often overexpanded by 30% to 50% until the final reconstruction can be performed. At the time of the final reconstruction, when advancement flaps and expanded donor site tissue are used, a capsulotomy can facilitate coverage by increasing the surface area of the expanded donor tissue.

Successful reconstruction of the face has been reported with tissue expanders placed superficial to the superficial musculoaponeurotic system (SMAS)/platysma layer over the mandibular angle and body, followed by a cervicofacial flap using the expanded tissue.11 Despite these uses, complications are reported with tissue expansion in head and neck reconstruction. The highest reported incidence of complications occurs in the cheek and neck region, and implant exposure is most common.15 Despite these complications, with careful planning at each stage of the procedure, the final reconstructive result using the expanded flap technique is usually satisfactory.
Cervicofacial Flap

Reconstructive choices for the face depend on multiple factors, including the defect size, depth, shape, and site. In general, most cheek defects occupying 30% or more of the cheek unit necessitate recruiting residual cheek and surrounding skin as rotational or advancement flaps. Local flaps allow reconstruction with similar tissue and provide the best aesthetic result.

The use of the cervicofacial rotation-advancement flap has traditionally been advocated for the reconstruction of defects of the cheek and lower eyelid region. The cervicofacial flap is frequently used for medium- to large-sized defects and provides tissue with an excellent color and texture match by recruiting the neighboring cervical cheek and subauricular skin adjacent to the defect. With adequate cervical skin laxity, the donor site can be primarily closed with ease and a good cosmetic appearance. The site, size, and orientation of the cutaneous defect determine whether a medially or laterally based cervicofacial flap is the best option.

The medially based cervicofacial flap is most useful in the reconstruction of medial cheek defects with a more vertical orientation. A standard, medially based cervicofacial rotation-advancement flap incision originates from the superolateral aspect of the defect, extends around the posterior cheek following the sideburn, and continues inferiorly along the preauricular crease and around the ear lobe and occipital hairline. The flap is dissected in the subcutaneous tissue plane, just above the SMAS layer, and the residual cheek and cervical skin are advanced medially to cover the defect. Superior dissection of the flap lateral to the eye is important to avoid ectropion as the flap is advanced. Any redundant skin or dog-ear created medially after the advancement can be excised within the nasolabial fold. Occasionally, however, this excess skin can be turned inward to reconstruct the lining in full-thickness medial cheek or lip defects. The subauricular and neck tissue is advanced superiorly to close the donor site. The medial vascular base for the flap is supplied by the facial and submental arteries. One of the main problems with the cervicofacial advancement flap has been distal flap necrosis, especially in smokers. A modification can be made to improve flap vascularity by performing flap elevation through the deep plane, below the SMAS and platysma muscle. Deep plane dissection increases flap reliability and permits more mobility for larger facial defect reconstructions.

Recently, Boutros and Zide described a modified angle rotation flap for cheek and eyelid reconstruction. The flap design is an anteriorly and inferiorly based, large, bilobed flap. It involves transposing the entire cheek and preauricular tissue to the cheek or lower lid defect as the first flap; the angle rotation flap from the subauricular region is rotated upward and medially as the second flap to close the donor site. The medial and upward rotation advancement allows significant mobilization of
Fig. 25-7 Medially based cervicofacial flap. A, The patient is shown after undergoing Mohs surgery for recurrent basal cell carcinoma involving the right cheek, nose, and upper lip. B, A cervicofacial flap was designed. C and D, The flap was elevated and transferred. E and F, The immediate and long-term postoperative results. The patient subsequently underwent a forehead flap for secondary nasal reconstruction.
abundant posterior soft tissue into the cheek defect and lower eyelid (Fig. 25-7). In addition, the angle rotation flap eliminates the need to extend the flap down into the neck, as seen in standard cervicofacial flaps, thus limiting donor site scarring and achieving a better cosmetic result. Moreover, the flap design allows future readvancement if further cheek defect coverage is needed.

Although the angle rotation flap has decreased the need to extend the cervicofacial flap onto the lower neck and the chest, the medially based cervicofacial flap can also be extended as a cervicopectoral flap to provide coverage for larger cheek defects.22,23 This flap recruits the chest and neck skin by extending the incision down into the anterior chest, passing 2 to 3 cm above the nipple-areola complex to the parasternal region. The cervicopectoral flap is vascularized by anterior thoracic perforators off the internal mammary artery and is elevated deep to the platysma muscle and anterior pectoral fascia. The cervicopectoral advancement flap can cover large cheek defects up to 6 to 10 cm without significant donor site deformity.

The laterally based or reversed cervicofacial advancement flap is an effective way to reconstruct defects located anteriorly and medially that have a more horizontal orientation, including the nasal sidewall and lower medial periorbital region16,24 (Fig. 25-8).
The incision for the reversed cervicofacial flap generally starts at the defect and follows the nasolabial fold beyond the oral commissure and the submental fold. The flap recruits the excess tissue from the lower aspect of the face, including the jowl and the submental tissue, and transfers it superiorly into the perioral cheek region. The laterally based cervicofacial flap has two main vascular supplies: branches of the facial artery, which supply most of the flap, and the transverse facial artery, which originates from the superficial temporal artery and supplies the superior aspect of the flap. Similar to the medially based cervicofacial advancement flap, the laterally based flap incision can also be extended inferiorly into the sternum and across the chest to the axilla as a cervicopectoral flap to provide coverage for larger defects.25

Forehead Flap

The forehead flap is a widely used local flap based on the supratrochlear or supraorbital vascular pedicle. It is most commonly used to resurface nasal reconstructions. This reconstructive option can also provide a useful soft tissue reconstruction modality in defects of the lower eyelid, cheek, and even the upper lip. The flap design should be tailored to match the facial defect, based on its size and location, and to optimize the arc of flap rotation. The use of a small template can facilitate this preoperative planning. In addition, a tissue expander can be placed and expanded under the forehead donor site before the ultimate flap reconstruction to create a thinner flap and/or to obviate the need for a skin graft during the donor site closure. Fig. 25-9 shows the use of a forehead flap in cheek reconstruction following radiation therapy and the surgical excision of angiosarcoma.

Fig. 25-9  Forehead flap. A, Left cheek residual angiosarcoma.
Fig. 25-9, cont'd  B-D, The reconstruction was designed using a forehead flap with a template guide, cheek advancement flap, and upper eyelid flap. E, The left cheek defect is shown after surgical excision. F and G, The immediate and long-term postoperative results.
Submental Flap

The submental artery island flap was first described by Martin et al26 and can provide a large, pliable cervical skin paddle for facial reconstruction. It generally provides a good color match for facial soft tissue reconstruction and allows hair-bearing tissue reconstruction in males. This flap is supplied by the submental arterial branch of the facial artery. Anatomic studies have shown that the submental artery has a diameter of approximately 1.2 to 1.7 mm and a long pedicle length of 50 to 60 mm.27 This long pedicle allows a wide arc of rotation and significant mobility of the submental artery island flap. Venous drainage of the flap is through the submental vein into the anterior facial vein and into the common facial vein.

The flap is designed with an elliptical skin paddle in the submental region that traverses the midline. To ensure vascularity, acceptable flap dimensions range from 5 cm by 5 cm to a maximum of 15 cm by 7 cm.26,28 The skin paddle borders the mandibular arch superiorly and both mandibular angles laterally. The flap is harvested with the platysma muscle from the contralateral to ipsilateral pedicle side after dividing the contralateral submental vessels. Once the submental flap with the pedicle has been dissected from the surrounding tissue, the flap can be mobilized and tunneled to the recipient site for reconstruction. The donor site is closed primarily and the resultant linear scar is well concealed within the submandibular region (Figs. 25-10 and 25-11).

Fig. 25-10  Submental flap. A, A full-thickness lip and chin defect is shown following sarcoma excision. B, A Submental flap was designed. C, The flap was elevated. D, The postoperative result.
Fig. 25-11  Submental flap. A, A right cheek deformity is shown after radiation therapy, surgical excision, and a full-thickness skin graft for recurrent melanoma. The skin graft resulted in a poor color/texture match and contour deformity of the right cheek. B, A submental flap was designed. C, The right cheek defect following excision of the skin graft and flap elevation. D, The early postoperative result.
The submental flap has also been used as a functional flap by maintaining innervation to the platysma muscle. The cervical branches of the facial nerve are kept with the flap during flap elevation. Once the flap is transposed onto the facial defect, the platysma muscle fibers are rotated to provide an upward pull on the oral commissure to assist with facial animation. This innervated platysma musculocutaneous flap is an effective way to augment facial animation while providing appropriate soft tissue for moderate-sized, full-thickness facial defects (Fig. 25-12).

Fig. 25-12  Functional submental flap. A, This patient underwent a full-thickness excision of squamous cell carcinoma that included the muscles of facial expression. B and C, A functional submental flap was elevated and transferred with the platysma muscle fibers oriented to facilitate facial expression.
The submental flap is a simple yet versatile regional flap that can be used to reconstruct large defects of the face and especially the cheek. It provides an excellent color and texture match for facial reconstruction with minimal donor site morbidity. The thin and pliable quality of the skin paddle facilitates reconstruction throughout nearly the entire ipsilateral face and oral cavity. The submental flap has been used as an alternative to free tissue transfer for reconstruction following the resection of orofacial malignancies in select groups of patients. Oral function can be satisfactorily preserved postoperatively. An additional advantage, particularly in older patients, is the cosmetic improvement achieved by removing excess submental subcutaneous tissue and skin redundancy (see Fig. 25-12, E).

Fig. 25-12, cont’d  D and E, The postoperative result after radiation therapy.
Pectoralis Flap

The pectoralis myocutaneous flap was first described by Ariyan in 1979 and is one of the most versatile distant pedicled flap options, providing coverage for sternal, oropharyngeal, and mandibular reconstructions and soft tissue defects of the face. The pectoralis major muscle originates from the medial half of the clavicle, sternum, and upper seven ribs, and inserts into the humerus. The dominant vascular pedicle is the thoracoacromial artery, which enters the muscle on its deep surface at the junction of the middle and lateral one third of the clavicle. The flap can be used to reconstruct external facial defects and the intraoral lining (Fig. 25-13). The pectoralis myocutaneous flap can be elevated and rotated 180 degrees if a skin island is designed to reconstruct the external facial defect, or it can be rotated and flipped over if the skin island is to be used to cover the intraoral lining. The donor site can be closed primarily if the size of the skin paddle is small; otherwise, skin grafting may be necessary. By releasing the muscle fibers and dissecting around the vascular pedicle, the flap mobility and rotational arc are increased to facilitate transfer to the face and neck region. Successful facial reconstruction has been achieved with evidence of pectoralis muscle reinnervation after suturing the pectoral nerve to a buccal branch of the facial nerve. The pectoralis myocutaneous flap is not typically the first reconstructive choice for large defects of the head and neck region; nonetheless, it is a reliable reconstructive option, especially when concomitant systemic medical problems or advanced disease contraindicates the option of free tissue transfer. It may also be a useful adjunct in patients with irradiated “frozen” neck or a complex wound with exposed major neck vessels.

Fig. 25-13  Pectoralis flap. A, An extensive lateral cheek lining and jaw defect is shown after cancer resection, radiation therapy, and the design of a pectoralis major myocutaneous flap.
The trapezius myocutaneous flap is another distant pedicled flap option that can be used for facial reconstruction, especially for more posteriorly located facial and scalp defects. Various types of trapezius flaps have been previously described, including the superior, lateral island, posterior island, vertical, and extended vertical flaps. The trapezius muscle originates from the occipital bone and the spinous processes of the seventh cervical through twelfth thoracic vertebrae and inserts into the scapula, acromion, and clavicle. The blood supply is from the transverse cervical artery, arising from the thyrocervical trunk or rarely the subclavian artery. The flap can be designed as an island flap from the lower trapezius muscle or as a vertical flap along the course of the transverse cervical artery. The superior fibers of the trapezius muscle can be left intact to prevent a functional deficit. The trapezius flap offers acceptable replacement tissue for facial reconstruction and adequate tissue bulk; however, it provides a poor color match and can have thick dermis of the back, which may not be ideal for the face.

Fig. 25-13, cont’d  B, The immediate postoperative result. C, The postoperative result shows a bulky flap and tissue mismatch. D, The long-term postoperative result after revision with local flaps.

**Trapezius Flap**

The trapezius myocutaneous flap is another distant pedicled flap option that can be used for facial reconstruction, especially for more posteriorly located facial and scalp defects. Various types of trapezius flaps have been previously described, including the superior, lateral island, posterior island, vertical, and extended vertical flaps. The trapezius muscle originates from the occipital bone and the spinous processes of the seventh cervical through twelfth thoracic vertebrae and inserts into the scapula, acromion, and clavicle. The blood supply is from the transverse cervical artery, arising from the thyrocervical trunk or rarely the subclavian artery. The flap can be designed as an island flap from the lower trapezius muscle or as a vertical flap along the course of the transverse cervical artery. The superior fibers of the trapezius muscle can be left intact to prevent a functional deficit. The trapezius flap offers acceptable replacement tissue for facial reconstruction and adequate tissue bulk; however, it provides a poor color match and can have thick dermis of the back, which may not be ideal for the face.
The extended vertical trapezius flap has been described for difficult head and neck reconstructions. It is designed as a long vertical flap along the route of the transverse cervical artery. With its wide arc of rotation, the distal portion of the flap can reach the cheek region without much tension, and the donor site can be closed primarily. However, the extended vertical trapezius flap requires a second-stage procedure for division of the pedicle.

The trapezius myocutaneous flap can be a good reconstructive option for posteriorly located defects of the head and neck or as a salvage procedure, especially when free tissue transfer may not be an option. Fig. 25-14 presents a clinical example of the trapezius flap used to reconstruct a retroauricular defect.

Fig. 25-14  Trapezius flap. A, This patient developed retroauricular radionecrosis. B and C, The necrotic tissue was widely excised and a trapezius myocutaneous flap was designed and elevated for coverage. D, The postoperative result.
Latissimus Dorsi Flap

The latissimus dorsi myocutaneous flap is another widely used reconstructive method for chest wall and breast reconstruction. However, it can also provide an effective soft tissue coverage option for large head and neck defects as a pedicled flap or a free flap (Fig. 25-15). The latissimus dorsi muscle originates from the lower six thoracic and lumbar spinous processes and the posterior iliac crest and inserts onto the humerus. The vascular supply consists of the dominant thoracodorsal artery and the segmental distal perforators from the intercostal and lumbar arteries near the posterior midline.

Fig. 25-15  Latissimus dorsi flap. A, This patient had a hypertrophic burn scar of the right lateral face and neck. B, The scar excision was planned and marked. C, A latissimus dorsi flap was designed.
For head and neck reconstruction, the latissimus dorsi flap is not used as a pedicled flap as commonly as the pectoralis myocutaneous flap; however, it can successfully provide coverage for lateral head and neck soft tissue defects and the intraoral lining.

**Supraclavicular Flap**

The supraclavicular area is considered one of the desired donor sites for facial reconstruction because of its good color and texture match with facial skin. To use this anatomic region for facial resurfacing, a prefabricated supraclavicular flap was developed by implanting a vascular pedicle underneath the flap. A tissue expander can be placed beneath the prefabricated skin flap to thin and increase the available donor skin surface area. More recently, the expanded supraclavicular fasciocutaneous flap has been successfully used in facial reconstruction, even without the need for a prefabricated vascular pedicle. The supraclavicular flap is an axial flap based on the supraclavicular artery, a branch of the transverse cervical artery, and its accompanying veins. The expanded supraclavicular island flap involves placing a tissue expander under the supraclavicular flap area as the first-stage procedure. After expansion, the tissue expanders are removed, and the expanded fasciocutaneous flap is raised to cover the facial defect during the second stage. The donor site is primarily closed using ventral and dorsal advancement flaps. The expanded supraclavicular flap has been effectively used to reconstruct the face, including the cheek and neck, and is a reliable treatment option, especially for postburn patients who require extensive facial resurfacing.

**Free Tissue Transfers and Full-Thickness Defects**

Although distant pedicled flaps can provide a dependable reconstructive option for large defects of the face, the part of the flap that ends up in the face is usually the distalmost part and thus less reliable. In addition, the bulky pedicle of the flap results in a cosmetic outcome that is usually inferior compared with the results from free tissue transfer. The ideal free tissue transfer for facial reconstruction that would provide a perfect tissue match does not exist, and the results remain suboptimal. Since the early days of microsurgery when there were only a few flap options, the number of potential donor sites for free tissue transfer has dramatically expanded the reconstructive possibilities for facial reconstruction. Although a technically challenging reconstructive option, microvascular free flaps can provide a large amount of distant tissue for reconstruction, with unlimited mobility. For instance, for complex central facial defects, microvascular tissue transfer has been used to provide a substantial amount of soft tissue bulk as a first stage and refined at a later stage through local tissue rearrangement or transposition flaps to optimize the functional and aesthetic result. Free flaps can be successfully used to appropriately resurface and contour facial defects of various degrees. Fig. 25-4 presents a patient with a facial defect who underwent a parascapular free flap procedure to restore contour and resurfacing, fol-
lowed by subsequent local flap procedures to optimize the cosmetic result. The free flap donor site selection can generally be based on the size of the facial defect. Small defects can be reconstructed with radial forearm or lateral arm free flaps. Medium defects can be treated with larger radial forearm, latissimus dorsi, or parascapular free flaps. Larger defects may be suitable for bulkier free flaps, such as rectus abdominis or anterolateral thigh flaps. Furthermore, free tissue transfer potentially can be performed as a single-stage procedure and result in less donor site morbidity. Complex facial defects that require judicious contouring and full-thickness defects that require composite tissue transfer can be successfully treated with free flaps. Extensive intraoral lining reconstruction can also be effectively performed using carefully designed free flaps. In addition, using microvascular surgery, newer and more sophisticated techniques of flap prefabrication and prelamination can be successfully incorporated in difficult facial reconstructions.

The microvascular transfer of a folded flap is an effective way to reconstruct full-thickness defects of the cheek. The radial forearm flap and the rectus abdominis myocutaneous flap are folded free flaps that have been successfully used in complex full-thickness facial defects. The radial forearm flap, based on the radial artery and venae comitantes vascular pedicle, can be designed with two skin islands connected by deepithelialized skin and folded on itself to simultaneously reconstruct the external facial skin and intraoral lining (Fig. 25-16). The flap can be harvested with a vascularized palmaris longus tendon, which can be used to suspend the flap for support.

![Fig. 25-16](image)

**Fig. 25-16** Folded free flap. A, This patient had an ulcerated AVM of the lower lip and chin that required a wide resection.

*Continued*
Fig. 25-16, cont’d  B and C, An Intraoperative alginate model of the defect was made following the resection. D and E, A two-dimensional template was made from the three-dimensional model and transferred to design a tailored radial forearm free flap.
Fig. 25-16, cont’d  F, Bilateral facial artery musculomucosal (FAMM) flaps were designed for lower lip vermilion reconstruction. G, An oral sling was made with a palmaris longus tendon graft. H and I, The immediate and long-term postoperative results.
The rectus abdominis myocutaneous flap, based on the deep inferior epigastric pedicle, can similarly be designed with multiple skin islands to reconstruct multiple cutaneous and mucosal surfaces in complex facial defects. It can provide a large epithelial surface area and soft tissue bulk that may be required for maxillectomy defects or base of skull tumor resections (see Fig. 25-2). Reconstruction with folded flaps involves more than simply providing replacement tissue and necessitates careful preoperative and intraoperative planning. A three-dimensional defect must be converted into a two-dimensional pattern to design the optimal folded free flap. To facilitate this conversion, Pribaz et al reported creating an intraoperative alginate moulage for the three-dimensional model of the defect and wrapping it with an Esmarch bandage to determine the locations and sizes of the epithelial surfaces required for the final reconstruction.

The anterolateral thigh flap is another potential donor site for free flap reconstruction of the face. This flap can be harvested as a fasciocutaneous flap or with a portion of the vastus lateralis muscle, based on the descending branch of the lateral femoral circumflex pedicle (Fig. 25-17). The anterolateral thigh flap is more appropriate for laterally located facial defects because of the need for more soft tissue bulk in this anatomic region. The flap can also be thinned to provide more aesthetic facial contour. For full-thickness cheek defects involving the oral commissure, restoring oral competence and replacing soft tissue are more comprehensive reconstructive goals. Recently, chimeric flaps from the lateral femoral circumflex system have been successfully used to reconstruct full-thickness cheek defects and simultaneously restore oral competence through the use of the tensor fasciae latae to suspend the oral commissure. This technique involves designing skin paddles that are individually supplied by separate perforator systems but joined more proximally in a single pedicle. Although it is technically challenging and offers a suboptimal color match to the face, this technique provides more aesthetic three-dimensional reconstruction with a good contour match.
Fig. 25-17  Free anterolateral thigh flap. A, This patient had recurrent squamous cell carcinoma following a resection and free rectus abdominis free flap surgery. B and C, The specimen and resulting defect are shown after a wide resection that included the orbit and maxilla. D, A free anterolateral thigh flap was designed for reconstruction. E, The postoperative result.
Facial Transplantation

Even the most successful reconstruction using distant donor site tissue falls short of fully restoring normal facial soft tissue anatomy. When dealing with highly specialized tissues such as those of the face, restoration to a normal or near-normal facial appearance can only be achieved by replanting an avulsed part or transplanting an equivalent part from a suitable donor. Although facial transplantation is in its early stages, it has recently become an option in complex, facial soft tissue reconstruction. Facial allograft transplantation is technically achievable and adds a remarkable new dimension to the reconstructive surgical field by providing potential options for patients with facial deformities that cannot be treated with current conventional autologous reconstructive techniques. For instance, complex defects in the central third of the face may benefit from facial transplantation because of the intricate and functionally important framework in the region. However, this type of composite tissue allotransplantation presents a significant immunologic challenge between the donor and recipient, and optimal immunosuppressive therapy needs to be developed before facial transplantation becomes a standard reconstructive option. In addition, potential ethical and psychological issues surrounding facial transplantation can be complex and warrant further examination and careful assessment. Nonetheless, there are unfortunate cases of devastating, severe facial deformities from burn injuries, trauma, or tumor resection that could potentially benefit from this reconstructive option, and the establishment of careful selection criteria can guide us toward its successful application.

Contour Defects

The restoration of facial volume and contour is just as critical as external skin coverage in achieving the most aesthetic facial reconstruction. Facial contour defects are frequently associated with Romberg’s disease, scleroderma, facial lipodystrophy, or the sequelae of trauma or tumor resection. Soft tissue augmentation options include dermal and dermis-fat grafts, free autologous fat grafts, and free tissue transfer. The dermal component generally survives better than the autologous fat graft volume, which can decline by 55% in 12 months. In addressing more extensive facial contour deformity, free tissue transfers from distant donor sites, such as the scapula, groin, thigh, and abdomen, have been successfully used. The use of a preoperative facial moulage or three-dimensional alginate model of the defect can facilitate flap design and optimize the outcome (see Fig. 25-3). The flap is deepithelialized and tailored to correct the facial contour. Secure suture fixation of the flap to facial muscle or underlying periosteum is performed to avoid displacement. Figs. 25-3 and 25-18 present clinical examples of facial contour restoration using tailored free tissue transfer methods.
Fig. 25-18  A, This 40-year-old woman presented with bilateral facial lipodystrophy. B, A template of the facial contour deformity was made. C, Bilateral free groin flaps were designed using the intraoperative template. D, The patient is shown 6 months postoperatively.
OPTIMIZING OUTCOMES

The following principles should be considered when planning facial soft tissue reconstruction:

- A careful evaluation and a multidisciplinary team approach to treatment, which may include specialists in otolaryngology, plastic surgery, maxillofacial surgery, radiation oncology, dentistry, dietetics, and psychology
- A comprehensive assessment of defect size, location, depth, and surrounding structures
- The restoration of contour and an optimal color and texture match for soft tissue defects, often using secondary local flap options
- The restoration of function, including facial expression
- The preservation, if possible, of the surrounding facial anatomy: eyelids, nose, lips, ears, and hair-bearing region. If extirpated as part of a large resection, then free flap reconstruction followed by secondary reconstruction of the anatomic structures using local flap options should be considered.
- Apparent scar minimalization through the methodical placement of incisions and flap choice
- Careful selection of the reconstructive method and donor site, based on defect coverage requirements, individual patient factors, and the recipient site

COMPLICATIONS AND SIDE EFFECTS

Flap Necrosis

Flap necrosis is one of the major complications after flap reconstruction of any soft tissue defect. Partial or total flap necrosis can be avoided by carefully evaluating potential risk factors before reconstruction. Smoking, diabetes, vascular disease, or prior radiation therapy may lead to vascular compromise of tissue. In these cases, flap vascularity can be augmented by performing deep-plane dissection during flap elevation. Excessive tension is a frequent factor contributing to distal flap necrosis in cervicofacial advancement flaps and should be assiduously avoided during flap inset. Careful assessment of the defect to ensure a clean wound base before reconstructive coverage is also important. Fig. 25-2 shows a clinical case in which the initial microvascular free transfer attempt following resection of a large facial arteriovenous malformation (AVM) was complicated by a total flap loss resulting from wound infection. This was later salvaged by a second free flap reconstruction.

Ectropion

Ectropion is one of the most difficult complications to treat in facial soft tissue reconstruction. Because of the proximity of the lower lid, facial reconstruction in the cheek region can lead to this problem by causing eversion of the lower lid away from
the globe. This cosmetic and functional deformity can be caused by gravitational and/or contraction forces that result from poor preoperative surgical planning and flap design. Chronic ectropion can lead to corneal exposure and injury, keratinization of the conjunctiva, chronic ocular irritation, and visual loss. To minimize the risk of lower lid malpositioning and ectropion during cheek and lower eyelid reconstruction, it is important to widely undermine the flap and ensure that the inset is tension free in an overcorrected position. Additional support can be obtained using anchoring sutures to the periosteum or by performing adjunct procedures such as lateral canthoplasty, canthopexy, and horizontal eyelid shortening.54

Disruption of the Hairline

The overall success of facial reconstruction involves preserving or restoring the existing hairline, especially in male patients. Poor preoperative planning can lead to disruption of the hairline after flap reconstruction. For instance, the incision for a medially based cervicofacial advancement flap should be designed to avoid anterior displacement of the sideburn or beard. If necessary, primary restoration of the hairline with V-Y advancement flaps and secondary restoration with hair-bearing transposition flaps are commonly used to enhance the final aesthetic result (see Fig. 25-4).

Postoperative Care

Postoperative care of patients who undergo head and neck reconstruction should be tailored to each reconstructive technique used. Wound healing should be optimized by minimizing tension and edema. Standard flap monitoring techniques should be used, especially after free tissue transfer, and immediate exploration is warranted if any sign of vascular compromise is noted. Secondary procedures are commonly performed to optimize the overall aesthetic outcome. These procedures may include simple scar revisions or flap contouring by debulking or augmenting. In addition, following primary distant pedicled flaps or free tissue transfers, serial adjunct procedures can be performed using local advancement flaps to re-create the facial subunits or hair-bearing zones.

Conclusion

The reconstruction of complex facial defects can be one of the most technically challenging but professionally rewarding tasks for a reconstructive plastic surgeon. Achieving optimal results requires thorough familiarity with intricate regional anatomy, sound clinical judgment, and technical skill. The wide variety of reconstructive options can be bewildering for less experienced surgeons but provides outstanding opportunity to achieve pleasing aesthetic and functional restoration.
**CRITICAL POINTS**

**Must Know**
- The aesthetic units of the face must be considered.
- The defect must be thoroughly assessed.
- Local tissue provides the best color and texture match.
- The surgeon should avoid distortion of the locoregional anatomy.

**Should Know**
- Multiple reconstructive modalities are available for facial soft tissue reconstruction and should be considered.
- Staging the reconstruction is often useful.
- Reconstructive plans should address both aesthetic and functional needs.
- A multidisciplinary team approach provides optimal treatment.
- Avoid irrevocable steps that can compromise ultimate outcome.

**Synopsis**
- Facial soft tissue reconstruction is subject to the most critique because of its visibility. Aesthetic appearance is extremely important in this region, but function cannot be compromised.
- Facial reconstruction can be a challenge given the intricate anatomy of the multilayered tissue and aesthetic subunits.
- Successful reconstruction involves multiple treatment modalities and stages to achieve optimal aesthetic and functional results.

**References**

   
   During the past 10 years, 17 flaps were prefabricated and 15 flaps were transferred successfully in 12 patients. Prefabricated flaps allow the transfer of moderate-sized units of thin tissue to recipient sites throughout the body. They have been particularly useful in patients recovering from extensive burn injuries who have limited thin donor sites.

The extended V-Y flap is a modification of the V-Y advancement flap, which is very useful in closing defects following the excision of facial lesions. The modification involves the addition of an extension limb onto the advancing edge of the standard flap.


The tissue expansion technique is advantageous in facial reconstruction, because it makes it possible to resurface even wider defects with neighboring skin that is similar in color and texture and superior to skin obtained elsewhere, thereby surpassing conventional methods. In each case, some modification is required with respect to the status of the defect. The experiences encountered in a series of 23 patients are described, and illustrations of several representative cases with advantages and problems are discussed.


After studying this article, the reader should be able to (1) describe the cheek unit and its specific requirements for quality, outline, and contour, (2) identify factors involving the patient, wound, and donor materials that determine technique, (3) understand the application of anteriorly based, posteriorly based, and advancement flaps and the use of serial excisions for specific defects, and (4) identify, prevent, and treat complications of cheek reconstruction.


The blood supply and reliability of cervicofacial rotation-advancement flaps for cheek reconstruction can be improved significantly by dissecting the flap in the deep plane (that is, below the superficial musculoaponeurotic system and the platysma). This modification, similar in technique to that used in composite or deep plane face lifts, was used successfully in seven patients, including several heavy cigarette smokers who were unlikely to achieve a successful outcome with a conventional cervicofacial flap.

Midface and Maxillary Reconstruction

Neal D. Futran, Michael G. Moore

HIGHLIGHTS

- The midface is made up of unique components that have various functional and cosmetic roles.
- Defects commonly result from traumatic and congenital causes or oncologic resection of sinonasal and oral cavity tumors.
- Defect analysis involves assessment of missing and residual facial skeleton, soft tissue, skin and mucosal lining, and functional dentition.
- Reconstructive options range from prostheses to the use of regional or free tissue transfers.
- Patient selection and timing of the intervention are critical for successful reconstruction.
- Successful reconstruction and rehabilitation of midface and maxillary defects require the care of a multidisciplinary team.

The midface is a complex area and the functional and aesthetic foundation for nearly every feature of the central face. It comprises the following components: the nose, upper lip, cheek, orbit, maxilla, and palate/alveolar ridge. Functionally, it provides support from the anterior skull base to the occlusal plane, with additional support to the orbital contents and the lateral and anterior projecting elements of the face. The palate, by separating the oral cavity from the sinonasal cavity, aids in speech and deglutition, and the facial contour and skin provide an individual with his or her characteristic appearance.
Defects of the midface and maxilla commonly result from surgical tumor extirpation, traumatic insults, and congenital abnormalities. They range from small defects in skin and soft tissue to large composite defects extending from the anterior skull base to the oral cavity. Such defects can impair speech and communication, deglutition, and orbital support and vision, as well as self-image and mental health, while challenging the patient to maintain personal hygiene and social acceptance. With the loss of one or more of these functional or aesthetic properties, the return to a good quality of life depends on successful reconstruction and rehabilitation.

Objectives of reconstruction include the following:
- Obtaining a healed and stable wound
- Separating the oral and sinonasal cavities
- Restoring maxillary buttresses
- Supporting the orbit and skull base
- Maintaining oral competence
- Restoring functional dentition, mastication, and deglutition
- Maintaining the nasal airway
- Resuspending adynamic facial soft tissues
- Reconstituting facial contour and projection

In this chapter we outline basic systems for classifying defects of the midface and maxilla and provide an algorithm for determining the appropriate methods of reconstruction and rehabilitation.

**INDICATIONS AND CONTRAINDICATIONS**

Advanced midface reconstruction with free tissue transfer is a complex but effective method for rehabilitating defects of the maxilla and surrounding tissue. Indications include defects that have failed a trial with a maxillary or palatal prosthesis and defects too significant to be adequately supported by an obturator. In patients with bony retentive surfaces and dentition inadequate to support a prosthesis, the use of a vascularized bone-containing free flap is recommended (see Chapter 16). The adequacy of dentition refers to the quantity and quality of teeth, with the maxillary molars and canines being particularly important. When additional bone is provided as part of the reconstruction, it can serve as a scaffold for the simultaneous or staged placement of osseointegrated implants to optimize mastication postoperatively.

For patients with total maxillectomy defects with preserved orbital contents, reconstruction of the orbital floor is necessary to maintain orbital height and eye function postoperatively. This can be accomplished either with separate reconstruction using nonvascularized free bone grafts or as part of a maxillary reconstruction using a scapular or iliac crest free flap.
Total maxillectomy with orbital exenteration defects are challenging because of the large amount of associated dead space that is created. Ideally, reconstruction is usually accomplished using a bulky soft tissue free flap, such as a rectus abdominis, latissimus dorsi, or anterolateral thigh flap. These flaps can be supplemented with separate free nonvascularized bone grafts for additional structural support when the zygomaticoorbital complex is removed as part of the resection.

Generally, free tissue transfer is relatively contraindicated in patients with a very poor underlying health status or those with a poor prognosis and expected short-term survival. In these cases, maxillary prostheses can be used in an effort to decrease operative time and morbidity. In addition, each flap donor site has specific contraindications (see Preoperative Management), and if the resulting morbidity from the flap harvest is unacceptable to the patient, a maxillary prosthesis or alternative reconstructive technique should be considered. Temporoparietal fascial flaps and temporalis flaps are contraindicated in patients in whom the superficial and deep temporal arteries were sacrificed during a past or the present surgical intervention, respectively.

**Preoperative Management**

The preoperative assessment of the patient begins by obtaining a thorough history. The nature of the problem (for example, a traumatic defect or tumor removal) and the time course of the process are discussed. If the planned repair is a secondary reconstruction, the following must be determined: when the defect was created, the details of the operative procedure, and any associated treatments (for example, radiation therapy, chemotherapy, or the placement of dental implants). If relevant and available, previous operative reports should include information on the previous use of local flaps and the availability of donor vessels for patients in whom a free tissue transfer may be recommended. In addition to previous flap procedures, each patient’s complete medical and surgical history should be reviewed with special attention given to conditions that could compromise wound healing, such as diabetes or malnutrition. A patient’s overall health status and ability to sustain general anesthesia should be assessed by the surgeon and medical team. Any history of peripheral vascular disease should also be elicited, especially in patients who may require free tissue transfer.

A complete examination of the head and neck is performed to determine the extent of the defect. The quantity and quality of dentition should be assessed. Any involvement of the facial skin and soft tissue, palate, and intraoral mucosa should be documented, and a detailed ophthalmic examination should be performed to determine any extension into the orbit. An assessment of cranial nerve function may help to identify perineural invasion or skull base involvement.
Imaging of the primary site should start with a CT scan of the sinuses and neck with a contrast medium to provide good detail of bony and dental involvement. An MRI can yield soft tissue detail and additional information if orbital or skull base involvement is suspected. In patients with residual dentition, a Panorex view may be beneficial to assess the quality of the remaining teeth. Patients who will be managed with a prosthesis to obturate the defect should be referred to a maxillofacial prostodontist for a preoperative evaluation and dental impressions so that a temporary prosthesis can be fabricated and placed at the time of the scheduled procedure.

For patients in whom a free tissue transfer is planned, a donor site–specific workup should be performed. In patients scheduled to receive a radial forearm free flap, a preoperative Allen test is important to assess the adequacy of the ulnar and palmar arch circulation. In this test, flow through the radial and ulnar arteries is occluded with digital pressure on the wrist. Blood is pumped out of the hand as the patient repeatedly opens and closes his or her hand. Once the palm and thenar eminence are white, the pressure on the ulnar artery is released and the hand, especially the thumb and index finger, are evaluated for refill. An absent refill implies a positive test and is a contraindication for the patient to undergo the flap harvest. If bone is to be harvested with the forearm flap, it is usually recommended that an orthopedic or hand specialist assist by plating the residual bone at the time of harvest to avoid the catastrophic complication of a pathologic fracture. If a fibular free flap is planned, circulation to the feet should be assessed to ensure three-vessel run off through patent anterior and posterior tibial arteries and the peroneal artery. This can be assessed successfully using CT angiography, MR angiography, or color flow Doppler studies. We perform color flow Doppler studies because of their reliability and low cost. For flaps from the subscapular system (for example, scapular, latissimus dorsi, and scapular tip flaps), no preoperative studies are recommended, but the patient should be questioned and examined to rule out prior axillary surgery or radiation therapy. No specific preoperative studies are recommended when using the iliac crest as a donor site.

**Defect Classification**

When analyzing a patient’s defect for reconstruction of the maxilla and midface, it is important to assess the missing and remnant facial skeleton, soft tissue, skin/mucosal lining, and functional dentition. Numerous classification schemes have been proposed with a main goal of standardizing the assessment of these defects. Classification allows the development of treatment algorithms and comparison of outcomes across multiple institutions.
Brown et al. devised a classification system based on a series of 45 maxillectomies, breaking down each defect into vertical and horizontal components. The vertical component is designated as class 1, 2, 3, or 4, based on the unilateral involvement, with emphasis on the orbit. For vertical classes 2 through 4, a corresponding letter, a, b, or c, is added to represent the horizontal component of palate and alveolar ridge missing in the defect. Therefore each defect falls into one of 10 possible categories, with the vertical component having a greater influence on the aesthetic result and the horizontal component having a greater functional consequence. This system effectively characterizes the dental, masticatory, and articulation deficits that can result from inferior defects, taking into account the aesthetic impact of the superior region and issues of orbital support.

Cordeiro and Santamaria proposed another popular classification system that classifies defects following maxillectomy into one of four distinct types, taking into account the surface area/volume ratio and the need for orbital and/or palatal reconstruction. Type 1 defects result when one or two walls of the maxilla are resected, with preservation of the palate. Type 2 defects occur after a subtotal maxillectomy with removal of the palate, maxillary arch, and medial and lateral walls of the maxilla, with preservation of the orbital floor. Type 3 defects result after a total maxillectomy, with resection of the orbital floor. In type 3A defects, the orbital contents are preserved, and in type 3B defects, the orbital contents are exenterated. A type 4 defect results after orbitomaxillectomy, with preservation of the palate. Cordeiro and Santamaria proposed an algorithm to determine the most appropriate reconstructive option for each defect; however, they failed to take into account the presence or absence of functional dentition.

In 2001 Okay et al. presented an additional classification system with a reconstructive algorithm based on the analysis of the defect. By initially evaluating the size of the palatal defect and assessing the adequacy of the residual dentition and retentive surfaces for supporting a maxillary prosthesis, the most appropriate method for reconstruction can be chosen. Additional classifications are available to designate when components such as the orbital floor or the zygoma were lost. Based on their series, with results supported by others, defects involving the ipsilateral canine and 50% or more of the palate achieved poor rehabilitation with an obturation alone. Similarly, when the zygomatic body and orbital floor were involved, vascularized bone-containing free flaps allowed the most effective method for reconstruction. Because of the success of their outcomes, their recommendations are largely focused toward the use of tissue reconstruction in the primary setting.
An alternative algorithm proposed by Futran and Mendez\textsuperscript{12} also takes into account the nature of the defect and the amount of viable dentition (Fig. 26-1). In patients with adequate remaining teeth to support a functional denture (canine and molar teeth are of particular importance), local or soft tissue flaps are typically recommended. For those without viable dentition and those losing significant amounts of their orbitozygomatic contour, bone-containing free flaps or soft tissue flaps combined with free bone grafts are recommended, allowing dental implant placement and reconstitution of the lateral projecting element.

![Fig. 26-1](image-url)  
Reconstructive options for midface defects.
RECONSTRUCTIVE OPTIONS/OPERATIVE TECHNIQUES

Reconstruction of the midface is particularly challenging because of the complexity of the three-dimensional anatomy and the number of specialized subsites that make up the area. In addition, each defect is different. Therefore no singular technique is available to reconstruct all defects.

The traditional reconstruction of maxillary defects involved the use of maxillary prostheses. By separating the oral and nasal cavities, obturators can assist with speech, deglutition, and mastication. Even now, when more detailed and complex reconstructive modalities are available, maxillary prostheses provide a viable option for reconstruction in the majority of patients, all with reduced surgical complexity and operative time compared with tissue reconstructions.

In patients who are not good candidates for prostheses or when expectations of postoperative rehabilitation are high, surgical reconstruction of the defect can be immediate or delayed. Options for the reconstruction of midface defects are numerous and must be tailored to the defect and each patient’s characteristics. An ideal reconstructive modality is safe, efficient, and reliable and is performed in a single stage with minimal donor site morbidity. In addition, the selected reconstruction option must not interfere with the completion of therapy, such as postoperative radiation therapy or chemoradiation therapy, and it must be able to tolerate the burden of healing in a poorly vascularized, contaminated wound bed. Available local tissues are limited to the reconstruction of small soft tissue defects. More often, free tissue transfer allows a custom selection of appropriate bone and soft tissue. The following sections describe preferred surgical options for reconstruction of the midface and maxilla based on analysis of the defect.

Palatal Defects

Reconstructive Options

For defects involving the hard palate, alveolar ridge, teeth, and any surrounding mucosa, without significant communication with the sinonasal cavity, options include healing by secondary intention or coverage with a local soft tissue flap. When choosing the method for reconstruction, it is helpful for the surgeon to have experience in cleft lip and palate repair and in the use of prostheses when adequate dentition is present.

The palatal island flap is known as the most versatile and reliable of these techniques for reconstruction of defects up to 15 cm². This is a pedicled flap based on the greater palatine vessels and can be harvested from up to 90% of the hard palate and rotated up to 180 degrees. In 2003 Moore et al published a series of 10 consecu-
tive palatal defects repaired with the palatal island flap in which 8 achieved closure without oroantral fistula. Those who did develop fistulas had more complex defects extending to the infratemporal fossa. The mean hospital stay was 3.3 days, and 9 of the 10 patients resumed an oral diet before discharge. Relative contraindications for palatal island flaps include a history of local radiation therapy and defects so large that residual palatal mucosa is insufficient to close the area. In these instances, the use of thin fasciocutaneous free flaps has been advocated. Genden et al compared the use of radial forearm free flaps with that of maxillary prostheses to close equivalent defects. All patients were able to resume a regular diet with normal mastication and articulation. In addition, both groups had similar satisfaction with their appearance, ability to chew, and sense of taste. Patients in the radial forearm free flap group, however, reported higher satisfaction with speech, comfort, convenience, and social interaction compared with patients managed with prostheses.

Operative Technique

The technique used to harvest the palatal island flap depends on the location and size of the defect. It is a mucoperiosteal flap based on the greater palatine vascular pedicle, which exits the greater palatine foramen in the lateral aspect of the transverse suture of the hard palate, approximately 1 cm medial to the maxillary second molar. The vessels course anteriomedially before ascending in the incisive foramen. An adequate flap is elevated on this pedicle using a combination of sharp dissection and periosteal elevators. The contralateral pedicle is ligated, and the donor pedicle is completely isolated to allow additional freedom of rotation. It can be inset to close the defect with 3-0 Vicryl sutures. The donor site is left to remucosalize. Postoperatively the patient should rinse regularly with saline solution to cleanse the exposed bone. A clear liquid diet is recommended for at least 24 hours, with the patient transitioning to a soft diet over the next week.

In patients previously treated with local radiation therapy and those with inadequate residual mucosa to close the defect, it is necessary to bring in vascularized tissue from a distant source (Fig. 26-2, A). Radial forearm free flaps provide a robust yet pliable source of skin and fascia that is ideal for closing these defects. The flap is harvested in a manner previously described (Fig. 26-2, B). To prepare the recipient site, the neck must be explored to isolate recipient vessels, and a tunnel must be created from the buccal mucosa to the neck in a subcutaneous plane superficial to the facial nerve branches. This tunnel must accommodate at least two fingers to ensure that pedicle compression does not occur. The skin edge is inset to the mucosal edge using 3-0 Vicryl sutures to close the defect (Fig. 26-2, C). Narrow undermining of the periosteum around the periphery of the defect can assist with closure. Fig. 26-2, D, shows the healed postoperative result.
Fig. 26-2  A, This patient had a palatal defect after undergoing resection and local radiation therapy for the treatment of a palatal squamous cell carcinoma. The edges of the mucosal defect need to be freshened and the surrounding periosteum elevated to accommodate the free flap. This allows an additional layer of vascularized tissue underneath the mucosal closure. B, The radial forearm free flap provides an excellent source of pliable yet robust vascularized soft tissue that is ideal for this type of reconstruction. C, The immediate postoperative result. The skin edge of the forearm flap is inset to close the mucosal defect with interrupted 3-0 Vicryl sutures. D, The 3-month postoperative result.
Inferior Maxillectomy Defects With Viable Dentition

Reconstructive Options

When an inferior maxillectomy is performed, by definition, an oroantral or an oronasal fistula is created. In patients with adequate remaining dentition and facial skeleton, a maxillary obturator is often a good option when used alone or in conjunction with a soft tissue flap. The use of a maxillary prosthesis is a time-tested and reliable method that has traditionally been used to obturate a variety of maxillary defects. The prosthesis allows separation of the oral and nasal cavities to aid in speech and deglutition. In addition, the obturator can be fashioned to provide optimal facial contour and support following orbital and nasal resections.

Successful rehabilitation with a maxillary prosthesis starts with a preoperative assessment by a qualified and experienced maxillofacial prosthodontist. Knowledge of the planned defect—the structures to be removed and those that will remain—is critical. In particular, the ability to maintain molar and canine teeth is assessed. A preoperative impression is made and used as a template to fashion a temporary prosthesis that can be placed intraoperatively. Over time, close communication between the patient and the prosthodontist is important so that the prosthesis can be adjusted to optimize comfort, function, and appearance.

Despite the advantages of prostheses, a number of drawbacks can make immediate reconstruction more appealing. First, effective use of the prosthesis depends on the patient’s ability to place the prosthesis and maintain hygiene of the surgical cavity. This requires a certain amount of vision and manual dexterity, which can be diminished in elderly patients and those with only one eye. In patients with poor remaining dentition, unhealthy retentive surfaces (especially when exposed to preoperative or postoperative radiation), and significant loss of the zygomatic body and orbital floor, functional and aesthetic outcomes can be compromised when a prosthesis alone is used. As described by Okay et al, when the ipsilateral canine is maintained, support for a prosthesis is usually adequate. With larger defects, however, the fulcrum created on the obturator often results in instability and difficulty with mastication.

The use of rotation or free soft tissue flaps can be used alone or in combination with prostheses. By providing permanent oronasal separation and decreasing the size of the cavity, wound hygiene can be improved and the size and weight of the prosthesis can be reduced. In addition, by providing a soft, vascularized insensate surface, the retentive bed of the soft tissue flap can better tolerate an imperfectly fitting prosthesis. Colemenero et al described the use of a rotated temporalis flap and skin
grafting to cover larger defects or those needing vascularized tissue, as in patients with prior radiation therapy. A similar technique was described by Choung et al,26 who also advocate the use of an attached segment of calvarial bone in select patients. These robust muscular flaps can provide good coverage. Their use, however, does result in a significant contour deformity at the donor site and can place the upper division of the facial nerve at risk when the bone of the zygoma is transposed during flap rotation. The advantage of a soft tissue free flap is that it provides the option of using transferred skin surfaces to reline the lost mucosal surfaces intraorally and interanasally. This can result in less contracture, allowing more robust healing and maintenance of a nasal airway. Frequently used soft tissue flaps include the radial forearm, rectus abdominis, latissimus dorsi, and anterolateral thigh flaps.

Hatoko et al15 described the use of radial forearm fasciocutaneous free flaps in patients with large inferior maxillectomy defects who were not able to tolerate an obturator. Defects up to 20 cm² could be successfully closed with the flap folded on itself to provide an epithelial cover for the floor of the sinonasal cavity and the re-created palate. Benefits in articulation and mastication were described, with two of the three patients using a denture on top of the reconstruction with good success. Futran and Haller27 and Villaret and Futran28 also described free tissue transfer for hard palate reconstruction. In select patients in whom the bony defect involved the premaxilla and anterior projecting element, a small amount of bone in the form of the radial forearm osseocutaneous flap was added to the reconstruction.28 Although this approach can provide additional support and allow the use of standard dentures, the bone stock is considered inadequate for dental implants. For patients with larger-volume defects, bulkier musculocutaneous soft tissue free flaps may be necessary.

Operative Technique

As described previously, the use of an obturator with or without an underlying soft tissue flap is a good option for reconstruction for inferior defects with good dentition on the opposite side of the arch. For patients in whom a soft tissue flap is not used, the inner raw surface of the cheek flap should be covered with a split-thickness skin graft (usually 0.015-inch thick) or cadaveric acellular dermis such as Dermamatrix. With this in place, the cheek dead space should be packed with Xeroform gauze before the facial incision is closed. Finally, the prefabricated maxillary prosthesis can be placed transorally to support the Xeroform bolster during the initial postoperative period. We tend to anchor the prosthesis onto remaining teeth when possible. If this does not provide adequate support, additional screws can be used to secure the plate to the residual hard palate. Dental wax can be applied over the screw head to minimize irritation to the tongue.
This patient had an inferior maxillectomy defect (Fig. 26-3, A). A rectus abdominis free flap was harvested with a skin paddle, designed to provide intranasal and intraoral lining (Fig. 26-3, B). This flap can be harvested with a large skin paddle to allow multiple surfaces, such as the palate and nasal cavity, to be lined. The harvesting technique was previously described. The intervening epidermis was removed, allowing the flap to be folded without burying any of the desquamating surface at the time of closure (Fig. 26-3, C). This technique provides a stable surface to support a denture and good facial contour when the lateral and anterior projecting elements are maintained during the resection (Fig. 26-3, D through F).

Fig. 26-3  A, This patient had a right maxillary sinus squamous cell carcinoma that required a subtotal maxillectomy with preservation of the orbital floor. He had adequate dentition to support a prosthesis postoperatively. B, A rectus abdominis free flap was harvested with a large skin paddle. Portions of the skin paddle were designated to facilitate realignment of the lateral nasal wall and palate. C, The rectus abdominis free flap was inset by reapproximating the mucosal surfaces with the cutaneous paddle from the flap. The intervening epidermis was removed to allow this portion of the flap to be buried during the closure.
In patients with inferior maxillectomy defects and insufficient retentive surfaces and dentition to support a prosthesis, it is preferable to reconstruct the area with vascularized bone to allow osseointegrated dental implants. In patients without contraindications who are unlikely to perform well with a prosthesis, implants can be placed immediately. However, if a prosthesis may be an option, a trial can be performed after allowing appropriate healing to avoid the expense of additional dental procedures. If implants are ultimately necessary, they can be placed as a second procedure after the initial reconstruction.29

Fig. 26-3, cont’d  

D, Intraoral closure. This 3-month postoperative view shows the closure of the mucosal defect with obliteration of the cavity dead space. E and F, Three months postoperatively the patient has acceptable contour.

**Inferior Maxillectomy Defects Without Viable Dentition**

**Reconstructive Options**

In patients with inferior maxillectomy defects and insufficient retentive surfaces and dentition to support a prosthesis, it is preferable to reconstruct the area with vascularized bone to allow osseointegrated dental implants. In patients without contraindications who are unlikely to perform well with a prosthesis, implants can be placed immediately. However, if a prosthesis may be an option, a trial can be performed after allowing appropriate healing to avoid the expense of additional dental procedures. If implants are ultimately necessary, they can be placed as a second procedure after the initial reconstruction.29
When choosing a flap, the main factors are the size of the palatal defect and the need for bony support in additional areas, such as the orbital floor or the zygomatic projection. In 2002 Futran et al. reported their series of 27 consecutive patients who received a fibular free flap for the reconstruction of maxillectomy defects that involved the palate and were not amenable to an obturator. Eighteen patients received implants; four patients had wound complications that were managed successfully with local wound care, and there was one flap loss. All patients had intelligible speech over the telephone. All were able to resume an oral diet, with 14 returning to a regular diet and 13 to a soft diet. Granick et al. used scapular osseocutaneous flaps to reconstruct similar defects.

We prefer the fibular free flap because of the large amount of available bone, the reasonable pedicle length, and the minimal donor site morbidity. Scapular flaps can be a versatile option for more complex defects; however, they provide somewhat thinner bone that does not as reliably accept implants, and simultaneous midface work and flap harvest are usually not an option. The iliac crest provides excellent bone stock but is less frequently used because of the excessive bulk of the flap, the short vascular pedicle, and the potential for donor site morbidity. When used in combination with soft tissue flaps, nonvascularized free bone grafts can provide structure to the face and improve contour but do not reliably accept dental implants.

**Operative Technique**

This patient had an inferior maxillectomy defect without significant residual dentition. To allow easier soft tissue reapproximation in the future, 3-0 Vicryl sutures were placed through the posterior mucosal line and meticulously kept in order before insetting the flap (Fig. 26-4, A). The fibular free flap was harvested using the standard technique (Fig. 26-4, B and C). The maximum length of bone was harvested, maintaining 6 cm proximally and distally to preserve the integrity of the knee and ankle joints, respectively. Closing osteotomies were performed from distal to proximal to allow the removal of the proximal bone. By preserving the proximal periosteum, the vascular supply to the bone was optimized and the pedicle length increased. Monocortical screws were used to secure 1.3 mm miniplates (Fig. 26-4, D). The vascular pedicle was passed through a tunnel created in the cheek and down into the neck for later reanastomosis. This tunnel is usually made in a subcutaneous plane superficial to the facial nerve branches and should be able to accommodate at least two fingers to ensure adequate space for the vessels. Miniplates were used to secure the fibula bone to the medial and lateral buttresses of the remnant facial skeleton (Fig. 26-4, E). The skin paddle of the fibula was inset to reconstruct the mucosal surface of the palate. Fig. 26-5, A and B, show a different patient with delayed osseointegrated implants.
Fig. 26-4  A, This repair of a posttraumatic inferior maxillectomy defect was performed in a staged fashion. The patient had a left hemipalate defect with inadequate dentition and retentive surfaces available to support a maxillary prosthesis. B, The ipsilateral fibular free flap was harvested. It was particularly important to maximize the length of harvested bone to maximize the pedicle length that could be delivered to the neck. C, A single closing osteotomy was performed to re-create the pre-maxilla and lateral alveolar ridge with a 1.3 mm titanium miniplate used to secure the two segments. Once good alignment is achieved, the proximal bone can be discarded after elevating off the perios- teum. D, L- or T-shaped titanium miniplates were used to secure the fibula bone to the remnant facial skeleton. E, The fibula skin paddle was closed to the mucosal edge to achieve a watertight seal.

Fig. 26-5  A, Osseointegrated dental implant posts can be placed after at least 8 weeks of adequate healing. B, These posts can support dentures to improve the cosmetic and functional outcome.
Total Maxillectomy With Orbital Preservation

Reconstructive Options

When orbital contents are preserved but the bony support provided by the floor of the orbit is removed, this must be addressed at the time of reconstruction to avoid enophthalmos and resulting visual compromise. The orbital floor can be reconstructed individually or as part of the rest of the maxillary reconstruction. When performed separately, one option is the use of free bone grafts from the calvarium or iliac crest, with rotation or free flaps to provide appropriate vascularized coverage. The use of a temporoparietal fascial flap has been described in which the flap is rotated after osteotomizing the zygomatic arch.\textsuperscript{32,33} In cases where the periorbita is taken as a margin, a piece of true temporalis fascia can also be used to line the undersurface of the orbital contents, between the periorbital and the free bone to minimize scarring. Another option involves the use of vascularized calvarial bone transferred with a temporalis rotation flap.\textsuperscript{26,34} In each instance, rotation requires at least partial removal of the orbitozygomatic complex, which can weaken the remaining maxillary structure and place the frontal branch of the facial nerve at risk. An additional disadvantage is the unnatural divot left at the temporal donor site.

After the orbital floor is restored, the infrastructure of the maxilla can be reconstructed as described previously. If viable teeth are present to support a prosthesis, soft tissue coverage can be accomplished through rotation flaps or free tissue transfer. When healed, the area can be fit with an appropriate denture. Shestak et al\textsuperscript{35} described the use of the latissimus dorsi free flap to reconstruct midface defects, which provides soft tissue contour for the face and cheek and yields satisfactory aesthetic results. Brown and Burke\textsuperscript{36} reported a series of 12 patients who underwent reconstruction of maxillary defects with rectus abdominis free flaps, with acceptable results. One disadvantage of using these myogenous or myocutaneous flaps is the unpredictable amount of atrophy (30% to 70%) that can occur. This drawback may be minimized by including the overlying fascia, fat, and skin in the reconstruction. Additionally, an anterolateral thigh free flap, primarily a fasciocutaneous flap, can be considered. Coleman\textsuperscript{33} reported a series of patients who had reconstruction with soft tissue free flaps combined with primary or secondary nonvascularized bone grafts. The orbital support was achieved with split calvarial bone or rib grafts, and the remaining dead space was filled with fat or muscle from the free tissue transfer. Similarly, Cordeiro et al\textsuperscript{6,7} described their results in 46 patients, with 43 eventually tolerating an unrestricted or soft diet. Futran and Haller\textsuperscript{27} reported a series of eight patients in whom split calvarial bone was used to reconstitute the missing zygoma and orbital floor, and a rectus abdominis or latissimus dorsi myocutaneous free flap was used to support the area.
If adequate retentive surfaces or dentition are not available, an osseocutaneous flap should be considered. These flaps not only allow placement of osseointegrated dental implants, but the vascularized nature of the bone tends to be more resistant to infection and resorption over time compared with nonvascularized grafts.\textsuperscript{33}

The most effective means of simultaneously reconstructing the orbital floor and maxillary skeleton is with vascularized bone-containing free flaps, with flaps from the subscapular system\textsuperscript{37,38} and iliac crest\textsuperscript{39,40} most frequently reported. Although the subscapular system is technically more complex, it offers perhaps the greatest versatility in free flap reconstruction. When a scapular free flap (based on the circumflex scapular artery) is harvested with an additional segment from the scapular tip (based on the angular branch of the thoracodorsal artery), one segment can be used to support the orbital contents while the remaining bone is used to reconstruct the maxilla and alveolar ridge. The associated latissimus dorsi muscle can be harvested as well, all on the same vascular pedicle if additional soft tissue and skin are needed to reconstruct the defect. Triana et al\textsuperscript{9} used this system of flaps to reconstruct maxillectomy defects in 10 patients, 4 of whom had their teeth, orbit, or both reconstructed. Disadvantages of the subscapular system include the inability to harvest the flap at the same time as the ablation; somewhat difficult geometry when reconstructing the orbital floor, zygoma, and alveolus; the short pedicle length; and a less robust bone stock that is not always suitable for the placement of dental implants.

The iliac crest osseocutaneous free flap is a reliable alternative that can be used for simultaneous reconstruction of the maxillary infrastructure and orbital floor. Based on the deep circumflex iliac vascular pedicle, a customized piece of iliac bone can be harvested to accurately reconstitute the maxillary structure from the inferior orbital rim to the alveolar ridge. This robust piece of bone is an ideal scaffold for osseointegrated implants, and the associated internal oblique muscle, when harvested with its ascending artery vascular supply, can provide additional soft tissue to optimize contour and obliterate dead space. Genden et al\textsuperscript{16} reported a series of six patients who underwent maxillary reconstruction with iliac crest osseocutaneous free flaps, with four patients requiring reconstruction of the zygomatic body and inferior orbital rim. One donor site complication and one minor recipient site complication occurred. Four of the patients were rehabilitated with osseointegrated implants, and all six resumed an unrestricted oral diet postoperatively and had normal speech with no velopharyngeal or oronasal insufficiency. Reported drawbacks of this flap include a short pedicle length, restricted mobility between the soft tissue and the bone, and donor site morbidity, including gait disturbance and the potential for abdominal wall hernia formation. The fibular flap provides excellent bone stock and adequate pedicle length, but unfavorable pedicle geometry can result when it is used to simultaneously reconstruct the inferior maxilla and orbitozygomatic complex.\textsuperscript{30}
Operative Technique
If the infrastructure of the maxilla is rehabilitated with a prosthesis, isolated orbital floor reconstruction can be achieved with a free bone graft, such as a split calvarial bone graft. The contour of the bone is ideal when it is harvested from the parietal calvarium (Fig. 26-6, A and B). The graft can be secured laterally to the zygoma and medially to the remnant lamina papyracea with 1.3 mm miniplates (Fig. 26-6, C). To avoid hardware infection and infection and resorption of the free bone graft, it is advisable to cover the graft and plate with vascularized tissue. In this patient, this performed by tunneling a temporoparietal fascial flap, rotating it, and securing it medially to residual periosteum and mucosa (Fig. 26-6, D). The inner surface of the cheek flap was lined with a split-thickness skin graft before closing the facial incision. The defect was packed with Xeroform gauze, and a temporary prosthesis was placed transorally.

Fig. 26-6  A and B, In this patient, split calvarial grafts were harvested from the parietal scalp to provide adequate bone with excellent contour for orbital floor reconstruction. C, Free bone grafts were secured laterally to the zygoma and medially to the remnant lamina papyracea using 1.3 mm titanium miniplates to reconstruct the orbit. D, By rotating vascularized tissue in the form of a temporalis flap or temporoparietal fascial flap, a more favorable wound bed can be provided to encourage graft survival.
Another option for reconstruction is to combine free bone grafts with a soft tissue free flap to provide additional bulk and vascularized coverage. Fig. 26-7, A, shows split calvarial bone grafts that have been used to re-create the orbital floor, the inferior orbital rim, and the medial maxillary buttress. A rectus abdominis musculocutaneous flap was used to envelop the bone grafts and seal the closure intraorally and intranasally and to bolster the orbital floor (Fig. 26-7, B). The resulting functional and cosmetic outcome is excellent in this patient (Fig. 26-7, C and D).

Fig. 26-7  A, In this patient, split calvarial bone grafts were used to recreate the inferior orbital rim, the orbital floor, and the medial maxillary buttress. Titanium miniplates secure the different fragments. B, A rectus abdominis musculocutaneous flap was used to envelop the bone grafts, providing them with a vascularized bed for healing. This is especially important after radiation therapy to avoid graft infection and resorption. C, Three months postoperatively, good closure of the palate defect is noted. D, The resulting orbital height and cosmetic result are excellent.
In patients who have undergone a total maxillectomy and are without adequate dentition, either in quantity or quality, an ideal reconstruction allows reconstitution of the maxillary alveolar ridge, simultaneously providing structural support for the orbital floor. We prefer to use free tissue transferred from the subscapular system of flaps. In this system, two separate pieces of bone can be harvested, one piece from the lateral blade of the scapula based on the circumflex scapular artery and another thin piece from the scapular tip based on the angular artery off of the thoracodorsal system (Fig. 26-8, A). The larger segment can be used to reconstruct the maxillary alveolar ridge and provide orbitozygomatic contour by plating it to the remnant premaxilla and zygoma with 1.5 mm miniplates. Although not as robust as the fibula or iliac crest, the bone provided in the blade of the scapula is usually adequate to accept dental implants. The smaller piece of bone from the scapular tip has a separate blood supply and can be manipulated with significant freedom and used to reconstitute the floor of the orbit. Miniplates can be used to secure the thin bone to the remaining lamina papyracea and zygoma or blade of the scapula, whichever allows better positioning. The muscular surface over the bone can be allowed to remucosalize and subsequently fitted with dental implants in a delayed fashion (Fig. 26-8, B). The patient in Fig. 26-8, C, has excellent eye positioning postoperatively. Fig. 26-8, D, shows the position of the scapular bone on a postoperative CT scan.

Fig. 26-8  A, Orbital floor reconstruction with a bone-containing free flap. The combined scapula/scapular tip flap can provide two separate bony segments with individual blood supplies arising from the same vascular pedicle. The more robust lateral blade of the scapula can be used to reconstitute the maxillary infrastructure, and the smaller tip segment can be rotated on its angular artery blood supply to provide support to the floor of the orbit. B, In this patient, the orbital contents were accurately positioned on the affected side. C, Six months postoperatively, he has complete remucosalization of the intraoral surface.
Total Maxillectomy With Orbital Exenteration

Reconstructive Options

Total maxillectomy with orbital exenteration defects provide a challenge to the reconstructive surgeon because of the large volume of dead space that is created. Although the tissue transferred is bulky, somewhat less precision is required in the reconstruction. In these patients, the main determinant of the reconstruction is the integrity of the orbitozygomatic complex, which serves as the lateral projecting element. If this bony structure is intact with functional dentition, a prosthesis can be considered. However, if an obturator is used to span defects extending from the palate to the orbit, cheek retraction can occur over time, and the person’s appearance can be compromised by an expressionless, unblinking prosthetic eye. In addition, a large cavity remains beneath this support that requires regular cleaning by the patient and/or physician to maintain acceptable hygiene. One approach to avoid this issue is to obliterate the dead space with a soft tissue free flap, such as a rectus abdominis, anterolateral thigh, or latissimus dorsi flap, and place a denture intraorally. This can improve the contour of the midface and decrease the need for postoperative wound hygiene. Cordeiro and colleagues reported success with this approach in a series of 13 patients, in which 6 excellent and 6 fair aesthetic results were obtained. Ten of the 13 patients achieved normal or near-normal speech postoperatively, and 11 of the 13 were able to tolerate at least a soft diet after appropriate healing occurred.

When the orbitozygomatic complex is removed as part of the resection, it is imperative to restore this lateral projecting element if an optimal aesthetic result is to be achieved. With these large defects, this is usually best accomplished through the combined use of free nonvascularized bone grafts and soft tissue free flaps, with vascularized bone-containing free flaps as an alternative. In their series of 19 patients
with orbital reconstruction, Chepeha et al\textsuperscript{41} described the use of fasciocutaneous free flaps for defects limited to the orbit, osseocutaneous forearm flaps for defects involving the removal of 30\% or more of the orbital rim, and osseocutaneous scapular free flaps for more radical resections involving the orbit, malar eminence, and overlying skin. Sixteen patients were followed for more than 4 months, and 10 had little to no contour deformity. Eight patients frequently engaged in social activities outside the home, and 5 of the 9 patients employed preoperatively were able to return to work after recovering from surgery.

**Operative Technique When the Orbitozygomatic Complex Is Preserved**

The patient in Fig. 26-9, \textit{A}, underwent a total maxillectomy with orbital exenteration, anterior craniofacial resection, and preservation of the orbitozygomatic complex. A muscle-only rectus abdominis free flap was harvested in the standard fashion and used to close the defect, providing reasonable contour and eventually a healed stable wound (Fig. 26-9, \textit{B}). The exposed muscle intraorally remucosalizes with time to recreate the hemipalate and ultimately provides a surface for a denture (Fig. 26-9, \textit{C}).

The flap inset is individualized for each defect and harvested flap. Skin surfaces of a myocutaneous free flap can be used to reline the nasal cavity and hemipalate mucosa (see Fig. 26-3, \textit{C}). Additionally, for myofascial flaps, the rectus sheath that is harvested can be used to tack the flap in a particular orientation or to serve as reinforcement for the closure of a skull base defect. A cheek tunnel in the subcutaneous plane is created to accommodate two fingers, allowing the pedicle vessels to be passed inferiorly into the neck.

**Fig. 26-9**  \textit{A}, This defect resulted from an anterior craniofacial resection, with orbital exenteration and total maxillectomy that resulted in a large amount of dead space. The majority of the zygoma and lateral projecting element was preserved during the resection.
Operative Technique When the Orbitozygomatic Complex Is Removed

If the orbitozygomatic complex is removed as part of a total maxillectomy, the area is reconstructed to provide a stable, lateral projecting element. Free bone grafts from the calvarium, rib, or iliac crest can be harvested and cantilevered on the residual zygomatic arch or zygomaticofrontal buttress, depending on the extent of the resection. Miniplates between 1.3 and 1.5 mm are usually appropriate. The dead space can be filled with a rectus abdominis, latissimus dorsi, or anterolateral thigh soft tissue free flap (see Fig. 26-7).

Vessel Selection

Midface reconstruction provides an additional challenge, because it is somewhat removed from the donor vessels in the neck. In ideal circumstances, flaps with adequate pedicle length are selected and vessels more superior in the neck are used for reanastomosis (facial artery and proximal external jugular vein). We prefer vessel geometry that provides mild tension on the anastamosis to avoid pedicle kinking, particularly of the vein. Care should be taken to avoid twisting the pedicle as it is passed through the cheek tunnel to avoid wrapping the artery around the vein (barber-poling). In addition, when possible the artery anastomosis should be performed first, allowing it to lie deep to the pedicle vein to avoid compression and potential outflow obstruction.
**Technical Tips and Tricks**

- Bone for rigid fixation is limited; 1.5 or 2 mm miniplates are preferred; the zygomatic buttress and piriform aperture areas provide the best anchorage.
- Upper neck vessels are preferred for vessel anastomoses. Although the superficial temporal artery is reliable in most cases, the vein caliber and integrity are quite variable and the geometry is not ideal.
- A generous subcutaneous tunnel should be established between the maxilla and the neck vessels to allow unimpeded passage of the vascular pedicle. The coronoid process of the mandible can also be resected for additional room.
- The pedicle flap length must be maximized so that the need for vein grafts is minimized.
- Facial vessels are dissected over the mandible, because these are excellent recipient vessels for anastomoses to bony flap vascular pedicles, which are typically shorter than soft tissue flap vascular pedicles.

**Pitfalls**

- When using bony flaps, the vascular pedicle can be pinched between the bony segments and in the pterygoid region. Careful attention in these areas is essential.
- Although it is preferable to minimize external facial incisions, adequate visualization of the tissue inset is essential and appropriate exposure should be achieved.
- The surgeon must be totally comfortable with the geometry of the vascular pedicle before plating the bone of the flap, because once the bone is secure and/or the soft tissue is inset, adjustments are difficult.
- In cases of inferior maxillectomy reconstruction, it may be helpful to pass the sutures through the posterior mucosal edge before putting in the flap. These sutures can be organized for later use to close the back part of the skin paddle. Without these sutures in place, it is often difficult to accurately approximate the posterior edges with the flap obstructing the view.
- Correct orbital positioning is technically challenging to achieve, and a forcedduction test should be performed to ensure that the globe is not entrapped during the reconstruction.
- It may be necessary to use vein grafts, because the vascular pedicle of the flap may not always reach to the recipient neck vessels.
**Postoperative Management**

In patients with a maxillary prosthesis, the cheek packing is left for 7 days postoperatively, and appropriate gram-positive antibiotic coverage is required during that time. At 1 week, patients see the maxillofacial prosthodontist. The obturator and the packing are removed, the cavity is cleaned and inspected, and patients are instructed about frequent nasal saline solution irrigations and home humidification. Over time, the maxillary prosthesis is altered to best fit the evolving defect.

When a free flap is used, it should be regularly monitored to ensure vascular integrity. A physical examination and assessment of the flap color, turgor, and capillary refill should be routine for at least the first 48 hours postoperatively. A handheld Doppler probe can be used to assess flow. We recommend performing a pinprick assessment with a 25-gauge needle to look for bright red bleeding every 6 hours for the first 72 hours postoperatively. In patients with buried flaps, an implantable Doppler probe placed just distal to the venous anastomosis can be used.

In patients with an intraoral mucosal-skin suture line, a feeding tube should be placed at the time of surgery, allowing the patient to maintain an NPO status for 5 to 7 days. If velopharyngeal insufficiency or dysphagia develops, assessment by a speech and swallowing pathologist may be indicated. When the lateral nasal wall is reconstructed, especially with a bulky soft tissue flap, the nasal airway should be stented with gauze packing or a Merocel sponge for 5 days.

The management of each free flap donor site has been previously described in the literature. In short, the radial forearm free flap donor site should be closed with a split-thickness skin graft, with a bolster placed over the area. The arm is placed in a cast or volar splint for 7 days to ensure that the graft takes. If bone is taken and the radius plated, appropriate follow-up with an orthopedic or hand specialist should be arranged. After a fibular free flap procedure, the donor lower leg should be placed in a cast with the ankle at a right angle for 5 days. Patients can bear weight as tolerated. After the cast is removed, the patient can ambulate and work with a physical therapist to optimize leg function. A splint should be placed to keep the foot flexed when in bed. Flaps from the subscapular system require no particular rehabilitation care, but closed suction drains should remain until minimal output is noted to prevent seroma formation. Rectus abdominis and iliac crest donor sites require that the patient not strain or lift heavy objects for at least 2 to 4 weeks to prevent hernia formation.
CRITICAL POINTS

Must Know

- Reconstruction of the midface starts with an analysis of the defect and consideration of a patient’s capabilities and goals for rehabilitation.
- Defects can range from small skin or soft tissue defects to large composite defects, from the anterior skull base to the anterior two thirds of the tongue.
- Goals for reconstruction focus on obtaining a healed stable wound, with additional efforts to optimize form and function postoperatively.
- Reconstructive options range from maxillofacial prostheses to the use of local or distant tissue that can be tailored to the components of the defect.
- In patients with adequate retentive surfaces and teeth, obturators are often appropriate options, alone or in combination with a soft tissue flap.
- For patients who are poor candidates for a prosthesis, free flaps containing vascularized bone can be used to reconstruct the facial skeleton and to serve as a scaffold for future osseointegrated dental implants.
- The perioperative and postoperative rehabilitation of these patients is most successfully accomplished with contributions from many members of a multidisciplinary team.

Should Know

- Prostheses are not appropriate for larger defects for which retention becomes an issue.
- Reconstruction of the bony skeleton with either autologous tissue or a prosthesis gives the best results.

Synopsis

- Reconstruction of the midface is important for aesthetics and function.
- A multidisciplinary approach is important.
- All reconstructive modalities must be considered and tailored to the patient’s defect and condition.

References


Maxillectomy defects become more complex when critical structures such as the orbit, globe, and cranial base are resected and reconstruction with distant tissues becomes essential. This study reviews all maxillectomy defects reconstructed immediately using pedicled and free flaps. The authors establish a classification system and algorithm for the reconstruction of these complex defects.


Free-flap reconstruction of the palate establishes reliable permanent separation of the oral and sinonasal cavities in one stage. In addition, it provides the potential for dental rehabilitation with the restoration of masticatory function and normal phonation. The flap choice is tailored to specific palatal defects and each patient’s needs. The authors present results of 30 patients with hard palatal defects that resulted from ablative oncologic surgery: 10 total or subtotal palatal defects, 14 hemipalatal defects, and 6 anterior arch defects.

The authors present a series of 27 patients who underwent midface reconstructions with a fibular osteocutaneous free flap. None of the patients had sufficient retentive surfaces and/or teeth to support a conventional prosthesis. The authors concluded that the use of the fibula osteocutaneous free flap to reconstruct the midface is highly reliable, and it is their flap of choice for lower maxillary defects requiring bony reconstruction. However, when orbitozygomatic support is the primary objective, the utility of this flap is limited. Because of the complexity of this procedure, the choice of midface reconstruction technique should be tailored for each patient.


The scapular flap has proved useful in restoring an obliterated maxillary sinus, bony and soft tissue contour of the face, rigid support for the velum, oronasal separation, and support for the orbit. The authors found the scapular free flap to be a useful tool for reconstructing complex and variable maxillectomy defects.

Reconstruction of Facial Nerve Defects and Facial Palsy

Peter C. Neligan, Craig Birgfeld

HIGHLIGHTS

- The loss of facial nerve function has devastating functional, social, and emotional effects.
- Treatment includes static slings, dynamic muscle transfers, implants, and standard cosmetic techniques.
- Because facial movement is so complex, there is a limit to what current reconstructive techniques can achieve.
- Most progress has been made in the area of smile reanimation.
- Significant work remains to be done for eyelid reanimation.

The loss of facial nerve activity has devastating functional, aesthetic, and psychosocial consequences. The effects of bilateral paralysis are even more profound. Facial expressions communicate emotions. As surgeons, we realize that communication can occur even with the slightest of facial expressions. We communicate every day in the operating room while wearing hats and masks that cover 90% of our faces; the crinkle of an eye can convey a smile, and the raising of an eyebrow can convey a host of emotions, including a question, approval, disapproval, cynicism, and amusement. In addition to losing the ability to communicate, patients with facial paralysis also have the stigma of not appearing normal. Patients frequently report that they are treated as if they were intellectually inferior or deficient. For someone with normal mental function, this can be devastating (Fig. 27-1). These patients avoid situations in which they are expected to smile, and many either avoid smiling or develop some other method of conveying their message.
Frequently regarded by insurers as a cosmetic issue, facial paralysis should be thought of more as a functional deficit. The face is our strongest asset in communicating with others. Facial expression transcends language. An unspoken message can be sent across a crowded room with a look or a grimace. Current state-of-the-art surgery to treat facial paralysis falls far short of perfection; however, we can offer some significant improvement for these patients.

Facial paralysis can be congenital or acquired. The approach to reconstruction is the same almost regardless of the cause. If the onset of paralysis is recent, it may be possible to reinnervate the nonfunctional nerve using any of a number of procedures. If the paralysis is long standing, then the approach to treatment is the same, regardless of the cause. *Long standing* is generally accepted to mean 18 months or longer.

The degree of deformity depends on which branch or branches of the facial nerve are nonfunctional. Paralysis of the frontal branch results in brow ptosis with inability to raise the eyebrows, because the frontalis muscle is paralyzed. In a young patient, this may not be very noticeable at rest and only becomes apparent during animation. However, with age, the degree of brow ptosis increases to the point where, not only is it obvious, but may also have functional implications leading to an impingement on the visual field, particularly in upward gaze. The presence of wrinkles in the brow on the nonparalyzed side draws further attention the smooth brow on the paralyzed side.

Paralysis of the orbicularis oculi muscle has significant functional and aesthetic implications. The orbicularis oculi muscle closes the eyes and causes them to blink. People with normal muscles blink several times per minute to facilitate spreading of the tear film and prevent desiccation of the cornea. These functions are lost if the orbicularis oculi muscle is paralyzed, and the eye becomes very vulnerable to injury from dryness. Furthermore, the inability to close the eye renders a patient suscep-
tible to corneal injury from wind and foreign material. The normal palpebral opening measures 9 to 11 mm. The upper eyelid generally covers the upper 2 to 3 mm of the upper corneal limbus, and the lower eyelid is usually positioned at the lower limbus. With paralysis of the orbicularis oculi muscle, more of the cornea is exposed.¹

**ANATOMY AND FUNCTION OF THE FACIAL NERVE**

The facial nerve exits the skull base at the stylomastoid foramen. This foramen lies anterior and deep to the mastoid process.² However, the nerve quickly becomes superficial after it exits, and increasingly susceptible to injury. It enters the parotid gland and divides into an upper and lower trunk (Fig. 27-2). These trunks further divide into five divisions: temporal, zygomatic, buccal, marginal mandibular, and cervical. The trunks divide further within the parotid gland so that, by the time they exit the parotid, multiple branches make up the five divisions. There is considerable functional overlap between branches and frequent duplication of branches providing the same function. This makes cross-facial nerve grafting possible, because a branch that innervates the same muscle or muscle group as another can safely be sacrificed and used for coaptation of the graft.³

![Fig. 27-2](image_url) This 52-year-old woman had unilateral facial paralysis following unresolved Bell’s palsy. She had significant eye symptoms with ectropion, epiphora, and imbalance between the paralyzed side and the normal side.

The temporal division is similarly branched. These branches run across the undersurface of the temporoparietal fascia after crossing over the zygomatic arch. They innervate the frontalis, corrugator, and upper orbicularis oculi muscles. Because there is little fatty tissue between the nerves and skin at the lateral border of the frontalis muscle, the nerves are highly subject to injury from lacerations. The zygomatic and buccal divisions have a total of five to eight branches with significant overlap of function between branches. They supply the lower and sometimes the upper eyelid, nasalis, zygomaticus major and minor, levator labii superioris, levator anguli oris, orbicularis oris, and buccinator muscles.
The marginal mandibular division, consisting of one to three branches, passes caudal to the angle of the mandible and then arches upward to cross the mandibular body approximately at the junction of the body and parasymphyseal region. The marginal mandibular branch or branches innervate the depressor anguli oris, depressor labii inferioris, mentalis, and sometimes the upper platysma and lower orbicularis oris muscles. The cervical division is the most caudal and usually consists of just one branch. It innervates the platysma near the junction of its upper and middle thirds. Both the marginal mandibular and cervical branches run on the deep surface of the platysma.2

**Facial Muscles**

There are 18 muscles of facial expression. Seventeen of them are paired; the orbicularis oris is unpaired (Fig. 27-3). These muscles are arranged in layers.4,5 The most superficial are the depressor anguli oris, zygomaticus minor, and orbicularis oculi muscles. The superficial and middle layers of muscles are innervated by nerves that enter their deep surfaces. The deepest layer consists of the buccinator, mentalis, and depressor anguli oris muscles. These muscles receive their innervation from nerves that enter the superficial surface (in the same plane as all the other nerves).

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**Fig. 27-3  Muscles of facial expression.**
PATIENT ASSESSMENT

An accurate patient history is essential. It is particularly important to obtain a detailed chronology of the facial nerve symptomatology, including the onset of symptoms and their progression. For example, if the cause of paralysis is Bell’s palsy, it is important to ensure that any recovery that is likely to happen has already occurred. The sequence of presentation can point toward a particular cause. For example, a gradual onset of facial paralysis may indicate increasing pressure on the facial nerve, which may occur with an acoustic neuroma or a malignant parotid tumor. These problems are very different and may require different approaches to treatment.

A detailed medical history is also critical, particularly if a major procedure is being contemplated. Finally, an understanding of the specific issues affecting each patient is important. A patient’s functional, aesthetic, and emotional concerns must all be assessed.

Functional Factors

Functional issues can be divided into eye problems and oral problems.

Eye Problems

Facial nerve paralysis causes loss of tone in the orbicularis oculi muscle. This has several repercussions. The blink reflex is lost, which renders the eye susceptible to drying, because blinking is a major mechanism in spreading the tear film produced by the lacrimal system. Loss of this reflex also reduces the amount of protection from foreign bodies. The ability to close the eye and protect the cornea depends on an intact Bell phenomenon (Fig. 27-4).

Fig. 27-4  Right-sided facial paralysis in a 49-year-old man. He was unable to completely close the right eye.
Innervation of the lacrimal gland may be affected, reducing the amount of tears produced and resulting in a dry eye.\(^7,8\) Alternatively, paradoxical hyperlacrimation (the crocodile tear phenomenon) results, which can be treated with botulinum toxin.\(^9,10\) Patients may also have tearing or epiphora, because the lacrimal drainage system is rendered ineffective. The lower lid falls away from the globe, and the tears cannot effectively empty into the lower lid punctum. This can produce the paradoxical situation of dry eye and epiphora occurring at the same time. Another paradoxical situation occurs in patients with normal lacrimal gland function. Because of ectropion, patients have the sensation of dryness. In addition, the tears are not drained properly. This culminates in compensatory overproduction of tears. Therefore, a patient with facial paralysis either has a dry eye, or the symptoms of a dry eye produce more tears and, therefore, more epiphora. These issues can affect visual acuity and render the eye prone to injury.

**Oral Problems**

Loss of tone resulting from facial nerve paralysis also affects the mouth. All of the muscles that control the oral sphincter are involved, and this loss of tone leads to drooping of the oral commissure (see Fig. 27-1). This can cause drooling. Inadequate tone in the cheek can also affect speech, because the loss of oral tone contributes to problems of articulation. Patients often physically support the cheek with their hand to make their speech more intelligible.

**Aesthetic Factors**

Patients with paralyzed facial muscles are always bothered by their aesthetic appearance. The paralysis is usually obvious and often carries with it the implication of mental challenge, because these patients cannot communicate normally. The deformity is often exacerbated or exaggerated during facial movement. In addition, movement of the normal side may appear exaggerated relative to the absence of movement on the affected side. For the purpose of discussing aesthetic issues, the face can be divided into the upper face, the eye, and the lower face.

**The Upper Face**

Because of the loss of function of the frontalis muscle, the brow on the paralyzed side tends to droop. This is very obvious and may impinge on the visual fields (Fig. 27-5). Loss of the corrugator and procerus muscles is less obvious.
The Eye

The palpebral opening is larger on the paralyzed side of the face. There is usually noticeable scleral show, and tearing may draw further attention to the abnormal appearance of the eye. Ectropion may be very noticeable in the presence of conspicuous conjunctival exposure (Fig. 27-6).

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Fig. 27-5  This man had significant brow ptosis (see Fig. 27-4).

Fig. 27-6  Right-sided facial palsy in a 45-year-old woman. The eye on the paralyzed side has an increased palpebral opening with significant scleral show.
The Lower Face

The nasolabial fold is absent in patients with facial nerve paralysis. The oral commissure droops. The cheek is flaccid. The imbalance between the paralyzed side and the normal side of the face is obvious (see Fig. 27-6). In patients with incomplete paralysis, any or all of these features may be present and of variable intensity. Therefore, the aesthetic outcome differs among patients. Nevertheless, even a minor degree of asymmetry may be very distressing for the patient.

Emotional Factors

Facial paralysis can have devastating emotional and psychological effects on patients, particularly those with acquired disease. Many of these patients are suddenly viewed as mentally challenged. Patients report being very aware of how people stare at them. They are usually very self-conscious about drooling and often avoid eating in public. They avoid situations in which they are expected to smile and generally strongly dislike being photographed. Children with facial paralysis generally tend to be introverted. They are conscious of being different and are often made to feel so by their peers. Grandparents with facial paralysis are often self-conscious of how they are perceived by their family, particularly their grandchildren. One of our patients who developed Bell’s palsy was devastated, because her grandson refused to kiss her. These psychological issues are easily overlooked, but being aware of them is extremely important for the team of care providers looking after these patients.

Examination of the Paralyzed Face

It is important to start from the top and document and measure all the changes and differences between the two sides of the face. This is best done with two clear plastic rulers, using defined points so that the same measurement is taken from each side (Fig. 27-7). Points to be measured include the mid brow, the palpebral opening, the amount of scleral show, and the position of the oral commissure relative to the other side. Examination of the eye should include an assessment of visual acuity and a measurement of the amount of closure achieved. It is also important to measure movement in the lower face. This can be done at the oral commissure, the mid upper lip, and the philtrum (see Fig. 27-7). The vector of lower facial movement is also important to appreciate, particularly when considering a functioning muscle transfer to produce a smile. The normal smile can have different vectors. Some people have a very horizontal smile, and others have a more vertical one, showing a significant amount of tooth. All of these are variations of a normal smile. Measurement of facial movement is important and indicates to the surgeon what sort of movement needs to be produced. This has implications for the choice of reconstructive procedure and the amount of muscle likely to be needed to match the movement on the normal side.
Synkinesis

Synkinesis is the simultaneous contraction of two or more muscles that normally do not contract at the same time. It can be a very vexing problem that is difficult to treat. It is commonly seen in situations of facial nerve recovery from injury or, for example, from Bell’s palsy. It is thought to be caused by misdirected sprouting of regenerating axons. Synkinesis may result in simultaneous eye closure with smiling or in any combination of movements. Sometimes the resulting contractions can produce a grotesque grimacing that is very difficult to control (Fig. 27-8).

Fig. 27-7  Measurements are obtained using fixed points around the mouth with two plastic rulers.

Fig. 27-8  A, This patient presented with Bell’s palsy. Her face appears reasonably symmetrical at rest. B, Severe synkinesis on animation causes the face to contort into a grimace.
MANAGEMENT OF FACIAL PARALYSIS

Nonsurgical Management

Management of the eye invariably involves some nonsurgical management. Most patients with facial paralysis require some degree of protection and lubrication or artificial tears for the eye. Drops such as those containing hydroxypropyl cellulose, hydroxypropyl methylcellulose, or polyvinyl alcohol can be used as lubricants to prevent drying of the eye and are very important. These drops generally last much longer than normal tears. The frequency of application varies among patients. Some patients need them hourly, and others may need them just once or twice a day. To prevent drying of the eye during the night, a thicker ointment is often required. These ointments generally contain petrolatum, mineral oil, or lanolin alcohol in their formulation. For the most part, patients dislike these ointments for daytime use, because they invariably cause blurring of vision from the sticky residue buildup that is difficult to clear. Paradoxically, excessive tearing improves for some patients with the use of artificial tears, which reduces the amount of reflex tearing initiated by the sense of eye dryness. Neuromuscular retraining by an experienced therapist can also have a very beneficial effect, particularly for patients with partial paralysis and especially for patients with synkinesis.

Finally, the outward appearance of facial paralysis can be exacerbated by hyperactivity, or perceived hyperactivity, of the muscles on the normal side. For example, very strong depressor labii inferioris and depressor anguli oris muscles on the normal side can accentuate the asymmetry of the smile, particularly in patients with partial paralysis who may have some movement. This can often be dramatically improved by weakening the depressors on the normal side to produce the semblance of more symmetry. Using a local anesthetic, the patient can be given a preview of what he or she might look (Fig. 27-9). Longer-term results can be achieved very effectively with Botox. The same effect can be achieved around the eyes with judicious injection and may be especially useful for brow asymmetry, particularly when there is significant wrinkling on the normal side and the degree of brow ptosis is not advanced. This treatment can also be very useful for patients with synkinesis.
Fig. 27-9  A, This patient with right-sided facial paralysis demonstrates strong contraction of the depressor on the nonparalyzed left side. This causes her mouth to appear extremely asymmetrical. B, The depressor is injected with bupivacaine to temporarily paralyze the muscle and give the patient a preview of what Botox or depressor resection could achieve. C, Symmetry is improved with the depressor paralyzed.
Surgical Management

Numerous surgical options are available for patients with facial paralysis. Similar to nonsurgical management, it is probably best to start from the top of the face and work downward.

The Brow

Brow drooping varies with a unilateral frontalis muscle paralysis, depending on a patient's age and tissue characteristics. In elderly patients, the brow may droop as much as 12 mm. However, a droop of 3 to 4 mm is quite apparent for most people (see Fig. 27-5). A direct brow lift through a superciliary lift is the best method to correct large discrepancies. The incision must be placed just along the main line of hair follicles (Fig. 27-10). It should not be placed above every follicle or it will be in a visible position. Thus a few hairs are excised. An ellipse of skin and frontalis muscle should be excised and the paralyzed frontalis muscle repaired. The skin should be closed with eversion. A problem with this procedure is that the scar may be visible if the incision is placed too high or if the scar is indented. This approach is particularly applicable in male patients, because the brow is usually heavier and the visibility of a scar is less of an issue.

Fig. 27-10  This patient presented with right-sided facial palsy. He is marked for direct brow excision. The normal side is also marked.
A coronal approach is a much larger operation but will leave a scar in the hair in an area where it is usually less visible. Nevertheless, it is difficult to obtain a large brow lift through a coronal incision. Similarly, it is difficult to obtain a large lift through an endoscopic brow lift. When using a coronal incision, it may be helpful to include a sling of fascia lata from the subcutaneous tissues of the brow to the periosteum or bone of the skull. Our approach has been to perform a direct lift through a supra-ciliary incision. A large proportion of patients report some numbness, despite extremely meticulous dissection of the supraorbital nerves. Thus great care needs to be taken with this dissection. However, this numbness is usually of little concern to the patient unless a major branch has been divided.

Another approach to correcting asymmetry is to perform a frontal branch neurectomy on the normal side. For patients with a marked wrinkling of the forehead on the normal side, a normal-side frontal nerve resection with or without a frontalis muscle resection helps to correct forehead asymmetry. Because a simple resection of the frontal branches often results in reinnervation, surgeons should consider resecting the entire lateral margin of the frontalis muscle to obtain a permanent paralysis. Alternatively, a temporary solution may be achieved with Botox injections.

### The Upper Eyelid

It is important to remember that, although the orbicularis oculi is paralyzed, the levator palpebrae superioris may be intact and function normally. As a consequence, patients can open their eyes but cannot close them. In cases such as this, the surgeon can use implantable devices to control eye closure. The simplest procedure is to insert a gold weight in the eyelid.\textsuperscript{11,12} By choosing the appropriate weight, the patient can close his or her upper eyelid by relaxing the levator muscle. An alternative approach is to insert a spring device in the upper eyelid.\textsuperscript{13,14} This functions like an open safety pin. The levator is strong enough to close the spring, and, when the levator is relaxed, the spring opens, thus closing the lid. The latter technique is much more user dependent, and our preference is to use the gold weight.

### Dynamic Eyelid Closure

Temporalis muscle transfer has also been used to produce dynamic closure of paralyzed eyelids, and excellent results have been reported.\textsuperscript{15} Despite this, results seem to be very operator dependent, and gold weight insertion is probably still the simplest and most reliable procedure for achieving this goal.\textsuperscript{16} Frontalis muscle transfer and free platysma transfer have also been reported. However, both procedures are extremely operator dependent and have not been universally adopted, despite the good results reported.\textsuperscript{17}
The Lower Eyelid

The upper lid is only partly responsible for eyelid function. Even if the upper lid functions well, the eye will still not close if significant ectropion of the lower lid is present. Lateral and/or medial tarsorrhaphy has been the traditional treatment for this issue. Various other lid-shortening procedures have also been advocated. However, in our experience, the use of a tendon sling for the lower eyelid, in combination with a gold weight for the upper lid, produces the most consistent correction (Fig. 27-11). The tendon sling is inserted through a small incision just below the lateral brow. Through this incision a small hole is drilled in the superior orbital rim, and a slip of palmaris longus tendon is passed through it. Using a Keith needle, the tendon is passed to the lower lid where, through a small stab incision, the tendon is passed just under the lash line to the medial canthus. An incision is made at the medial canthus through which the medial canthal tendon is exposed. The palmaris tendon sling is passed around the medial canthus and sutured to itself (Fig. 27-12). The tension is adjusted at the superior orbital rim, and the tendon is again sutured to itself using 5-0 nonabsorbable sutures.

Fig. 27-11 A tendon sling to the lower eyelid. The tendon is passed through a drill hole in the lateral aspect of the superior orbital rim, threaded down to the lower lid and just beneath the lash line to the medial canthus, around which it is looped and sutured to itself.
The Lower Face

Several features of the mid and lower face need to be addressed when treating patients with facial paralysis. The cheek is flaccid and the mouth is ptotic and incontinent. In addition, these patients have nasal obstruction. This is purely mechanical and is related to the absence of tone in the cheek and the relative pull of the intact facial muscles on the nonparalyzed side, which tend to pull the paralyzed side toward the nonparalyzed side. This distorts the face and, as a secondary effect, distorts the nose. Patients report that pulling laterally on the cheek facilitates breathing.

The optimal operation for lower face paralysis depends on many factors. These include the cause of the paralysis and the patient’s prognosis, age, and general medical condition. Essentially, the choice is between static support and dynamic reconstruction. Static operations involve the insertion of some sort of internal sling to restore symmetry to the face at rest; dynamic restoration involves the transfer of a functioning muscle unit to replace the paralyzed muscles.

Fig. 27-12  A tendon sling to the lower face. The plantaris tendon is woven through itself. The muscle is sutured to both the orbicularis oris and the zygomatic fascia, and is woven back and forth to produce the most natural smile vector.
Static Reconstruction

Fascia lata slings have been the traditional means of supporting the face. The use of such a sling can produce facial symmetry at rest (Box 27-1). The fascia is attached to the oral commissure, with slips incorporated into the upper and lower lips. The other end is attached to the zygomatic fascia, or occasionally wrapped around the zygomatic arch at the appropriate tension to lift the corner of the mouth to create symmetry. In our experience, this technique works very well in the short term, but over time the fascia tends to attenuate. Our current preference is to perform a similar operation using plantaris tendon, which tends to give more lasting results in our experience. Synthetic slings can also be used, consisting of material such as Gore-Tex; however, occasionally patients develop redness, possibly because of an inflammatory reaction to the Gore-Tex.

Box 27-1  Principles of Static Reconstruction

- Static operations work well for the eyelids.
- The best combination is a weight in the upper eyelid and a sling in the lower eyelid.
- For lower face static operations, the placement of the sling is critical.
- Multivectoral placement achieves good improvement with symmetry at rest.
- Overcorrection is necessary to obtain optimal results.

The plantaris is present in approximately 85% of patients and can easily be harvested through a single, short transverse incision just behind the medial malleolus. The tendon is identified just anterior to the lateral aspect of the Achilles tendon and, at this level, may initially seem to be fused with it. A long tendon stripper is used to harvest the tendon so that a second incision is not required. The incision used to insert this fascial sling is the standard face-lift incision extended for a short distance onto the neck as is done for a parotidectomy. The plantaris tendon is woven through orbicularis oris muscle and the zygomatic fascia and then woven through itself in a Pulvertaft weave. Usually the tendon is woven back and forth so that several vectors of pull can be applied to give a more natural appearance. Placement of the tendon is critical, particularly in the region of the mouth. Our preference is to avoid incisions elsewhere in the face, such as in the nasolabial fold, because these tend to be noticeable in the long term. Preoperatively, the position of the nasolabial fold is marked on the nonparalyzed side, and this line is projected onto the paralyzed side. The function of the sling is to hold the lower face and mouth in a better position but also to improve the position of the alar base on the paralyzed side. The tendon should create a nasolabial fold that is symmetrical with the normal side. This should be assessed intraoperatively and adjusted until perfect positioning is achieved. A slight overcorrection is best, because there is always some attenuation following the
procedure. A small overcorrection at the time of insertion compensates for this. Usually, in patients with full paralysis, the alar base is displaced caudally, and the unopposed pull of the musculature on the normal side tends to pull the nasal tip toward the paralyzed side. The net effect has a functional and aesthetic component. The functional component is the airway, which is usually diminished, and the aesthetic component is the appearance of asymmetry of the nose. The results of these slings are sustained over time and can provide the patient with good symmetry at rest even though the face still does not move on animation.

*Dynamic Reconstruction*

Every person has a unique smile. The variables are the presence, extent, and position of the nasal labial fold, the shape of the smile as revealed by the shape and exposure of the red lip, the amount of teeth showing, the direction and amount of movement of the commissure and mid upper lip, and the presence or absence of depressor labii function pulling the lower lip downward. It is important to carefully analyze and measure each patient’s smile on the nonparalyzed side to determine the shape of smile required on the paralyzed side and evaluate the strength of the smile. From this evaluation, the most effective muscle transfer can be designed.

Dynamic reconstruction has the advantage of restoring movement, and not just symmetry as with the static operations. Dynamic reconstruction can be achieved with regional muscle transfers using the masseter muscle or the temporalis muscle, or with a combination of these two, including the option for differently oriented vectors of pull (Box 27-2). The alternative is to use microneurovascular functioning muscle transfers. The goals are to support the mouth at rest and provide movement of the mouth and cheek. There are advantages and disadvantages to each approach. The advantage of local muscle transfer is the relative simplicity of the procedure. There are two main disadvantages. The first is that rotation of local muscle, particularly the temporalis muscle, produces some increased bulkiness and widening of the face in the region of the zygomatic arch. With the masseter muscle, the defect produced is a hollowness in the region of the angle of the mandible following rotation of this segment of the muscle toward the oral commissure. The second disadvantage, and in our estimation the more serious one, is that there is very little leeway for how the muscles lie in terms of the direction of pull, because the origin of the muscles is fixed and the only possible adjustment is at the point of inset.

**Box 27-2 Principles of Dynamic Reconstruction**

- It is essential to choose the appropriate motor nerve.
- The vector of smile needs to be determined.
- Meticulous detail is required to place the muscle medially.
- Care is critical in setting the muscle tension.
In our practice, most dynamic reconstructions involve microneurovascular free functioning muscle transfer. This transfer is preferred because of the freedom of muscle placement within the cheek. However, a microneurovascular free muscle transfer also produces some unwanted fullness to the cheek. The degree of fullness depends on the thickness of the muscle transferred and the degree of debulking that can be performed in the cheek to accommodate it. We generally reduce the bulk in two ways; the first is to resect the buccal fat pad and the second is to excise some fat from the undersurface of the cheek flap. Resection of the buccal fat pad has the additional advantage of making dissection of the facial vein much easier by exposing it. Regardless of the method of muscle transfer, whether regional or free, these procedures are best performed by someone with some experience in the treatment of facial paralysis, because an understanding of the nuances of these procedures at every step can make the difference between a mediocre result and an excellent one.

Many muscles have been used to reanimate the face. These include the gracilis, the pectoralis minor, rectus abdominis, latissimus dorsi, extensor carpal radialis brevis, serratus anterior, tensor fascia lata, and abductor hallucis muscles. The average length of muscle needed in these procedures is 10 to 12 cm, and most muscles need to be cut to the desired length for reconstruction. The gracilis is our muscle of choice for this procedure. A piece of muscle can be tailored based on the dominant pedicle. The size of the muscle required varies, depending on whether a patient is a large person with total paralysis or a small person with partial paralysis. The gracilis is an eminently expendable muscle. It also has the advantage of being distant from the face so that two surgeons can work simultaneously, one preparing the face and one preparing the muscle.

The face is approached through the face-lift incision already described (see Fig. 27-7). As with the static slings, we avoid using other incisions on the face because, in our experience, this one produces the most natural result. Attaching the muscle to the region of the oral commissure is probably the most critical part of the procedure. Preoperatively, the smile is analyzed. Its vector of movement and is noted and marked. The nasolabial fold is marked on the normal side, and this position is replicated on the paralyzed side (Fig. 27-13). The position of the nasolabial fold is critical. From the face-lift incision, the zygomaticus major muscle is identified, and this is the level at which the dissection proceeds. The orbicularis muscle is identified, and sutures are placed at strategic points in this muscle. These points are chosen based on the analysis of the pull of the smile on the normal side. Usually three or four sutures are placed. The most common configuration involves placing one suture in the orbicularis at the level of the lower lip, one at the level of the commissure, one at the level of the upper lip, and one at or near the level of the alar base, in a manner very similar to that already described for static slings (see Fig. 27-7). The only exposure is a preauricular incision with a small extension inferiorly. No incision should be placed elsewhere on the face, because, in our experience, they are noticeable and interfere with the ability to produce a natural-appearing nasolabial fold. The facial artery and vein are usually the recipient vessels.
The muscle is innervated with either a cross-facial nerve graft or a local nerve, usually the masseter motor nerve. The advantage of the cross-facial nerve graft is that it produces a natural-appearing, spontaneous smile and, when it works well, it produces the nicest result. The nerve graft is anastomosed to a branch of the contralateral normal facial nerve. The appropriate branch is identified by dissecting the branches of the facial nerve on the nonparalyzed side and stimulating them. We look for two branches with overlapping motor innervation. Only branches that have smile function should be used. There should be no orbicularis oris function present in any of these branches. Once identified, one of the branches can safely be sacrificed as the donor nerve for the sural nerve graft. Using as short a nerve as is practical ensures the most rapid and reliable reinnervation. We generally tunnel the nerve graft into the upper lip of the paralyzed side, where it is tagged with a fine Prolene suture and banked until the second stage of muscle transfer, usually 6 months later. When we subsequently transfer the gracilis muscle, the nerve coaptation is performed in the upper lip. Initially, we used a cross-facial nerve graft before the muscle transfer for all unilateral paralyses. Ideally, a microbipolar nerve stimulator should be used during the cross-facial nerve graft, because it allows the function of each branch of the facial nerve to be clearly identified. Disposable nerve stimulators are less effective, because the stimulus is not as discreetly focused on the nerve as with the microbipolar stimulator. Furthermore, they produce a single, jerk-like muscle movement rather than a steady tetanic contraction that can be easily analyzed visually and by palpation. If the sural nerve is significantly larger than the donor nerve on the normal side of the face, it is split longitudinally into two components using the operating microscope. Splitting may give a better end-to-end match, because the available branches of the facial nerve are often smaller in cross section than a sural nerve. When only a 10 to 12 cm length of nerve graft is required, it is usually possible to split this length of the sural nerve without dividing any nerve fiber crossovers between fascicles.
Single-stage muscle transfers can also be performed. Harii et al.\textsuperscript{24} recommended a single-stage procedure using the latissimus dorsi with a long nerve segment. We have been using the masseter motor nerve for innervation of the muscle transfer in a single-stage procedure (Fig. 27-14). We initially used it mostly for bilateral muscle transfers, but we currently use it more frequently for unilateral transfers instead of a cross-facial nerve graft. In our initial experience, we used this nerve in patients with bilateral facial paralysis when the seventh nerve was not available as a cross-facial nerve graft. Using the masseter motor nerve, we found that the amount of movement obtained in the transferred muscle was usually greater than that obtained with a cross-facial nerve graft; the onset of movement occurred sooner and was more reliable. The cross-facial nerve graft produced great variability in the amount of excursion, from very little to moderate. We rarely see more than 60% to 70% of the movement compared with the normal side. In contrast, using the masseter motor nerve routinely produces as much movement as on the normal side.

One of the main concerns with the use of the masseter motor nerve has been patients’ inability to use it spontaneously to smile. They instead have to clench their teeth to produce movement. However, this is not always the case. It has previously been reported that more than 80% of patients are able to smile without a biting motion, and 60% develop the ability to smile spontaneously. This approach requires a

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig27-14.png}
\caption{Gracilis muscle placement in the cheek. The muscle is sutured to the orbicularis oris at points that are determined visually to produce a nasolabial fold that will be symmetrical with the other side.}
\end{figure}
training process in which patients work in front of a mirror a number of times daily, observing themselves when biting. In this way, they can learn how to make smiles of varying intensity and speed. They learn how to control their smile. Constant practice produces a very acceptable and sometimes spectacular result. Patients are also encouraged to smile with everyone they meet. With time, usually within the first 6 months, patients may develop the ability to separate the muscle movements of smiling and biting, and develop some spontaneity. These adaptations are most likely examples of cerebral plasticity. In our experience, this seems to occur as frequently in older patients as in younger patients.

The decision as to which nerve to use depends on several factors and is reached in consultation with the patient. The advantages of the masseter nerve are several. The procedure is a single-stage operation. The amount of time it takes to reinnervate the muscle is shorter (usually 3 to 4 months) than the time required with the cross-facial nerve graft (approximately 1 year). The major disadvantage is that the process of smiling is tedious and needs to be learned. However these patients are generally extremely well motivated. The major advantage of the cross-facial graft is spontaneity in the smile produced. There is no learning process involved. This technique has several major disadvantages. It is a two-stage procedure. It can potentially damage the intact motor nerve on the other side. It leaves a scar on the normal side of the face and takes about 1 year from the time of the initial graft placement to appreciate a smile. We now tend to reserve cross-facial nerve grafting for younger patients (20 years or younger) and offer our older patients a masseter nerve transfer to innervate the gracilis transfer (Fig. 27-15).

Fig. 27-15  A, This patient’s final appearance at rest is shown following gracilis muscle transfer with innervation by the masseter motor nerve (see Fig. 27-6). B, Her smile shows the improved position of her lower lid after the tendon sling procedure and gold weight placement.
CRITICAL POINTS

Must Know

• Eye symptoms may require urgent treatment using either surgical or non-surgical approaches.
• Functional muscle transfer requires an intact donor motor nerve.

Should Know

• The choice of treatment modality may depend on the cause of the paralysis.
• Slight overcorrection of static slings is important.
• Careful facial measurements are important in treatment planning.

Synopsis

• Treatment of facial paralysis combines static and dynamic reconstructions.
• Aesthetics and function are both important. The minimal goal should be to achieve symmetry at rest, but dynamic reconstruction is the optimal goal.

References

   The handheld ruler technique is used to evaluate the severity of facial paralysis. Two experienced examiners, working independently, measured the rest position of 21 patients with unilateral facial paralysis. Each examiner obtained measurements twice, creating 84 sets of measurements. Accuracy was assessed by simultaneously measuring the movement of the commissure and mid upper lip on 10 people without facial paralysis while they were smiling. Results were obtained using a handheld ruler and a proven technique—the facial reanimation measurement system. The handheld ruler technique is simple, reliable, accurate, and provides useful measurements for the evaluation of facial paralysis for reconstructions.

   Modern microvascular reconstructive surgeons have quite an arsenal when managing patients with facial paralysis and injury to the facial nerve. After a brief description of the anatomy, cause, facial nerve syndromes, and grading schemes, this paper details the authors’ approach to these patients. They discuss the organ-based timing protocol and advancements in surgical technique.

   Facial paralysis is a relatively common disorder from which most people recover without complications. However, some are left with significant functional impairment and disfigurement. The treatment has challenged physicians for centuries. The spectrum of surgical procedures to reanimate the face includes cross-facial nerve grafting. This article chronicles the history of cross-facial nerve grafting, including its past and present use, and describes various factors associated with its use. A brief discussion of causes and morbidity of facial paralysis and some fundamental surgical options are presented.

Mimic muscles are arranged in four layers, regarding their origins, and these four layers should be considered when muscle tissue is added or lifted. All mimic muscles are built up by parallel fibers. Mean values of length, width, and thickness of the three lip elevators have been determined. These data might be important when dealing with this muscle system, which appears rather different from all other muscles in humans. The individual muscles receive their innervating facial nerve branches from their deeper surface when they belong to the superficial (first, second, or third) layer and from outside when they lie in the deepest (fourth) layer. Nerve branches communicate at least four times before innervating their respective muscles.


The principles of nasal reconstruction established by Burget and Menick\(^1,2\) reflect an artistic meshing of subunit anatomy, structural support, flap design, skin texture, and color to achieve an aesthetic result. This approach has worked well when applied to partial nasal defects and has been accepted as the benchmark of nasal reconstruction. For total and subtotal nasal defects, however, standard approaches often fall short of achieving aesthetic and functional results because of the large dimensions of the deformity and the relative paucity of available local facial tissues.\(^3-7\) Additionally, using intranasal tissues to restore the nasal lining is often associated with compromising the nasal airway.
The use of nonfacial tissues for reconstructing total and subtotal nasal defects preserves facial aesthetics and function. Until recently, remote tissues used for nasal reconstruction were applied as pedicled flaps and required multiple surgical stages to complete.\(^8\)\(^{-11}\) Sporadic accounts of microsurgical transfer of remote tissues for nasal reconstruction have been reported.\(^12\)\(^{-15}\) Most of these early attempts were performed to restore the external nose. A typical case involved the use of a reliable flap, such as a scapular or groin flap, to restore the external surface of the nose. The “blob” of tissue was debulked in several subsequent procedures to achieve the desired nasal form (Fig. 28-1). This approach was a carryover from the days of the tubed pedicled flaps that were commonly used for total nasal reconstruction. Remote free flaps used for external nasal coverage rarely matched the texture and color of the surrounding facial skin and were soon recognized to be inferior in quality compared with forehead skin, when this was available. For this reason, the paramedian forehead flap, a derivative of the ancient Indian forehead flap, continues to be the preferred flap for external nasal coverage.

Fig. 28-1 In this early attempt at microsurgical reconstruction of the nasal lining, a radial forearm flap was transferred to the nasal site. Over several operations, the blob of tissue was sculpted and repositioned to duplicate the missing lining. Historically, these procedures often resulted in partial flap necrosis and contraction. Experience has shown that remote flap tissues cannot withstand excessive kinking or twisting to the extent tolerated by well-vascularized facial soft tissues.
As experience with free flap design and manipulation evolved, so did the application of free tissue transfers for nasal reconstruction.\textsuperscript{16,17} One important finding was the observation that remote flap tissues could not withstand kinking or twisting to the extent tolerated by well-vascularized facial soft tissues. This led to the design of multi-island flaps that are positioned and coapted three-dimensionally to duplicate the missing nasal anatomy. The restoration of the nasal lining and its composite elements of vestibule, floor, columella, and adjacent cheek and/or lip has come to represent the keystone for complex, total, and subtotal nasal reconstructions. Free flaps also provide a means to restore a functional nasal airway, now accepted as an integral part of total or subtotal nasal reconstructions. As noted previously, the use of free flaps for restoration of the external nasal cover has been limited to cases in which the forehead is unavailable.

Although this chapter emphasizes the microsurgical aspects of nasal reconstruction, it must not be forgotten that microsurgery in many of these cases merely sets the stage to facilitate conventional reconstructive techniques. Combining the expertise of two surgeons, one a specialist in microsurgical techniques and the other in classical plastic surgical reconstruction, has worked extremely well in our hands. In many cases, multiple stages are needed following completion of the microsurgery to achieve the final result. This combination of microsurgical and nonmicrosurgical techniques achieves results that neither technique on its own can produce.

**PREOPERATIVE MANAGEMENT**

**Patient Selection**

In most large centers throughout the world, microsurgery has become a routine adjunct in the reconstruction of complex deformities. Most centers have a dedicated facility and nursing support to conduct these procedures safely and efficiently. Today, success in elective microsurgical free tissue transfer can be expected to exceed 95\% in all age groups.\textsuperscript{18,19} Patient selection plays a significant role in achieving this success rate. Clearly, patient morbidity and complication rates are increased in patients with underlying systemic disease and dysfunction. Hypertension, heart and lung disease, kidney disease, and diabetes mellitus are associated with increased complication rates and flap failure rates, and these risks should be carefully weighed against the potential benefits of microsurgical transfer.\textsuperscript{18} Interestingly, patient age does not appear to directly relate to success or failure in free tissue transfers.\textsuperscript{18,19}

For patients in whom systemic disease rules out extensive surgery for significant facial defects, a prosthesis may be the most appropriate approach to management.\textsuperscript{20} Patient compliance and the ability to undergo numerous operative procedures to achieve an aesthetic/functional result must also be considered. Microsurgical nasal reconstruction involves many surgical interventions that require time away from friends and loved ones, with subsequent recuperation, pain, and donor site morbidity.
ity. Patients who have unrealistic expectations about the process, or who are unreliable and noncompliant with the reconstructive plan, should be offered alternative solutions to reconstructive surgery.

In most cases, children who present for total or subtotal nasal reconstruction have congenital nasal defects or have lost their noses because of traumatic injury. They are otherwise healthy, and the patient selection process is relatively straightforward. With very few exceptions, children adapt quite well to the reconstructive process. Although the blood vessels in children are relatively small, they are quite pristine and flap failures are uncommon. We have performed elective microsurgical nasal reconstruction in children as young as 3 years without a problem. These reconstructions grow as the child grows but not to the extent seen in normal nasal growth and development. In some patients, a second reconstruction may be necessary as the child grows into adolescence.

**Evaluation of the Nasal Defect**

The nasal defect in total and subtotal nasal reconstructions often involves adjacent lip and cheek soft tissues, in addition to the nasal lining elements and the external nose proper. The defect analysis and approach to management must therefore encompass the full extent of the deformity in a logical, stepwise fashion. Restoration of the nasal base and lining elements should be an initial goal, followed by replacement of structural support and an external cover. In most cases, the microsurgical component of the reconstruction is reserved for the nasal lining elements and any adjacent defects of the upper lip and cheeks.15-17,21,22 If skin grafts were used to close the original wounds, with subsequent radiation therapy, the risk is increased for wound breakdown at the flap/skin graft junctures, and removal of the irradiated skin graft should be considered. This will expand the total extent of the nasal defect.

Scars from previous surgeries may be noted on careful examination. Telltale signs of previous radiation therapy include pigmentary changes and telangiectasias. Most important, the examination should assess the vascular access points of the facial and superficial temporal vessels. In most cases, we prefer the facial vessels for vascular inflow because of their constant anatomy, size, and proximity to the nasal site. Our access point is usually at the lower border of the mandible. A Doppler assessment of each potential access site is essential, although the definitive choice is made only at the time of surgical exploration and evaluation.

The initial physical examination provides information for the reconstruction (Fig. 28-2), but the precise sizes, shapes, and orientations of the various missing elements are determined during surgery, when the defect is restored to its original dimensions and templates of the elements to be reconstructed are fabricated. In some cases in which adjacent cheek or lip defects are excessively large, a separate free flap may be required.
For defects involving only the nasal lining, such as those caused by cocaine use, or deformities arising from systemic disorders, such as Wegener granulomatosis, pemphigus, or leprosy, flap planning is approached differently than for total or subtotal defects. In these cases, computer imaging is used to visualize the bony landmarks of the piriform aperture; the nasal pyramid, floor, and spine; and the integrity of the midline bony structures, paranasal sinuses, and maxillary walls. Using high-resolution, facial CT scans, normal or optimal external nasal dimensions can be predicted and used to reconstruct/replicate the shape and volume of the nasal airways with...
positive acrylic airway models (Fig. 28-3). These are used to design a forearm flap that, when assembled, duplicates the desired dimensions of the missing nasal lining elements (Fig. 28-4). Unlike the multiisland flaps used in total and subtotal nasal defects, the microsurgical flaps used to reconstruct nasal lining–only defects are usually delayed, single-island flaps. Because these flaps must fit entirely within an intact external nasal cover, they must be ultrathin and configured anatomically before placement, which explains the need for surgical delay.

**Fig. 28-3**  A, A high-resolution CT scan of the face with three-dimensional reconfiguration of a diseased nasal airway. B and C, The cobalt coloration represents a computerized prediction of the normal airway dimensions. These models are used to fabricate the precise configuration and dimensions of the nasal lining flap.

**Fig. 28-4**  Computer-generated positive acrylic nasal airway models derived from high-resolution CT scans. These models are used to design the lining flap.
Computer imaging is invaluable for preoperative planning of nasal lining–only reconstructions. Precise skeletal and soft tissue models of the pathologic anatomy provide inestimable insight into the numerous reconstructive challenges. By avoiding a blind approach, computer imaging allows reconstructive surgeons to design a flap that precisely fulfills the objectives of reconstruction while avoiding flap deficiency or excess.

Operative Consent

The reconstruction of a major nasal defect requires numerous surgical interventions over an extended period of time, incurring donor site deformity at multiple body sites, temporary functional disability, pain, permanent scarring, and evolving facial deformity. Informed consent is essential to a successful outcome. Patients must understand the complex nature of such an undertaking and the time commitment required to complete the reconstruction. We have found it helpful to share with patients actual sequence photographs of the reconstructive scenario of other patients (with their consent). These images present the operative sequences, donor sites, facial appearances, and final results. Patients who are deemed noncompliant, immature, uncertain, or ambivalent to the proposed treatment plan should be offered less invasive alternatives.
**OPERATIVE TECHNIQUE**

**MULTIISLAND RADIAL FOREARM FLAP FOR MAJOR NASAL DEFECTS**

**First Stage: Reconstruction of Nasal Base Elements**

**Flap Design**

The first goal in the reconstructive sequence is restoration of the nasal lining and adjacent cheek and upper lip elements, that is, the nasal base. This is accomplished using microsurgical transfer of remote tissues to the face. Our flap preference is the radial forearm flap because of its consistent anatomy, large vessel size, long vascular pedicle, thinness, and ease of elevation. In defects that involve large areas of adjacent cheek or lip, a second free flap from another site (such as the scapular or superficial inferior epigastric flap) may be required. To determine the precise size and configuration of each of the missing nasal base elements, the nasal site is dissected first with excision of the remnant scar and any skin grafts to re-create the original defect (Fig. 28-5).

![Fig. 28-5](image-url) This patient's nasal defect was surgically prepared (see Fig. 28-2). The old scars were removed, revealing the original wound dimensions. Foil templates of the missing lining defects (vestibule, right floor, and columella) are fabricated intraoperatively.
Templates of the missing vestibular and adjacent lip and cheek defects are made of foil, aligned, and attached together with skin tapes (Fig. 28-6). They are articulated to ensure proper orientation and spacing to avoid kinking or twisting the vascular pedicle, and to accommodate the three-dimensional positioning of these elements at the nasal site. After the island orientation has been set, the joined island templates are transferred to the forearm, where they are aligned to the radial vascular pedicle (Fig. 28-7). For the vestibular lining element, we have found it helpful to orient the vascular pedicle at the cephalic edge of the island. This allows access to the nasal tip and vestibule for placement of the supporting cartilage grafts and subsequent sculpting. In this instance, the radial or cephalic edge of the flap is positioned to overlap the vascular pedicle by no more than 5 mm.

Fig. 28-6  Templates of the missing vestibular and adjacent lip and cheek defects are made of foil and then articulated with skin tape to ensure proper orientation and spacing at the nasal site.

Fig. 28-7  The lining flap design on the volar forearm. The templates are aligned to the radial vascular pedicle.
**Forearm Flap Dissection/Elevation**

Before the radial forearm flap dissection/elevation, an Allen test is performed to ensure adequate hand perfusion through the ulnar vascular pedicle. In more than 120 of these flaps, we have had no cases in which hand perfusion was compromised by ligation of the radial vascular pedicle. Nevertheless, there are likely rare circumstances in which hand perfusion may be supplied primarily through the radial artery that require reconstruction of the radial artery with a vein graft, or the use of an alternative flap for nasal reconstruction.

After the flap template is aligned to the donor forearm, dissection begins under tourniquet control (Fig. 28-8). Each island is dissected starting at its ulnar margin above the level of the forearm fascia to the tendon of the flexor carpi radialis. Here, the dissection transitions to the subfascial plane and continues to the radial vascular pedicle. On the radial side of the flap, the dissection proceeds dorsally through the subcutaneous tissue, taking care to identify and protect the sensory branches of the radial nerve. Occasionally, one or two small branches of the radial sensory nerve are found entering the flap. These must be divided and their proximal stumps ligated and transplanted dorsally into the subcutaneous fat, or dissected proximally and buried in an adjacent forearm muscle. Each of the island flaps is isolated to the radial vascular pedicle using operative magnification, with identification and preservation of the multiple, small, filamentous vascular branches emanating from the pedicle into the flap. After the flap islands are isolated to the radial vascular pedicle and all remaining nonflap branches are ligated and divided, the vascular pedicle is dissected proximally to its predetermined length, with ligation and division of its multiple muscular branches. Proximally, the venae comitantes join to form a common outflow vein that communicates with the cephalic vein. This vein is usually encountered just distal to where the radial and ulnar arteries branch from the brachial artery. Including this common outflow vein greatly simplifies the vascular repairs to the facial vessels.

![Fig. 28-8](image) Dissection of the multiisland radial forearm flap. A, The flap is elevated in the suprafascial plane and isolated to the radial vascular pedicle. B, The flap islands are separated using operative magnification.
The flap is allowed to perfuse at the forearm site for 30 minutes before transfer, and perfusion of all elements is assessed. During this time, the operating microscope is used to debulk subcutaneous fat from selected areas of the flap, especially the vestibular element (Fig. 28-9). This is accomplished by incising the fat globules and gently suctioning the fat—a process called *lipoplasty*. This allows selective debulking without compromising the fine vascular connections between the pedicle and the flap (Fig. 28-10). We have found this to be a very effective technique for the initial flap debulking in the acute setting.

![Fig. 28-9](image)

Fig. 28-9  **A** and **B**, The flap islands are debulked by incising isolated fat globules and gently suctioning the content away under operative magnification (*lipoplasty*). This technique minimizes direct injury to the fine vascular connections between the pedicle and the overlying skin island. **C**, After defatting, the flap is ready for transfer.

![Fig. 28-10](image)

Fig. 28-10  Fine vascular connections (*arrows*) between the radial vascular pedicle and the overlying skin island must be preserved to ensure flap viability.
Dissection of the Facial Artery and Vein Recipient Vessels

The recipient facial artery and vein are dissected before flap elevation to ensure their suitability for vascular anastomosis and to allow adjustments in flap design, such as additional vascular pedicle length or the addition of vein grafts for distal access. The vascular pedicle of the flap should be at least 8 to 10 cm long to allow it to span the subcutaneous distance from the nasal defect site to the facial artery/vein anastomotic site at the inferior border of the mandible. This distance is measured intraoperatively so that adequate pedicle length is provided. The facial artery pulse is identified using manual palpation of the vessel, just medial to the mandibular notch, and confirmed with Doppler imaging. Access to the recipient facial artery and vein is gained through a 2 cm incision just below and parallel to the inferior border of the mandible, directly above the facial artery site (Fig. 28-11). The platysmal fibers are dissected apart longitudinally to expose the facial artery and vein. The marginal branch of the facial nerve is identified immediately beneath the muscle fibers and just at or below the mandibular border. Blunt dissection is used to expose the facial vessels. To avoid injury to the marginal mandibular branch of the facial nerve, it is important to avoid cutting any structure traversing and parallel to the mandibular border. Identifying the facial vein can occasionally be problematic. Infrequently, a large, submandibular lymph node obstructs access to the facial vein. Careful removal of this structure will reveal a suitable vein for anastomosis.

Fig. 28-11 Dissection of the recipient facial artery and vein. A 2 cm incision is made directly below the border of the mandible just anterior to the mandibular notch and directly over the Doppler signal of the facial artery. The artery and vein are exposed just beneath the fibers of the platysma. The marginal branch of the facial nerve courses parallel to the border of the mandible and lies superficial to the facial vessels.
Following identification and isolation of the facial recipient vessels, a sub-SMAS tunnel spanning the nasal site and the facial vessel site is created to receive the vascular pedicle. This tunnel is created by gently passing a large Kelly clamp from the nasal site to the facial vessel site and sequentially dilating this passage with progressive cervical dilators (Fig. 28-12).

Fig. 28-12  Dissection of the cheek tunnel to receive the flap pedicle. A sub-SMAS tunnel is created from the nasal site to the dissected facial vessels by blunt dissection and then widened using progressive cervical dilators.
Flap Transfer

After the flap and pedicle are dissected, the radial pedicle is divided distally with separate ligation of the artery and each vena comitans using fine monofilament polypropylene sutures. The flap is transferred to the nasal site, where it is temporarily secured with 4-0 silk sutures. To facilitate passage of the flap pedicle through the substance of the cheek without twisting or avulsing its ligated vascular side branches, a 36 Fr chest tube is first guided through the cheek with a large cervical dilator (Fig. 28-13). Gentle hand-controlled suction is applied from below, with a lactated Ringer's solution drip from above. The vascular pedicle is gently directed into the tube and allowed to flow unobstructed from the nasal site to the facial vessel site. Once it has traversed the full length of the cheek, the chest tube is removed from below.

The vascular repairs of the facial artery and vein are performed end to end. Although no systemic anticoagulation is used, we routinely use high-concentration heparin irrigation (50,000 units heparin/100 ml lactated Ringer's solution) while performing the vascular anastomoses. Aspirin (81 mg) is also administered intraoperatively per rectum and then orally for 21 days postoperatively.

After vascular inflow is reestablished, the flap islands are articulated anatomically and inset using fine sutures (Fig. 28-14). All intranasal repairs and repairs to the remnants of the intranasal mucosal lining are performed using fine 4-0 or 5-0 chromic suture. The remaining flap elements of the upper lip and cheek abutments are repaired with fine, monofilament, absorbable intradermal sutures, and fine, interrupted polypropylene sutures are used for the epidermis.
Fig. 28-14 Insetting of the multiisland radial forearm flap. A-E, After microvascular repairs are made to the facial artery and vein, the flap islands are articulated anatomically and inset. F, The vestibular element is stented with cadaver cartilage to reduce shrinkage between the lining flap inset and the application of the external cover flap. G-I, Following inset, the exposed undersurface of the vestibular and columellar elements are closed with full-thickness skin grafts.
The undersurface of the vestibular element, which now lies exposed, is closed with a full-thickness skin graft from the lower abdomen or inguinal region. These flaps are braced with small, matchstick-size grafts of cadaver cartilage to minimize any contraction between the microsurgical transfer and the application of the permanent external cover flap (Fig. 28-15). The grafts are placed in the midline, columella, and along the caudal edges of the vestibule and secured with 6-0 PDS suture. After the cartilage allografts are secured, the wound is closed with the full-thickness skin graft (see Fig. 28-14). In this setting, the take of the full-thickness skin graft is not compromised, because it has an excellent capacity for bridging. A fine suction drain, fashioned from a 22-gauge butterfly intravenous needle, may be placed beneath the skin graft and brought out through a separate stab incision adjacent to the nose. This is connected to a Vacutainer tube for suction drainage to facilitate graft adherence and promote serous drainage. A simple Xeroform/mupirocin ointment dressing is applied to the skin-grafted vestibular element. Internal nasal packing and stents are not used.

Fig. 28-15  Stabilization of the vestibular element with cadaver cartilage allograft. Following flap inset, the vestibular element is braced with matchstick-sized grafts of cadaver cartilage (arrows) secured with 6-0 monofilament absorbable suture.

The forearm donor site is closed in a layered fashion over a small subfascial channel drain with a full-thickness skin graft from the lower abdomen or inguinal region for optimal pliability and cosmetic appearance. The graft is tailored to perfectly match the forearm defect and inset under mild tension with 4-0 silk tie-over sutures (Fig. 28-16). A two-layer Reston Foam stent dressing is configured to overlap the grafted defect by 1 cm all around and secured in place with the tie-over sutures. A bulky
dressing is applied to the forearm and hand for immobilization—we have found plaster splinting to be unnecessary. The graft stent is removed 7 days postoperatively, and the skin graft is inspected for vascularity. The sutures are removed and the graft site is dressed with mupirocin ointment and Kendall Telfa dressing and wrapped in an elastic compression sleeve for 6 weeks. Graded, active use of the hand begins 10 days postoperatively.

Fig. 28-16  Closure of the forearm donor site. A, The wound is closed with a full-thickness skin graft from the lower abdomen or inguinal crease. B, The graft is secured with foam stent dressing secured with tie-over sutures. C, The forearm and hand are immobilized in a bulky, soft compression dressing for 10 days.
Second Stage

The second operative stage is performed 8 to 12 weeks after the microsurgical transfer and involves preparing the nasal site for the supporting bone/cartilage framework and designing and applying the external cover flap/paramedian forehead flap.

At surgery, the previously placed full-thickness skin graft covering the undersurface of the vestibular element of the nasal lining flap is removed, and further debulking of the lining flap is performed to the level of the subdermis to construct a patent, functional airway (Fig. 28-17). At this stage, more aggressive debulking can be done with little chance of compromising the flap’s blood supply. The vascular pedicle is protected during flap debulking (Fig. 28-18). The vascular pedicle will have decreased in size by nearly 50% from the original surgery, which accounts for its lower profile following debulking. The pedicle is more adherent to the undersurface of the flap, and debulking may extend to where the pedicle joins the flap to ensure optimal thinness and robust perfusion. The lower profile of the pedicle also negates any possible adverse influence on nasal shape or size. If the vascular pedicle is cut or ligated during the secondary debulking process, partial flap loss may occur. The safe approach, therefore, is to make every attempt to preserve the vascular pedicle.

Fig. 28-17  Second stage: nasal framework and paramedian forehead flap. The patient returns 6 to 8 weeks after the radial forearm lining flap is transferred. The skin graft and cadaver allograft cartilages are removed, and the vestibular lining and columella elements are further debulked to the subdermis. A nasal framework is constructed and covered with a paramedian forehead flap.
Chapter 28  Microsurgical Reconstruction of the Nasal Platform and Lining

The Nasal Framework

During the secondary debulking procedure, the cadaver allograft cartilages are removed, and a more formal structural support is provided using autologous costal cartilage (and occasionally calvarial bone). Autologous costal cartilages in older patients are generally quite friable, prone to calcification, and exhibit very little flexibility. The poor quality of the cartilage grafts in these patients has prompted the use of preserved cadaver cartilage allografts for nasal reconstruction. We have found that cadaver cartilage allografts that are irradiated and stored in saline have better flexibility and are less likely to resorb than lyophilized cartilage allografts. It is important to note, however, that the tendency for fresh autologous and preserved cadaver cartilage allografts to warp is quite similar, and both require careful rendering using a balanced cross-sectional technique. Alloplast materials are rarely used for structural support in nasal reconstruction because of their propensity for infection and extrusion.

Fig. 28-18  Preparation of nasal site. The vestibular element of the lining flap (V) is further debulked, with preservation of the vascular pedicle (P).
The structural support of the reconstructions consists of a columellar strut, a dorsal graft, alar batten grafts, nasal side walls, and a tip graft (Fig. 28-19). The grafts are carefully carved from fresh autologous costal cartilage stock harvested from the fifth to eighth ribs. To avoid warping (especially in the dorsal and columellar grafts), the grafts are carved from a balanced cross-sectional area. The carved grafts are bathed in sterile saline solution for 30 minutes to determine their proclivity to warp. Early warping can be checked by placing horizontal mattress sutures on the convex side of the graft in the technique used by Gruber et al.\textsuperscript{24,25} The cartilage grafts are articulated anatomically at the nasal site and inset with 4-0 and 5-0 Prolene sutures. Mattress sutures may also be used to effect a desired arc or curve in the graft, particularly when used for support of the alar rim.

![Fig. 28-19](image)

The nasal framework. An autologous costal cartilage framework is used. Key framework elements include a columellar strut, dorsal graft, alar batten grafts, nasal sidewall grafts, and a tip graft. The grafts are assembled using 5-0 and 6-0 polypropylene sutures.

The cartilage grafts are assembled in sequence, with the dorsum and columella elements placed first to establish the appropriate relationships of nasal height, length, and projection. The columellar strut is carved to angle approximately 15 to 20 degrees cephalad to duplicate the normal angle of the columella. In placing the columellar support strut, the columellar element of the flap is opened anteriorly and debulked aggressively to receive the columellar appendage of the paramedian forehead flap. The inferior end of the columellar strut is anchored to the nasal spine through a labial gingival sulcus incision. This is facilitated by drilling a fine hole in the nasal spine, or its maxillary remnant, and securing the cartilage with a fine polypropylene suture. The columellar strut and dorsal graft are joined using a tenon-mortise articulation secured with fine polypropylene sutures. Temporary stabilization of the cartilage grafts with fine needles facilitates precise placement of the supporting sutures. Next, the nasal sidewalls are carved using foil templates. To stabilize the nasal pyramid, these grafts are secured to the dorsal graft superiorly and to the
maxillary/piriform aperture soft tissues inferiorly with fine mattress sutures of polypropylene. The alar support grafts are placed along the caudal edge of the nasal lining flap. The base end of the rim graft is seated against the nasomaxillary buttress of the maxilla through a bluntly dissected soft tissue tunnel. The nasal tip end of the alar rim graft is anchored to the dorsal graft at the junction with the columellar strut. Here the grafts are slightly above the projection point of the dorsal graft. Again, temporarily anchoring the grafts in position with fine, 25-gauge, straight needles facilitates suture placement. The tip graft is placed last, between the crura of the alar rim grafts. In some reconstructions, conchal cartilage may be harvested to provide support for the alar rims. However, these grafts tend to be somewhat flimsy and are reserved for partial tip reconstructions or for secondary revisions, where they are placed to improve nasal tip definition with little requirement for structural support.

The vestibular lining flaps are secured to the overlying cartilage framework grafts with fine 6-0 PDS sutures, without taking large bites of tissue and avoiding excessive tension on the sutures. Following placement of these support sutures, capillary refill of the intranasal vestibular lining is assessed. If any blanching is noted, the offending suture or sutures are removed.

Bone grafts are used infrequently in total or subtotal nasal reconstruction because of their rigidity. However, they may be used to restore the bony nasal pyramid when this structure is missing (Fig. 28-20). Calvarial bone grafts are generally preferred because of their durability and resistance to resorption. Occasionally, vascularized rib and scapular bone grafts have been used to provide dorsal support in complex total and subtotal nasal reconstructions.1-3,10,11,16,17 Cantilevered bone grafts for restoration of the nasal dorsum are intrinsically unstable and are rarely used in total or subtotal nasal reconstruction.

Fig. 28-20  Split calvarial bone grafts are used to reconstruct the bony nasal pyramid.
At this stage of the reconstruction, the proportions of the nose should be complementary to those of the face, the airways should be widely patent without obstruction, and the lining elements should be well perfused.

**THE FOREHEAD FLAP FOR RESTORING EXTERNAL NASAL COVER**

The central forehead flap is the flap of choice for restoring the external nasal cover because of its excellent color, texture, and reliability. It is based primarily on the vertical extensions of the supratrochlear and dorsal nasal vascular systems that pierce the flap at its base and traverse the superficial surface of the frontalis muscle, supplying small branches to the overlying skin26-28 (Fig. 28-21). The medial forehead branch of the dorsal nasal artery anastomoses with the supratrochlear artery, which tracks axially in the paramedian plane. Recently, detailed studies of the blood supply to the forehead have revealed a rich periorbital vascular plexus that contributes to the paramedian forehead flap.28 This vascular plexus receives direct communications from the angular, supratrochlear, and supraorbital arteries and extends from the medial canthus to 7 mm over the superior orbital rim. Maximal three-vessel blood flow into the flap can be achieved by preserving periosteum over the superior orbital rim and beginning the flap no less than 7 mm above the orbital rim.

![Fig. 28-21](image)

*Fig. 28-21* The central forehead flap is based primarily on the vertical extensions of the supratrochlear and dorsal nasal vascular systems that pierce the flap at its base and traverse the superficial surface of the frontalis muscle supplying small branches to the overlying skin.
It is important to verify the presence of the supratrochlear system before surgery. Vessels are identified using Doppler ultrasonography, and their vertical course through the forehead is marked. It is preferable to choose the side with the most pronounced Doppler signal to optimize flap perfusion. In some patients, a Doppler signal may not be heard, and this may necessitate using an alternative flap or surgical delay of the forehead flap.

The size and shape of the paramedian forehead flap are usually based on a clay nasal model adapted to a plaster moulage of the patient’s original facial defect. The template is made from foil and carefully checked to ensure adequate size of all of the elements. The flap template is then positioned over the prepared nasal framework to confirm that it fits properly. After the size and configuration of the template are finalized, it is positioned on the forehead with its central axis aligned with the previously determined course of the supratrochlear vessels (Fig. 28-22). The template of the flap is drawn on the forehead and carefully measured and remeasured to ensure that it will transfer to the nasal site easily without tension. The base of the forehead flap should not be less than 1.5 cm to ensure inclusion of the major branches of the supratrochlear system. In most instances, the columellar portion of the forehead flap will include a portion of the frontal hairline, necessitating later surgical depilation. In patients with a low frontal hairline and forehead, preoperative laser hair removal may be advantageous, particularly in patients with naturally dark hair.

Fig. 28-22  Forehead flap design. The paramedian forehead flap is oriented to the axis of the supratrochlear artery encompassing the medial periorbital plexus. The width of the base of the pedicle is approximately 1.5 cm.
The paramedian forehead flap is rapidly elevated above the plane of the frontal periosteum to the root of its supratrochlear pedicle. The caudal 1.5 cm edge of the flap and distal two thirds of the columella are sharply debulked to remove fat and frontalis muscle to facilitate insetting. Occasionally, if flap perfusion appears excellent, the scalp hair follicles at the distal 10 mm edge of the flap are also removed. The flap is inset after hemostasis using bipolar cautery.

To inset the forehead flap, simple 5-0 Prolene sutures are used for coaptation to the columella and caudal edge of the vestibular lining flap (Fig. 28-23). The lateral nasal edges are inset in a layered fashion using 5-0 PDS for the dermis and 5-0 polypropylene sutures for the skin. The semblance of an alar bulge is obtained by advancing the forehead flap distally under slight tension and placing a dermal holding suture at the point of origin of the alar groove, allowing a slight excess of the base portion of the ala for a tension-free inset. To avoid cutting the flap tissues and suture tear-through, noncutting, tapered needles are used (RB-1, RB-2, C-1, or C-2 Ethicon). The exposed undersurface of the proximal forehead flap pedicle is closed with a split-thickness skin graft from the lateral buttock or thigh, secured with 5-0 chromic sutures. To facilitate occlusion of the nasal lining flap and external cover flap to the nasal framework, a 21-gauge butterfly drain is placed beneath the external cover flap and brought out through a small stab incision in the cheek. Vacutainer tube suctioning is maintained for at least 5 days.

Fig. 28-23 Forehead flap inset. Following placement of the cartilage framework, the forehead flap is elevated above the plane of the frontal periosteum down to within 2 cm of the orbital rim, where the dissection is subperiosteal to protect the fine vascular communications from the orbital plexus and nasalis vessels.
The forehead defect is closed vertically as high as possible. This is facilitated by performing wide, subfrontalis undermining to the lateral brow followed by layered closure of muscle, dermis, and epidermis, beginning at the glabella and progressing upward. The upper aspect of the forehead defect, the widest part of the paramedian forehead flap, cannot be closed primarily. The edges of this portion of the defect are closed where possible with simple interrupted 4-0 polypropylene sutures. The remaining aspect of the forehead defect is left open to heal by secondary intention. The forehead defect with its periosteum base must be protected from drying, because this results in death of the periosteum with exposure of the frontal bone. To prevent drying, the defect is packed with petrolatum gauze secured with simple tie-over sutures. The petrolatum gauze dressing is changed 7 days postoperatively, and the patient is instructed in subsequent wound care that includes transitioning from sequential petrolatum gauze dressings to simple Telfa pad dressings when a healthy granulation base is evident. Complete epithelization of the defect takes 6 to 8 weeks. To promote epithelization, we have used topical Preparation H ointment as a daily dressing.\textsuperscript{29,30} Following epithelialization, the forehead should not be exposed to sunlight for at least 3 months to avoid hyperpigmentation. A skin moisturizer is used twice daily to maintain pliability of the healed forehead donor site (Fig. 28-24).

Fig. 28-24  A, The forehead donor site is closed in layers starting from the glabella and working upward. The upper aspect of the donor site cannot be closed primarily. The remaining wound is made smaller by the placement of mattress sutures at its angulated terminal points and then packed with petrolatum-impregnated gauze to prevent drying of the exposed frontal periosteum. Care is taken to keep the periosteal layer from desiccation, which results in exposure of the frontal bone and wound healing complications. B and C, Epithelialization of the wound is complete by 6 to 8 weeks.
Although the forehead flap has a relatively consistent anatomy, it is not always as robust and well perfused as one would like. Patients who smoke and those with collagen vascular disease, chronic hypertension, or established peripheral vascular disease are at risk for compromised flap circulation. For these patients, it is best to optimize their underlying medical conditions before surgery. Smokers should discontinue smoking. The use of a calcium channel blocker is advocated for some patients to increase dermal capillary perfusion. Patients who have had previous forehead surgery (including a previous forehead flap) or trauma may present particularly daunting challenges, especially when a scar traverses a portion of the forehead flap (Fig. 28-25). In these cases, surgical delay of the flap may be necessary. Surgeons should always exercise a high degree of caution with a patient who presents with any of these premorbid conditions. In these cases, the design and elevation or surgical delay of the flap is indicated before preparing the nasal recipient site. If flap perfusion is marginal, the flap should be returned to its original bed, and the transfer should be attempted at a later date.

Fig. 28-25  The design of the paramedian forehead flap in the presence of previous forehead scars, which can pose a significant dilemma for forehead flap design. In this case, the right alar element is nearly completely traversed by a previous scar (arrows). Delay of the flap is indicated in these situations, because acute elevation and transfer may result in partial flap necrosis.

**Flap Contouring Stages**

Subsequent contouring procedures are performed as previously described for nasal reconstruction. These are staged 4 to 6 weeks apart in the following sequence:

First contouring: Debulking and contouring of the nasal sidewalls and dorsum
Second contouring: Debulking of the nasal ala and tip and placement of additional tip and alar grafts
Third contouring (if necessary): Sculpting of the alar grooves and fine tuning of the construct
Fourth contouring: Division and inset of the forehead flap pedicle

Debulking/contouring of the flap involves placing temporary mattress plication sutures between the wound bed and the overlying flap to obliterate dead space and force the external cover flap to adhere to the underlying bed (Fig. 28-26). There are several technical points on this portion of the procedure that must be followed. The first is to ensure absolute hemostasis in the wound bed after debulking the forehead flap. We prefer to elevate the forehead flap at a uniform thickness of 2 to 3 mm of subcutaneous tissue and then to resect the underlying fatty tissue and scar to induce contour. Judicious use of fine autologous cartilage grafts are also placed at this time to effect further definition. These grafts are firmly secured with fine 6-0 monofilament sutures. After contouring, the external cover is replaced and inset and then secured to the underlying bed with multiple quilting sutures as described previously. Care must be exercised to avoid tying the quilting sutures too tightly, because this can cause flap ischemia and necrosis. It is a good idea to place the sutures, allow some intraoperative flap swelling to occur, and then loosen the sutures with a fine needle holder or clamp if blanching is noted. The quilting sutures should be examined at 24 and 48 hours with further adjustments in tension being made as needed. Forty-eight hours postoperatively, the quilting sutures are snipped on one side and left in place. They are subsequently removed on the fifth or sixth postoperative day.
Fig. 28-26, cont’d  D-F, Basting sutures are placed at key points to ensure flap adherence to the underlying nasal framework. These sutures must be placed with utmost care to avoid compromising dermal blood flow in the flap. G, The sutures are removed at 48 to 72 hours to avoid suture marks. The second contouring intervention focuses on contouring the nasal tip, ala, and columella elements through alar rim and columella incisions. After debulking selected portions of the external cover flap, additional cartilage grafts may be placed in the ala and tip areas. H and I, After the desired nasal shape/contour has been achieved, the pedicle is divided and inset. Notice that inset of the proximal stump of the pedicle is limited to the region of the glabella.
Results

The time invested in reconstruction can span 6 to 18 months, depending on the severity of the defect, patient availability, complications, and other factors (Fig. 28-27). Although there are no particular issues intrinsic to rendering the paramedian forehead flap following a microsurgical nasal lining flap transfer, the surgeon should always be aware of the vulnerability of the nasal lining flaps to excessive manipulation and suture-induced ischemia.\(^{16,17}\) The vascular pedicle should be preserved whenever possible, particularly in the early stages of the reconstruction. Late division of the free flap vascular pedicle does not appear to have any untoward effects, most likely because of the establishment of alternative vascular connections.

Fig. 28-27  The completed nasal reconstruction 5 years postoperatively.
ALTERNATIVE MICROSURGICAL FLAPS FOR RESTORATION OF NASAL LINING

Alternative microsurgical flaps for restoring the nasal lining can be used when the radial forearm flap is unavailable. The choice of flap in these cases depends on donor site availability and the requirements for reconstruction. The anterolateral thigh flap is quite useful, because it has a long vascular pedicle with large-diameter vessels, it can be elevated in a multiisland configuration, and it can be aggressively thinned without a surgical delay (Fig. 28-28). Other options include the scapular, superficial inferior epigastric, deltoid, and lateral arm flaps. When used for nasal lining, these flaps have limited application as multiisland flaps and usually require secondary debulking procedures. Also, the pedicle length of these flaps may be insufficient to reach the facial vessels through a subcutaneous tunnel. They may require a direct nasolabial incision for angular artery access or the use of interposition vein grafts to reach the facial vessels at the margin of the mandible.

MICROSURGICAL RECONSTRUCTION OF THE EXTERNAL NOSE

The paramedian forehead flap is preferred for restoration of the external nasal cover because of its excellent color match, texture, reliability, and minimal donor site deformity of the central forehead. In certain situations, however, such as when
there is previous trauma or surgical injury, the forehead is not available as a donor site. In these cases, alternative donor sites must be used.

The use of flaps above the clavicle provides an optimal color match for reconstruction. Unfortunately, flaps in this area are not anatomically well defined and, as free flaps, tend to be thick with short vascular pedicles. Pribaz and Fine,\textsuperscript{31,32} Khouri et al,\textsuperscript{33} and Costa et al\textsuperscript{34} have described the use of delayed, engineered, pedicled flaps from the neck and/or supraclavicular regions for reconstructing the external soft tissue envelope of the nose and cheek. These flaps require several surgical interventions to establish a reliable blood supply. They also tend to be rather rigid, bulky, and prone to venous congestion following transfer.

In burn patients or in patients who undergo multiple episodes of facial trauma and/or skin grafts, the face is a mosaic of colors quite dissimilar to their normal skin, making the color match of the external nasal flap less problematic. Because of its reliability, thinness, and ease of harvest, we prefer the radial forearm flap in these situations (Fig. 28-29). Other flaps include the deltoid, scapular, and anterolateral thigh flaps. The relatively large dimensions and complex configuration of the caudal end of the external nasal cover make it somewhat risky for transfer without surgical delay. In several of our patients, partial loss of an ala or columellar element has occurred following acute flap elevation and transfer. This problem can be avoided by a simple surgical delay in which the complex, convoluted borders of the flap are surgically rendered and undermined to ensure uniform vascularity. In designing an external cover flap, it is also important to consider the placement of the vascular pedicle. Generally, the flap is thickest where the pedicle enters. Therefore, in critical contour areas such as the tip and ala, orientation of the pedicle entry at these sites is not recommended.

Fig. 28-29  Free flaps for external cover are used if forehead tissues are unavailable. In this patient, a free deltoid perforator flap was used.
Epidermal overgrafting is an alternate technique for improving flap color match. This technique involves deepithelializing the external nasal cover flap and resurfacing it with a thin, split-thickness skin graft from the scalp. Significant improvement in flap coloration can be achieved with this technique.\(^{35}\)

**MICROSURGICAL RECONSTRUCTION OF NASAL LINING–ONLY DEFECTS**

Patients who present with nasal lining–only defects represent a unique challenge because of the difficulty with exposure and access to the problem site and in configuring a flap that can be placed in the nose without compromising the airway. Systemic disorders such as Wegener granulomatosis, pemphigus, and leprosy can result in inflammation, ischemia, necrosis, and contraction of the nasal lining and cartilaginous support elements, while leaving the external nose relatively unscathed.\(^{16}\) Cocaine abuse can also lead to a similar clinical picture of lining and support destruction and likely represents the most common cause of this unique clinical disorder in the United States.\(^{21}\) Restoration of the nasal lining for these defects has traditionally involved skin grafts and/or local nasolabial flaps with variable success.\(^{36}\) Acutely transferred remote flaps are problematic because of their size and bulk, which pose technical problems with transfer and airway obstruction. To address this problem, we have developed a forearm-based flap that duplicates the three-dimensional anatomy of the nasal lining (floor, vestibule, and columellar elements) while preserving the functional nasal airway.\(^{22}\) It is called the *bat flap* because of its resemblance to the silhouette of a bat, and it is based on the radial forearm (see Fig. 28-4). Through a series of 2 to 3 surgical delays, the vestibular and columellar elements are thinned extensively to eliminate all of the fatty subcutaneous tissue, isolating the radial pedicle inflow to the posterior cranial aspect of the floor element.

The flap is designed using measurements taken from a high-resolution CT scan and physical examination. The width and length of the floor element and the height of the airway at the coronal plane of the bony aperture are noted. More precise measurements can be derived from a three-dimensional, computer-generated acrylic model, as described previously (see Fig. 28-4). A flap template based on these measurements is fabricated from paper and assembled into a three-dimensional construct to ensure appropriate size and configuration. The design can be altered to accommodate variations in the reconstructive needs of the vestibular lining, floor, and columellar defects. It is always helpful to allow a little extra length (2 to 3 mm) in the caudal edge of the vestibular lining element to compensate for shrinkage and adjustments in the flap inset.
After the flap template is fabricated and assembled, and the size and configuration are checked, it is oriented to the radial vessels on the distal volar forearm. The posterior/cranial aspect of the floor element is aligned to the radial vessels to position the pedicle at the most remote portion of the construct to minimize subsequent surgical injury (Fig. 28-30). In the first procedure, the columellar element is incised, undermined, and advanced onto the floor element so that its anterior/caudal margin subsequently articulates with the cranial or posterior edge (membranous septum) of the native columella. The remaining circumference of the bat flap is incised, and the tips of the wings of the vestibular elements of the flap are undermined just below the level of the dermis to the midpoint of each wing. The wounds are closed with 6-0 PDS dermal sutures and Steri-Strips. The vestibular element dissections are drained with 21-gauge butterfly drains, which are removed 2 days later. A noncompressive, soft, Kerlix fluff gauze dressing is applied and secured with web netting.

Fig. 28-30 Reconstruction of nasal lining–only defects. A, Design of a radial forearm bat flap. B and C, The radial vascular inflow to the flap is isolated to the cephalic end of the floor element through two or three delayed surgeries. D, Isolated to its radial vascular pedicle, the delayed flap is assembled to reproduce the three-dimensional configuration of the nasal lining.

Continued
The second procedure is performed 2 weeks later. In this stage, the columellar element is undermined, keeping its flap and distal connections intact, and tubed. The columellar wound bed is closed with a full-thickness graft. The circumference of the bat flap is incised again, and the proximal portions of the vestibular elements are undermined at the level of the deep dermis, keeping the previously elevated, distal edges attached. The undermined sections of flap are again drained using butterfly drains. Microsurgical transfer of the flap is performed 2 weeks later.

Flap perfusion is evaluated at the time of microsurgical transfer. The vestibular wings are completely elevated to their origin from the floor element, and the distal attachment of the columellar element is released. The elevated elements should exhibit robust bleeding from the flap edges and pink, brisk capillary refill. If any congestion or mottling is noted, the flap is replaced to its original bed and transfer is delayed for an additional 10 to 14 days. If perfusion is deemed adequate, the floor element is elevated and isolated to its radial vascular pedicle attachments. The floor element can be debulked as necessary along its perimeter, using magnification to avoid injury to the fine vascular branches from the radial pedicle. Following proximal dissection of the vascular pedicle, the flap is allowed to perfuse in situ while the facial site is prepared.

Access to the diseased nasal lining is performed through an intraoral approach using a labiogingival sulcus incision (see Fig. 28-30). The diseased nasal lining is carefully excised using low-power electrocautery dissection to achieve absolute hemostasis while avoiding injury to the external nasal skin. A 3 to 4 mm rim of nostril mucosa and membranous septum/posterior columella is preserved to facilitate inset of the caudal edge of the flap, and a cuff of mucosa at the bony aperture is preserved for in-
setting the cranial edge of the flap. Removal of the contracted, scarred nasal lining allows rather dramatic expansion of the external nasal envelop to nearly its original dimensions. Following excision of the diseased nasal lining, the facial artery and vein are dissected as previously described and prepared for anastomoses.

The flap is transferred to the nasal site and positioned in the nasal defect. It is temporarily secured with 4-0 silk sutures. The flap is inset after allowing revascularization. The cranial aspect of the flap is inset first with 4-0 chromic sutures. This is followed by closure of the dorsal articulation of the vestibular elements. Care is taken to evert the flap edges using vertical mattress sutures. Autologous costal cartilage grafts are fabricated and inserted to provide structural support for the nasal dorsum, columella, nasal sidewalls, and alar rims. These are secured with 5-0 and 6-0 polypropylene sutures. A short No. 24 Kirschner wire is useful for temporary stabilization of the proximal aspect of the dorsal support graft using the technique described by Daniel (personal communication, 2005). The graft is anchored to the remnant nasal periosteum with a through-and-through mattress suture of 4-0 polypropylene through small stab incisions in the nasal skin. Following placement of the cartilage support grafts, the anterior vestibule lining is inset. The wound is drained with one or two 22-gauge butterfly drains connected to Vacutainer suction. The drain serves to occlude the dead space and draw the vestibular lining flap against the overlying cartilage support grafts, opening the airway.

The flap is allowed to heal and settle into its new position for 3 months before any secondary revisions are performed. The thickness of the flap dramatically decreases during this time as the intradermal swelling of the vestibular elements abates. Secondary revisions are directed toward refining the external appearance of the nose and may require additional cartilage grafting of the nasal tip and/or dorsum.

**Complications: Management and Avoidance**

The complexity of total and subtotal nasal reconstruction engenders a host of complications, some relatively small, others significant. Common complications can be grouped according to location as follows:

- Nasal site: Infection, partial or total flap loss, and airway obstruction
- Forearm donor site: Skin graft loss, neuroma, and stiffness

**Nasal Site Complications**

**Infection**

Infection in nasal reconstruction can be devastating and should be avoided at all costs. In our experience, infection has been observed mostly in patients who received previous radiation therapy and/or have poor perfusion or ischemia of the lining or external cover flaps. Clearly, the combination of previous radiation therapy and flap ischemia/necrosis presents a great risk for infection complications. Infection can result in flap contraction, resorption of cartilage, and significant distortion of the nasal contour.
Our approach to early infection is aggressive (within 3 to 7 days postoperatively). The purulent material must be drained and the nasal wound irrigated profusely. If the external cover and lining flaps are adequately perfused, an indwelling, flow-through irrigation catheter containing culture-specific antibiotics has proved immensely valuable in eradicating infections. If either the lining or external cover flaps are not viable, they must be debrided and replaced with healthy tissue (usually another free flap). The absence of soft tissue adherence to the cartilage represents a significant problem. In early infections, if the cartilage has not softened and has a pristine, white coloration, it is preferable to attempt salvage using flow-through irrigation. Late-presenting infections usually imply that the cartilage has been contaminated for some time. In these situations, it is probably wise to remove all cartilage that is not adherent to the soft tissues, debride all nonviable tissue, control the wound infection, and allow the wound to heal. Reconstruction of the resulting deformity is performed 8 to 12 weeks later, after the swelling and inflammation have subsided.

Infection is best avoided by ensuring robust vascularity of the soft tissue flaps and minimizing the amount of suture foreign body used to coapt the cartilage grafts. Additionally, careful closure of the intranasal coaptation points, with eversion of epidermal edges, cannot be overstressed. Also, intranasal positive air pressure must be avoided for at least 3 weeks after the lining flap transfer. Blowing the nose or forced exhalation of air through the nose may result in the injection of mucus through the coapted suture lines, contaminating the laminated milieu of the construct. As part of the postoperative care, patients are instructed in the topical application of mupirocin ointment using a cotton-tipped swab intranasally to minimize bacterial proliferation at the suture sites.

**Total and Partial Flap Loss**

Fortunately, total flap loss is a rare event in total nasal reconstruction. In situations of total flap loss, early intervention and repair using another flap or graft is the guiding rule. More commonly, partial flap loss occurs. The causes of partial flap loss fall into two main categories: flap design and iatrogenic causes. As noted previously, for external cover flaps, it is sometimes advantageous to delay the flap to ensure complete perfusion of the flap territory, particularly if the pedicle is situated at the extreme edge of the flap. Flap designs that include scars from previous trauma or surgery should be avoided. For the radial forearm flap, it is important to avoid using a forearm that has undergone previous arterial line placement in the radial artery, because flap perfusion may be compromised.

There are many ways a surgeon can inflict injury to a flap. Division or ligation of the vascular pedicle during secondary debulking of the lining flap can lead to partial necrosis. Excessive debulking in the first stage may disrupt the subdermal capillary plexus, leading to ischemia or necrosis. Tying through-and-through sutures too
tightly can impair flow and result in segmental necrosis. Suspension of the nasal lining to the overlying cartilage framework can result in excessive tension in the flap, compromising dermal perfusion. Avoiding these complications requires careful planning, fastidious technique, and astute observation. Surgeons should check the dermal capillary flow in the flap after every potentially adverse intervention such as suture placement or pedicle violation and, if perfusion appears compromised, make every attempt to reverse the insult.

If partial flap necrosis occurs, salvage options include a second flap (usually a free flap) or a skin graft. A second free flap is generally preferred over a local facial flap to avoid visible facial scarring. Exceptions to this are elderly patients, high-surgical-risk patients, and patients with very small lining defects. Intervention for salvage after a partial flap loss should be undertaken before the onset of wound contraction or before the fifth postoperative day. For external cover flaps, replacing the entire flap may be preferable to a partial reconstruction using a second flap. Revascularization is generally performed using the pedicle of the first free flap in end-to-side fashion.

Nasal Airway Obstruction

Early in our experience, nasal airway obstruction was a common sequela of total and subtotal nasal reconstruction (Fig. 28-31). The reasons for this were failure to render the lining flaps thin enough and failure to provide sufficient structural support to prevent collapse of the flaps into the airway. Additionally, we learned that the flaps we used needed to be made larger to allow sufficient airway capacity and to compensate for the shrinkage that inevitably occurs when resting skin tension is released.

Fig. 28-31  Previous attempts at microsurgical reconstruction of total and subtotal nasal defects were complicated by a relatively high incidence of nasal airway obstruction. Improvements in flap design have resulted in significant improvements in nasal airflow. Functional restoration of the nasal airway has emerged as a key element in aesthetic reconstruction of total and subtotal nasal defects.
For multiisland radial forearm flaps, the vestibular elements should be designed so that their caudal projection exceeds the anticipated position of the external cover alar margin by 5 to 10 mm. At the nasal site, the vestibular elements should be temporarily braced with cadaver allograft cartilage to reduce contraction between flap transfer and forehead flap placement. These grafts are matchstick sized and placed in the columella, dorsum, and alar margins. They are secured with fine 6-0 PDS sutures using a tapered needle. At the second intervention, the overlying skin graft and cartilage allografts are removed, and the vestibular lining flaps are debulked to the level of the dermis. Proper design and placement of the permanent autologous cartilage framework are critical for establishing a patent airway. The nasal sidewall should abut the edge of the piriform aperture, allowing a sturdy brace for suspending the underlying vestibular lining. In addition to a choice few suspension sutures, the use of 21-gauge butterfly suction drains has proved useful in occluding the neo-lining of the overlying framework.

**Radial Forearm Donor Site Complications**

Since we started harvesting the radial forearm flap above the level of the deep forearm fascia, we have observed very few donor site problems such as tendon exposure, necrosis, skin graft loss, and contracted scar. The use of a full-thickness skin graft to close the donor site has resulted in a very durable donor site scar that is pliable with little tendency to contract.

The most common donor site complications in the radial forearm are small areas of skin graft loss, neuroma formation, and wrist stiffness. Skin graft loss is usually isolated to a dime- or nickel-sized area overlying an isolated hematoma. These are debrided and the wound is allowed to epithelialize using local dressing changes. This complication can be avoided by ensuring stringent hemostasis before graft application, the use of fine tapered needles to secure the skin graft, placement of a uniform graft stent, and immobilization of the hand, wrist, and forearm in a large, bulky compression bandage. Additionally, the placement of a small-channel drain beneath the graft site facilitates the evacuation of residual blood and serum.

Small, painful neuromas occasionally form at the sites where branches of the radial dorsal sensory nerve have been cut as they enter the flap. These can be managed with reexploration and, under magnification, interfascicular dissection proximally for 3 to 4 cm, burying the nerve stump (after neuroma amputation) into an adjacent muscle or into a dorsal vein without tension. Painful neuroma formation can be avoided in the same manner. Once a cut dorsal sensory nerve branch is recognized, the proximal nerve is mobilized and the stump is buried into adjacent muscle or vein.
Wrist stiffness is associated with any volar forearm injury. It is especially prevalent in patients with a low pain threshold, painful neuromas, or delayed healing of the skin graft scar. To avoid stiffness, the forearm should be allowed to heal for a minimum of 10 to 14 days by keeping the wrist immobilized in the bulky dressing for 7 days and then in an elastic wrap for 7 days. The graft site is then kept wrapped in an elastic bandage for 6 weeks. It can be removed for daily bathing and the application of moisturizing creams. Light activity is allowed beginning 2 weeks postoperatively with progressive flexion and extension of the wrist. During this time, patients can use the hand to open and close doors and carry light parcels. Gradual loading is accomplished by having patients carry a weighted purse or lunch pail. Wrist extension exercises are introduced if restriction is noted at 4 weeks. These include wall walking with the hands and push ups. Scar thickening is managed with massages.

**UNSOLVED PROBLEMS AND FUTURE CONSIDERATIONS**

**Restoration of Flap Sensibility**

Surgery to restore sensibility in the external nasal cover flap is not generally performed. These flaps regain variable levels of sensibility over time, presumably by sensory nerve branch ingrowth from the adjacent facial soft tissues. Aesthetic restoration of the nose is the first priority; however, enhanced sensibility might be considered a valuable adjunct to the reconstructive effort. Although we have not pursued this option, the potential for restoration of sensibility is available for most of the flaps used to reconstruct the external nose. In the radial forearm flap, branches of the medial antebrachial cutaneous nerve, the dorsal sensory branch of the radial nerve, and the sensory branch of the musculocutaneous nerve are all potential conduits for sensibility to critical areas of the flap. In most cases, the recipient nerve is a branch of the inferior orbital nerve.

**Tissue Engineering**

Tissue engineering for nose reconstruction is quite appealing. It could potentially provide a means to construct a composite nose of the desired dimensions at a site remote to the face, with very little donor site morbidity or risk to the patient.

The process of tissue engineering involves growing the composite nasal elements on a biocompatible scaffold and isolating the engineered construct to a blood supply that can be used for transfer and revascularization at the nasal site.38 Experimentally, it has been shown that a fibrovascular stroma can be engineered to an alloplast scaffold and that this vascularized construct is sufficient to support a skin or mucosal
graft. The weak link in this scenario, however, is the scaffold. Alloplast scaffolds have a high risk for exposure/extrusion and, as polymers, degrade over time. A stable, flexible, biocompatible scaffold that exhibits excellent surface characteristics of adhesion, retains its shape, and, if exposed, promotes soft tissue healing without extrusion has been elusive. Cartilage or bone constructs that have been engineered on absorbable scaffolds in three-dimensional molds would be an ideal scaffold for a nasal construct, yet these have failed to retain their shape over time. Shape, in biologic tissues at least, is optimally predetermined by genetics. The scaffold, therefore, assumes a role of critical importance for this technology to advance to the clinical stage. With the ideal scaffold, a tissue-engineered construct would revolutionize the process by which nasal reconstruction is performed and greatly benefit patients.

Nasal Transplantation

Over the past 15 years, a great deal of progress has been made in composite tissue allotransplantation (CTA). To date, more than 30 hand transplants have been performed worldwide, and 5 partial facial transplants have been reported. In light of the relative morbidity of multistage reconstruction for total or subtotal nasal defects, it is easy to conjecture the possibility of a nasal transplant for the restoration of such defects. The ability to restore a nose or missing nasal part with a real human nose while minimizing or completely negating issues of donor site morbidity clearly represents the pinnacle of composite reconstruction. Unfortunately, problems of transplant tolerance and the need for chronic immunosuppression are current major drawbacks to the full-scale application of this technology. Even though intermittent acute and chronic rejection have been observed in nearly all of the composite tissue transplants to date, no organ has been lost as a result of the rejection process, provided that immunosuppressive therapy is maintained. In addition, it appears that function in the composite tissue allotransplant is not significantly compromised as a result of acute and/or chronic rejection.

Despite the current limitations, it is important to realize the extraordinary potential benefits of transplant technology in nasal and facial reconstruction. With improvements in our understanding of immune tolerance and the development of better immunomodulation strategies, the morbidity associated with chronic immunosuppression will likely diminish in the future, paving the way for practical application of this technology. Significant progress has already been demonstrated in the Louisville experience with five hand transplants, the last two of which have been managed without the use of systemic steroid administration. The ideal nasal transplant patient might be one who is already immunosuppressed, such as a heart or renal transplant patient. Given the current state of immunomodulation with its attendant risks and shortcomings, however, it currently difficult to justify a nasal transplant in lieu of a nasal reconstruction using conventional techniques (including microsurgical techniques).
**Critical Points**

**Must Know**
- The forehead flap is preserved for final nasal coverage.
- Adequate skeletal support is vital for the success of the reconstruction.

**Should Know**
- Alloplast scaffolds have a high exposure/extrusion risk and degrade over time.
- Failure to provide adequate structural support and a thin lining flap will lead to airway obstruction.

**Synopsis**
- Reconstruction of the nose is a multistage procedure of great complexity. It demands careful attention to detail and meticulous planning. However, excellent results can be achieved.

**References**

   - The authors present a method of nasal reconstruction emphasizing the use of thin but highly vascular local lining and cover flaps to allow successful primary placement of delicate cartilage grafts. The cartilage fabrication provides projection in space, airway patency, and, when visible through conforming skin cover, the delicate contour of the normal nose. Because tissue is replaced in kind and quantity, the need for multiple revisions to sculpt and debulk is decreased. Techniques and four case reports describe its applications to tip, heminose, subtotal, and total nasal defects.

   - Historically, surgeons have avoided the forehead for nose reconstruction, because they believed that larger areas of tissue were required. As plastic surgery has evolved to achieve successful replacement of major nasal defects, the paramedian forehead flap has been refined as the best alternative, resulting in a normal-appearing nose with correct shape and color.

   - The pivoting septal flap ensures a robust blood supply through its narrow pedicle centered on the septal branch of the superior labial artery. It provides nasal support from the radix to the most distal nasal tip and from the tip to the columella base, in addition to a large supply of lining tissues for the nasal vault and vestibules. In cases of total nasal amputation, a pivoting septal flap permits the fabrication of dorsal nasal support weeks before lining and cover flaps are assembled.


This report defines the uniqueness of the surgical challenges inherent in reconstruction of the nasal lining and presents an overview of the authors' approach to management. Reconstruction of the nasal lining alone is a very challenging endeavor that demands careful surgical planning and precise technical execution. The use of microsurgical transfer for these defects allows considerable latitude for duplication of the missing, complex, three-dimensional anatomy and avoids sullying the adjacent facial soft tissues. Because of the poor condition of the local tissues, most of these cases could not have been brought to a successful conclusion without the use of free tissue transfer, and this is particularly relevant in patients with cocaine-injured noses.

Facial reconstruction with only free microvascular flaps rarely produces a good aesthetic result. Earlier techniques using a single large nasal lining flap or bilateral nasal lining vaults incurred a high incidence of airway obstruction. Microvascular free flaps have proved highly reliable and effective for restoring missing elements of the nasal lining and adjacent facial soft tissue defects in total and subtotal nasal reconstruction. Combined with a forehead flap, this aesthetic approach allows reconstruction of the center of the face, layer by layer, and facial unit by facial unit. Specific attention is paid to the artistic creation of normal nasal dimensions, proportion, and form using carved and assembled cartilage grafts and secondary subcutaneous contouring. In addition, this technique produces a patent airway.
Before reconstructing the buccal mucosa, a thorough evaluation of the missing soft tissue elements is needed to determine the optimal reconstruction method. Many options are available for buccal mucosal reconstruction. Local or regional flaps are indicated for smaller defects, and free tissue transfer has become the benchmark index for larger defects. Meticulous attention to the recipient vessel and vessels in its vicinity and the selection of an appropriate donor site form the foundation for a satisfactory reconstruction. Early complications (infection with or without salivary fistula) and late complications (trismus, sunken cheek, oronasal fistula, and tethering of the tongue) are additional considerations that help determine the most appropriate form of reconstruction.

Oral mucosal defects have many causes. These include defects following the excision of benign (including submucosal fibrosis) and malignant lesions and traumatic and corrosive injury. Buccal mucosa forms the inner lining of the cheek. Its mobility plays an important functional role in the preparation of a food bolus for swallowing and mouth opening to achieve satisfactory speech and emotional expression. It has an aesthetic role in that it contributes to facial symmetry. An ideal reconstruction should restore the form of the lost mucosal tissue and the lost function.
Various reconstructive options are available to reconstruct the buccal mucosa. The spectrum encompasses skin grafts, local flaps, regional flaps, and free flaps. The selection of reconstructive procedures must be based on many important factors (Table 29-1). These include the size and character of the missing tissue, the condition of the wound bed, the availability of the recipient vessels and donor tissue, and the prognosis of the patient.

<table>
<thead>
<tr>
<th>Table 29-1  Surgical Options for Buccal Defects</th>
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<tr>
<td>Small Mucosal Defect (less than 2 cm diameter)</td>
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<tr>
<td>Locoregional Flaps</td>
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<tr>
<td>BFP flap</td>
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<tr>
<td>NL flap</td>
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<tr>
<td>Submental flap</td>
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<tr>
<td>FAMM flap</td>
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<tr>
<td>Free Flaps</td>
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<tr>
<td>Radial forearm flap</td>
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<td>ALT-FC flap</td>
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<td>ALT MC flap</td>
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<td>MSAP</td>
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<tr>
<td>RAMC flap</td>
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<tr>
<td>Peroneal flap</td>
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<tr>
<td>Lateral arm flap</td>
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</tbody>
</table>

++++, Excellent; +++, good; +++, fair; +, acceptable.

ALT, Anterolateral thigh; BFP, buccal fat pad; FAMM, facial artery musculomucosal; FC, fasciocutaneous; MC, musculocutaneous; MSAP, medial sural artery perforator; NL, nasolabial; RAMC, rectus abdominis musculocutaneous.

Today it is possible for even the most complex microsurgical reconstruction to be successful 96% to 98% of the time. However, satisfactory reconstruction of the buccal mucosa requires replacing lost tissue in the defect and restoring its function. This necessitates meticulous preoperative planning, a good choice for reconstruction, and attention to the postoperative course and rehabilitation.

**Classification of the Defect**

Buccal mucosa is one of the functional units of the oral cavity. Tissues affected by traumatic or surgery-related defects range from the buccal mucosa only to variable involvement of the adjacent tissue, including bone. A comprehensive review of the defect and evaluation of the functional loss help to make correct decisions regarding reconstructive options and achieve a satisfactory final result.
Buccal Mucosa Only

The reconstruction of buccal mucosal defects that do not involve other structures is relatively simple. This requires restoration with soft and pliable tissue of adequate thickness and size. Special attention is required for involvement of the buccal sulcus because of its important functional role. The natural structure of the sulcus helps to direct salivary flow to achieve normal clearance and serves as a reservoir for food during chewing and swallowing. The re-creation of the sulcus allows these functions to resume, and prevents retraction of the lower lip to achieve a more natural-looking contour after surgery. The neosulcus can be created with flaps inset from below the alveolar edge and shaped as a valley to achieve functional reconstruction.

The required soft tissue thickness can be determined by pinching the cheek between the thumb and index finger and comparing the thickness to the normal, contralateral side. Adequate volume replacement achieves symmetry of the face after surgery. However, too much bulk in the flap should be avoided, because it alters symmetry and prevents oral closure.

Before reconstruction, the length and width of the defect can be measured using a sterile towel as a template while the patient’s mouth is fully opened with the assistance of an instrument. The flap can then be designed and harvested according to the specifications of the template. Attention to the required flap width and length helps prevent limited mouth opening postoperatively and excess tissue leading to tissue bulk.

The radial forearm free flap is the first choice for buccal mucosal reconstruction because of its pliable, thin, and reliable character in these defects (Fig. 29-1). Different options are available if two independent flaps are needed, especially when releasing bilateral trismus or contralateral trismus simultaneously with tumor excision.5,6

Fig. 29-1  This 50-year-old patient is shown 6 months after treatment for cancer involving the left buccal region and a small part of the upper lip. A and B, The defect was reconstructed with a radial forearm free flap. C, The donor site was resurfaced with a skin graft.
Buccal Mucosa and the Trigone

Defects in the trigone region commonly involve the tonsillar pillar, which drains lymphatic fluid and separates the regions of the oropharynx and nasopharynx. It is frequently possible to close the wound primarily, because the mucosa tends to be lax in this region. However, restoring the integrity of the tonsillar pillar provides better functional results. The anterior tonsillar pillar extends to the posterior mobile tongue. Adequate flap reconstruction also prevents tethering of tongue movement. A well-shaped flap separates the oropharynx and nasopharynx, prevents food regurgitation into the nasal cavity during swallowing, and provides better resonance during speech.

The selection of donor flaps depends on the size and volume required. In a small defect without tonsillar pillar involvement, a radial forearm flap is optimal. However, the anterolateral thigh (ALT) flap provides adequate soft tissue for large-volume defect replacement.2,6-10

Through-and-Through Defect

A through-and-through defect is a full-thickness cheek defect including the buccal mucosa, the underlying muscle, and external skin. To restore the missing tissue, a large myocutaneous flap is usually required, unless a very thick fasciocutaneous flap is available.10 The most commonly used flaps in our experience are the ALT myocutaneous flap and rectus abdominis muscle flap. The flap is inset beginning with the deepest intraoral area. After accurate approximation to the mucosa, the flap can be folded so that the other half of the flap is outside the mouth (Fig. 29-2). The skin between the cheek and the oral cavity is deepithelialized and its edge sutured to the external skin and oral mucosa of the wound edge. When using chimeric flaps, the external and internal flaps are also separated before flap inset.

Fig. 29-2  A, This 41-year-old man was diagnosed with cancer of the right buccal region staged as T4aN0M0. A through-and-through defect remained after the tumor excision.
Bulky flap coverage is essential for the reconstruction of through-and-through defects, because most free flaps shrink to some degree after microsurgery. Postoperative radiation therapy also has this effect. In addition, the oversized volume can be revised as a secondary procedure shortly after radiation therapy and chemotherapy are complete, once patients are disease free.

**Buccal Mucosa, Inferior Maxilla, and the Partial Palate**

Dead space is created during a partial maxillectomy. The secretion from overlying mucosa acts as a source of chronic infection if the mucosa is not removed entirely. Radical curettage of the mucosa and dead space obliteration are two main considerations when reconstructing defects involving the inferior maxilla. Moreover, if the defect also includes part of the hard or soft palate, the missing palate should also be replaced. The hard palate separates the oral cavity from the nasal cavity. The soft palate contains muscles that close the posterior pharynx during speech, separating the oropharynx from the nasal cavity. Without restoration of the palate, complications such as oronasal fistula and hypernasality occur.
To achieve a comprehensive reconstruction, a myocutaneous flap is usually required to obliterate the dead space.\textsuperscript{8,10,11} In our center, the ALT myocutaneous flap is preferred, because it has the advantages of adequate volume and skin length, which may be folded and deepithelialized to obliterate the dead space, line the buccal surface, and support the midface.

**Buccal Mucosa and Marginal Mandibulectomy**

For defects created during a marginal mandibulectomy, the reconstruction functions to resurface the defect and securely cover the exposed bone. The ALT flap with vastus lateralis (VL) muscle is the flap of choice for this type of defect. During flap insetting, the exposed bone should be well covered and the flap should be shaped to create a sulcus. A three-dimensional shape created by the flap in this way generally achieves a better functional result. For defects involving buccal mucosa and segmental mandibulectomy, see Chapter 33.

**SURGICAL OPTIONS FOR BUCCAL RECONSTRUCTION**

**Primary Closure**

Primary closure of the buccal mucosa is only appropriate for very small defects with no tension or restriction on any mobile functional units.

**Skin Graft**

Skin grafts are rarely used in buccal mucosal reconstruction today because of the tendency for secondary contracture. Many local flaps or free tissue transfers are available and provide better function.

**Local or Regional Flaps**

**Buccal Fat Pad Flap**

Buccal defects less than 5 cm in diameter can be reconstructed with a pedicled buccal fat pad flap. The buccal fat pad is an encapsulated adipofascial tissue located in the maxillofacial region. It comprises a central body on the anterior border of the masseter muscle with extensions to the buccal, temporal, and pterygoid regions. The buccal extension runs below Stensen’s duct to the retromolar trigone region. The central part and buccal extension (more than 50% of the entire buccal fat pad) are the most clinically useful parts in oral mucosal reconstruction because of their anatomic location and large size. The blood supply comes from various source branches from the facial, superficial temporal, and internal maxillary arteries. The branches from each mother vessel have a very good network in the buccal fat pad, providing a rich, reliable blood supply.

The buccal fat pad flap can be harvested through an intraoral mucosal incision 5 mm above the upper second molar.\textsuperscript{12-16} The dissection is carried out between the
gingivobuccal sulcus and the opening of Stensen’s duct, passes through the buccinator muscle, and continues 2 cm posteriorly. After the overlying fascia is opened, the fat pad can be retracted by an assistant compressing the cheek. After the pad is transferred to the defect, it may be left uncovered or grafted with skin. If left uncovered, epithelialization takes 15 to 20 days.

**Inferiorly Based Nasolabial Flap**

The nasolabial flap is nourished by the facial artery, the transverse branch of the superficial temporal artery, and the infraorbital artery. Because of its rich vasculature, the flap can be designed as a superiorly or inferiorly based flap and as a pedicled, islanded, or random flap. Only the inferiorly based nasolabial flap is suitable for oral mucosal reconstruction. The nasolabial flap can measure up to 2.5 by 8 cm. In very lax skin, the width can be 3.5 cm. Because of the limited width of the flap, its use in buccal mucosal reconstruction is reserved for small defects.

**Submental Flap**

The submental flap is an axial flap based on the submental branch of the facial artery. Because of the anastomosis between bilateral submental arteries, the skin paddle spans from one submandibular angle along the mandibular border to the contralateral submandibular angle. During flap harvesting, an incision is made that passes along the lower mandibular border and traverses the platysma muscle. The dissection continues beneath the platysma muscle and the pedicle is identified, usually at the superior border of the submandibular gland. The dissection can be continued to the midline for a longer pedicle. Perforators are usually located around the anterior belly of the digastric muscle, and this muscle belly may be included if the perforators are too small to dissect out.

The flap can reach the floor of the mouth, bilateral cheek mucosa, and lower two thirds of the ipsilateral face. However, many buccal mucosal defects result from cancer surgery; therefore the availability of this flap should be carefully evaluated, because the vasculature and flap might be damaged during lymph node dissection in the neck.

**Facial Artery Musculomucosal Flap**

The facial artery musculomucosal flap contains mucosa, submucosa, and a small portion of buccinator muscle and is a good alternative for buccal mucosal reconstruction if the defect is small. It can be superiorly based on the angular branch of the facial artery or facial branches from the infraorbital vessels or inferiorly based on any branches coming from the facial artery.

The course of the facial artery can be detected intraorally using handheld Doppler imaging. The flap extends from the retromolar trigone region to the gingivolabial sulcus intraorally at the level of the alar margin. The average width is 1.5 to 2 cm and
the length is 8 to 9 cm. The flap has to be raised as an axial flap to obtain adequate flap length. It can be harvested as a superiorly or inferiorly based flap with a smooth arc of rotation and transferred to a slender defect. Care should be taken not to injure Stensen’s duct while raising this flap.

**Free Flaps**

**Radial Forearm Free Flap**

Before performing a radial forearm free flap procedure, an Allen test is important to ensure that the ulnar artery is adequate for the distal hand blood supply. In our center, the radial forearm free flap is one of the most commonly used flaps for buccal mucosal reconstruction.28 Because of its thinness, adequate flap size, pedicle length, and reliability, this flap is often the first option for buccal mucosal reconstruction when the defect involves only buccal mucosa without bone.4,5,29

The radial forearm flap is a type C fasciocutaneous flap based on the radial artery in the forearm region. Proximally, it can also be harvested based on a septocutaneous vessel.30 The combination of the conventional method and the proximal forearm flap based on septocutaneous vessels can replace two, small, adjacent but not connected defects simultaneously with only one microvascular anastomosis.28 The radial artery is enclosed by deep fascia between the brachioradialis and flexor carpi radialis tendons in the distal third of the forearm. In the middle third of the forearm, the radial artery runs in the intermuscular septum, between the brachioradialis and flexor carpi radialis muscles. The superficial branch of the radial nerve runs along the radial artery from the proximal forearm and gradually angles dorsally to provide sensation to the dorsum of the wrist. This sensory nerve should be carefully preserved during flap dissection.

The flap is designed with the axis of the flap parallel to the radial artery. The skin paddle of the flap is outlined. Suprafascial dissection is performed after the radial and ulnar incisions are made to the subcutaneous level.31 The distal end of the radial artery and venae comitantes are identified and ligated. Dissection continues beneath the pedicle vessel, with the septocutaneous vessels and the superficial layer of the conjoined tendon intact. The brachioradialis muscle is retracted to allow better visualization of the pedicle. The dissection is completed once an adequate pedicle length has been obtained.31 After the flap is divided, the donor site is closed primarily if the flap dimension is less than 3 cm. For a larger flap harvest, the donor site should be grafted with a split- or full-thickness skin graft (see Fig. 29-1, C). In most buccal reconstructions, the patient has an excellent functional and cosmetic outcome when the radial forearm flap is used (see Fig. 29-1, A and B).

**ALT Flap: Myocutaneous or Fasciocutaneous**

The ALT flap has become one of the most frequently used flaps for soft tissue reconstruction because of its reliability, versatility, and availability in various volumes and sizes.2,6-11,28,32,33 Because the flap has a large skin territory and includes the vas-
tus lateralis and tensor fascia lata muscle, it is a good choice for the reconstruction of large buccal defects, through-and-through cheek defects, and defects with exposed bone (see Fig. 29-2, A).

The ALT flap is supplied by the descending branch of the lateral circumflex femoral artery (see Fig. 29-2, B). The pedicle runs in the groove between the rectus femoris and vastus lateralis muscles. The vessel gives branches to the vastus lateralis muscle, including some perforators traversing the vastus lateralis muscle to the skin of the anterolateral thigh (see Fig. 29-2, C). A skin paddle measuring up to 20 by 40 cm can be harvested from the donor site. The vastus lateralis muscle can also be harvested as a musculocutaneous flap when a large-volume replacement is required (see Fig. 29-2, D).

Before harvesting, a line between the anterior superior iliac spine and the lateral border of the upper patella is drawn. This line represents the intermuscular septum between the rectus femoris and vastus lateralis muscles. Most of the perforators located within a 3 cm radius of the midpoint of this line are circled. The perforators can be detected using a handheld Doppler probe and marked. The flap is designed according to the location of the identified perforators. The ALT flap may be inset as a myocutaneous flap for bulk and coverage of the bony raw surface or as a fasciocutaneous flap for buccal reconstruction (Fig. 29-3).

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**Fig. 29-3** This 53-year-old man underwent surgery for recurrent left buccal cancer. **A**, The defect that remained after the excision involved the left buccal mucosa, trigone, and a limited area of the left maxilla. **B**, An ALT flap was divided. **C**, He is shown immediately after surgery.
Medial Sural Artery Perforator Flap

The medial sural artery perforator flap, located in the posteromedial calf area, is primarily applied in lower limb reconstruction as a pedicled flap. It is also used as a free flap to replace thin soft tissue defects.\textsuperscript{34-38}

The pedicle of the medial sural artery perforator flap is the medial sural artery, which emerges from the popliteal artery. The flap’s perforators are located 7 to 18 cm beneath the popliteal crease, in the axis of the midline between the midline of the gastrocnemius muscle and a parallel line drawn from the medial condyle. With adequate dissection, a pedicle length of 10 to 17 cm can be obtained, and a reliable skin paddle 12 to 15 cm long and 7 to 9 cm wide can be harvested. However, to achieve direct closure of the donor site, the width of the flap to be harvested can be determined using the pinch test.

The medial sural artery perforator flap is thin and pliable, similar to the radial forearm flap, and is suitable for intraoral reconstruction. However, the flap dissection is more difficult and the pedicle length is shorter with the medial sural artery perforator flap and therefore it is less popular than the radial forearm flap. In addition, the hair-bearing characteristic of the flap is unpleasant for some patients.

Rectus Abdominis Myocutaneous Flap

The rectus abdominis muscle and the overlying fasciocutaneous tissue are nourished by the superior and deep inferior epigastric arteries. With the vascular network in between these structures, the rectus abdominis myocutaneous flap can be harvested based on either main pedicle. When based on the deep inferior epigastric vessels, the flap is used as a free flap because of its robust blood supply. In the past, it was one of the most commonly used flaps in head and neck reconstruction. However, most of the advantages of this flap have been replaced by the ALT flap. As a result, the rectus abdominis myocutaneous flap has largely become a second-choice flap for head and neck reconstruction in our center.

Peroneal Artery Perforator Flap

The peroneal artery perforator flap is located in the lower, lateral area of the leg.\textsuperscript{39-41} The skin paddle is thin and pliable. Most of the perforators are located in the lower third of the posterior border of the tibia bone and along the intermuscular septum between the peroneal and soleus muscles. They can be septocutaneous vessels or true perforators traversing the soleus muscle. The perforators are detected preoperatively using a handheld Doppler device. The flap is harvested with a tourniquet in place to ensure a bloodless operative field. After dissecting the perforators, the pedicle is identified behind the fibula.
The vasculature of the peroneal artery perforator flap allows either a fasciocutaneous flap to be raised or, by including the proximal part of the fibula bone and the soleus muscle, a composite flap. It is recommended that this flap not be used as a first choice, because it may be needed later for bony reconstruction of the mandible or maxilla if the tumor recurs or severe osteoradionecrosis occurs.

Lateral Arm Flap

Within the lateral intermuscular septum of the arm, four to seven fasciocutaneous branches arise from the posterior radial collateral artery. These are located 1 to 15 cm proximal to the lateral epicondyle. The lateral arm fasciocutaneous flap can be designed based on these branches.\textsuperscript{42-45}

A longitudinal line is drawn between the insertion of the deltoid muscle and the lateral epicondyle. After locating the septal branches with a handheld Doppler probe, a flap with a maximum size of 8 by 14 cm can be harvested. The dissection is carried out from posterior to anterior to explore the septocutaneous branches and trace the branches and pedicle in the lateral intermuscular septum. Care should be taken to avoid injuring the dorsal branch of the radial nerve while dissecting the radial side of the flap. A pedicle length of 8 cm can be obtained. With further dissection along the spiral groove of the humerus, the pedicle can be lengthened by 2 cm.

INDICATIONS AND CONTRAINDICATIONS

Many options are available for buccal mucosal reconstruction.\textsuperscript{1,46-48} However, optimal reconstruction requires a careful evaluation of the defect and the selection of an appropriate donor flap. Local flaps are indicated only for small defects. The nasolabial flap and facial artery musculomucosal flap provide limited width and are better used in defects less than 2 cm wide. The buccal fat pad flap can provide coverage for areas as large as 5 cm in diameter. However, without covering the surface, potentially severe scar contracture is possible from secondary wound healing. With the high success rate of microsurgery, the advantage and disadvantage of performing a pedicled buccal fat pad flap in a defect of 5 cm should be weighed.\textsuperscript{49} The most sizable pedicled flap in the head and neck region is the submental flap. Because of its location, it is not indicated in buccal reconstruction if the neck is dissected. The floor of the mouth, the lower level of the face, and the anterior sulcus area are better recipient sites for the submental flap.

The free flap has been used as a benchmark in head and neck reconstruction for large defects. The selection between a fasciocutaneous or a myocutaneous flap is based on the size of the defect and whether there is a dead space to be obliterated or bone surface to be covered. The radial forearm flap and medial sural artery flap are better in thin mucosal defects. The lateral arm flap is an alternative. The ALT and
the rectus abdominis flaps are indicated for larger or through-and-through defects. Because of our familiarity with and the versatility of the ALT flap, it is our first choice over the rectus abdominis flap. The transverse rectus abdominis myocutaneous free flap has the risk of donor site morbidity and is our second choice.

**PREOPERATIVE MANAGEMENT**

Preoperative preparation should include an assessment of the defect size and the missing tissue, the availability of donor flaps, and a patient’s general health and medical history. The selected donor site is inspected for scars from previous surgeries, because these could affect the circulation of the flaps to be used for reconstruction. The use of local flaps from areas that were previously irradiated should be carefully avoided. Radiation therapy can make the flap dissection more difficult and decrease the blood supply, affecting wound healing. Patients with diabetes, severe infection, or peripheral vascular disease, and those who smoke, are undergoing hemodialysis, or have had radiation therapy have a higher risk for complications because of the long anesthesia time. The use of an option lower on the reconstructive ladder, such as a regional flap, should be considered preoperatively.

If a free flap reconstruction is planned, the hemodynamic status of the donor vessels of the flap must be evaluated. Although color duplex or multidirectional CT scanning has proved effective and highly sensitive, I (M-H.C.) do not use it routinely. In most cases, a handheld Doppler device is adequate to detect the perforators and identify the course of the vessels.

Trismus, difficulty swallowing, and pain resulting from ulcerative tumors, are frequently encountered in patients with head and neck tumors. Poor oral intake resulting in malnutrition may affect wound healing and should be adequately corrected preoperatively. Nutritional support can be easily provided through a nasogastric tube. Poor dental care may place patients at risk of developing postoperative wound infection and should be corrected before surgery.

Some patients with buccal cancer have infections from the ulcerative tumor. It is important to control infection using parenteral antibiotic agents and intensive dental care before the tumor excision and reconstruction. This can effectively decrease the chance of postoperative wound infection and subsequent vascular complications.

Preoperative chemoradiation therapy is common for advanced cancer treatment. The risks posed by a previously irradiated bed include bleeding easily during dissection, difficulty finding a pair of healthy recipient vessels, and poor wound healing. It is better to wait to perform the reconstruction until 1 to 3 months after the completion of radiation therapy to prevent these complications.
**OPERATIVE TECHNIQUE**

**Recipient Site Preparation**

A template made of sterile towel is tailored to the dimensions of the defect. The template is sterilized again for further flap design. Copious irrigation with normal saline solution reduces the risk of postoperative infection. One or two Jackson-Pratt suction drains are inserted in the dependent site of the neck for better drainage. Satisfactory drainage is important during surgery to keep the operative field dry and clear, especially when irrigating with heparinized saline solution during an anastomosis. Furthermore, suction drainage may decrease dead space and help avoid hematoma or secretion accumulation in the neck postoperatively. Because of the previous ablative oncologic surgery, the recipient vessels in the neck are explored. A good, spouting flow is needed to ensure the perfusion of the recipient artery. Good backflow from the recipient vein confirms its patency.

**Selection of Recipient Vessels**

In head and neck reconstruction, four sets of vessels are available for end-to-end microvascular anastomosis: superficial temporal, facial, superior thyroid, and transverse cervical vessels. After neck dissection, the superior thyroid vessels are usually well exposed. The facial vessels may be exposed, sacrificed, or injured. The ipsilateral superior thyroid vessels are the most commonly used vessels in primary oncologic reconstruction because of the ease of exposure. In primary reconstruction without neck dissection, the facial vessels are the first choice and have the advantage of requiring a shorter flap pedicle length and smaller subcutaneous tunnel.

The selection of recipient vessels in previously operated or irradiated patients presents a challenge when performing reconstruction. To avoid vessel exploration and anastomosis in the scarred or irradiated tissue, the superficial temporal vessel is an alternative. In patients with previous neck dissection, the supraclavicular region is usually less scarred; thus the transverse cervical vessel is another choice. It also has the advantages of reliable blood flow and a straightforward dissection of the vessels. However, the disadvantage of these vessels is the longer distance from the defect, which may require a vein graft.

**Donor Site Preparation**

The free flap has become the first choice for a suitable donor site because of its robust blood supply, versatile flap inset, and variable tissue availability. A handheld Doppler device is used to locate the perforators and determine the direction of the pedicle. The flap is designed according to the template, with the perforators or axial pedicle positioned in the center of the flap. The flap is raised accordingly.
Technical Tips and Tricks

- Ischemia time is minimized by dividing the flap pedicle after the recipient vessel preparation is complete.
- The flap is inset before the vascular anastomosis to reduce tethering and protect the pedicle.
- The deepest, most inaccessible part of the flap is inserted first.
- Tunnels must be wide enough to permit edema and minimize the risk of compression.

Pitfalls

The most difficult buccal reconstructions with microsurgery are those performed following previous operations and radiation therapy. A healthy pair of recipient vessels is critical. If the flap is dissected before the recipient site is prepared, the flap inset and pedicle positioning may be difficult. Occasionally, suitable recipient vessels are not available for anastomosis. It is better to prepare the recipient site well and ensure that the recipient vessels are healthy before selecting, dissecting, and dividing the flap.

Complications

Early Complications

Infection With or Without Salivary Fistula

Infection is the most common complication in buccal mucosal reconstruction.\textsuperscript{55,56} Occasionally, a salivary fistula is found. Although the incidence of salivary fistula is only 3\%,\textsuperscript{57,58} the effect on the microvascular anastomosis of progressive thrombophlebitis or rupture of the vascular anastomosis is significant.\textsuperscript{56,59} To prevent fistula formation during an operation, each stitch on the flap inset must be watertight. The recipient area of the neck should be well drained. The recipient neck wound is best closed with a simple suture pattern. Several stitches are removed to allow further drainage if the neck becomes erythematous or swollen. Postoperative mouth care is also important to decrease the possibility of wound infection.
Hematoma

Bleeding frequently occurs after tumor resection in the head and neck region, and it is worse in previously operated or irradiated patients. Secure hemostasis is critical to prevent postoperative hematoma formation. Patients are under anesthesia during the operation, and their blood pressure is well controlled. Minor wound oozing can become significant bleeding when the blood pressure is increased because of postoperative pain. The hematoma accumulation around the recipient site may result in vascular compression and threaten flap survival. Hematoma also increases the risk of postoperative infection. A progressive swelling of the neck indicates emergent exploration to prevent further thrombosis of the pedicle.

Vascular Compromise and Free Flap Failure

After revascularization of a free flap, vascular compromise is most critical to flap survival and requires urgent intervention. Arterial compromise frequently results from technique errors and commonly presents during the first postoperative day. The initial presentation of arterial compromise is a pale-colored flap that has lost its skin turgor. Immediate exploration and revascularization is critical for reducing ischemia time and preventing irreversible change. Venous compromise presents initially as increased oozing from the wound edge, progressive swelling, and a tense appearance of the flap. After progressive congestion, the flap becomes dark red and then blue. External compression, vascular kinking, or intravascular thrombus formation can result in venous problems. However, each of these situations results in progressive thrombus formation that can fill the pedicle vein and progress backward to the perforator and capillary network without intervention. The venous anastomosis should be divided immediately after a venous problem is detected to allow venous drainage and stop the vicious circle. Reexploration, thrombectomy, and venous reanastomosis should be performed as soon as possible.

Although the success rate of microsurgery is currently more than 96%, free flap failure is still a cause of stress for reconstructive surgeons. Different factors contribute to a free flap failure, including the quality of recipient vessels, surgical technique, a patient’s medical history, and postoperative infection. Each patient’s medical history requires a comprehensive review. Diabetes should be under control and patients should quit smoking before the reconstruction. Technique errors can be prevented with careful flap dissection, adventitia removal around the vessel, and a well-performed anastomosis. The selection of appropriate donor and recipient sites can decrease the requirement for vein grafts. Anastomosis should be avoided in previously irradiated or operated surgical beds to decrease the possibility of thrombosis formation. A careful flap inset with intraoral, watertight sutures may prevent orocutaneous fistula formation and subsequent infection. After each operation, frequent and careful monitoring of the flap circulation is essential. Immediate exploration is indicated for any compromise of the flap circulation.
Medical Complications After Surgery

Postoperative atelectasis is the most frequent cause of postoperative fever. Intensive chest care from the nurse and respiratory therapist are required immediately after the operation. Chest percussions are important, and patients are encouraged to perform lung expansion exercises. Buccal cancer patients are often in a malnourished state before the operation. Enteral feeding through a nasogastric tube and adequate intravenous fluid are helpful to prevent complications from electrolyte imbalance and poor wound healing.

Tumor resection with microsurgical reconstruction is a long, major operation and is stressful for patients. We routinely administer a proton pump inhibitor for 3 days postoperatively to reduce the formation of gastric stress ulcers and the resulting upper gastrointestinal bleeding.

Late Complications

Sunken Cheek

The sunken cheek appearance occurs with inadequate volume replacement, flap shrinkage after radiation therapy, or partial flap loss. To prevent this complication, the thickness of the required flap is carefully measured. Generally, it is better to provide greater flap coverage to compensate for shrinkage if postoperative radiation therapy is needed.

Tethering of the Tongue

Tethered tongue movement occurs with inadequate soft tissue coverage of defects involving the buccal mucosa and part of the mouth floor and tongue margin. A three-dimensional design of the flap, based on the missing tissue, is important. Floor-of-mouth and marginal tongue defects need to be resurfaced, and a small part of the flap folded to imitate an original sulcus and provide free movement of the tongue.

Oronasal Fistula

An oronasal fistula results when a buccal mucosal defect extends to part of the maxilla and palate, without adequate reconstruction. As mentioned previously, palatal defects should be reconstructed with part of the flap folded in half to mimic the shape of the original palate. A muscle component of the flap is required to fill the maxillary dead space.
Trismus
Trismus is the most commonly occurring late problem after buccal mucosal reconstruction, especially in patients receiving postoperative radiation therapy. The first step in preventing trismus is to choose an optimal reconstruction method. Skin grafts are not recommended in buccal mucosal reconstruction, because the postoperative contracture limits mouth opening significantly. Wound healing by secondary intention also causes severe contracture and trismus. Many patients with buccal cancer have variable degrees of trismus preoperatively. Early postoperative rehabilitation for mouth opening helps to prevent further trismus.

Postoperative Management
Patients should be kept in the intensive care unit for careful monitoring of respiration and vital signs. Adequate lung volume expansion is needed to keep patients and their flaps well perfused. Flaps are easily monitored by assessing the temperature, color, skin turgor, and capillary time. If any doubt about its viability remains, a flap puncture test can be performed by surgeons familiar with the intraoperative procedure for each patient. The flap is intraoral in buccal mucosal reconstruction, so to prevent inadvertent biting of the flap or flap compression during mouth closing, a gauze roll may be placed between the upper and lower teeth for 7 days postoperatively before going to bed, if needed. However, patients should be taught to withdraw the gauze and perform very slow mouth movements frequently. Early rehabilitation precludes further fibrosis.

Low-molecular-weight dextran, PGE1, and heparin are frequently administered to microsurgery patients. A routine prescription is not recommended. Dextran is used to expand fluid volume and to prevent platelet aggregation; however, complications such as pulmonary edema may occur. PGE1 is used to inhibit vessel spasm that is noted intraoperatively. Low-dose heparin may be used to prevent thrombosis formation postoperatively. The postoperative rehabilitation should focus on the recipient and the donor sites to achieve better functional reconstruction and prevent donor site morbidity.

Conclusion
A successful buccal mucosal reconstruction requires a step-by-step evaluation and management. The oral cavity contains different functional units, each requiring reconstruction to restore function and achieve a good aesthetic result. A thorough review of the defects, a reasonable donor flap selection, and a well-performed surgery are equally important. A strategic approach helps to achieve a successful reconstructive outcome and satisfied patient.
CRITICAL POINTS

Must Know
- The goals of buccal mucosal reconstruction are to restore function and achieve a good aesthetic result.
- The defect must be carefully evaluated and classified.
- The best reconstructive option is selected.
- Surgeons must be familiar with the anatomy of the defect, donor flap, and recipient vessels.

Should Know
- Each flap has advantages and disadvantages that must be understood.
- Surgeons should be familiar with common complications and the ways to prevent them.

Synopsis
- A successful buccal mucosal reconstruction should be functionally and aesthetically satisfactory.
- A thorough evaluation of the defect and reasonable selection of options help achieve a good result.
- Surgeons should be familiar with the reconstructive options and difficulties that may occur.
- With adequate knowledge about the possible complications and how to treat them, a good result can be obtained.

References

   The authors explain that early in their experience with head and neck reconstruction, they evaluated results mainly based on the final contour of the mandible. With further experience, the bony reconstruction becomes more and more accurate, and the intraoral soft tissue reconstruction poses a continuing challenge.


   Microvascular free tissue transfer has gained worldwide acceptance as a means of reconstructing postoncologic surgical defects in the head and neck region. Since 1977 the authors have used this reconstructive procedure for head and neck reconstruction after cancer ablation, and a total of 2372 free flaps were transferred in 2301 patients during a period of over 23 years. The most frequently used flap was the rectus abdominis flap, followed by the jejunum and forearm flaps. The authors believe that these three flaps have been a major part of the armamentarium for head and neck reconstruction because of their lower rate of flap necrosis compared with other flaps.

The authors review sixty consecutive patients in whom a free radial forearm flap was used to reconstruct an intraoral defect. The results demonstrate the effectiveness of this method of intraoral reconstruction and indicate that such complicated and prolonged surgical techniques do not increase the risks associated with major head and neck surgery.


Tongue defects can heal without major reconstruction. Because of its mobility, durability, and vascularity, it can be sutured to almost any skin graft, rotation flap, or even to itself to make a wound safe, facilitate healing, and prevent complications. These characteristics raise several questions: Do we use an organ as a myocutaneous flap that is critical for eating, speaking, social interaction, personal interaction, and
employment? Do we design ways to facilitate tongue function in an attempt to minimize the morbidity of tongue resection? Do we treat disease or do we try to create wellness?

Oral cavity carcinoma is not responsive to chemotherapy or radiation therapy; adequate treatment requires wide margins. Because of the need for mobility, suppleness, and secretions, radiation is unlikely to become a good alternative to surgery, even with the newer molecular targeting agents. Therefore extirpation with generous margins to clear the disease and reconstruction to finesse the many critical functions of the tongue are critical and require passion and perseverance.

The goals of tongue reconstruction are the following:

- **Obliterate the oral cavity.** Obliteration of the oral cavity is achieved when all oral cavity mucosal surfaces are in contact with one another when the mouth is closed. Successful obliteration decreases the likelihood of food getting lost in a dead space in the oral cavity and, as a result, improves the handling of secretions by bringing the tongue (native and reconstructed portions) in contact with the remaining native mucosa.
- **Maintain premaxillary contact.** This is an extension of the goal of obliteration of the oral cavity. Premaxillary and palatal contact is important for attaining precise articulation of a number of speech sounds. Generally, reduced precision of linguodental, alveolar, palatal, and velar sounds occur if adequate premaxillary contact is not achieved. When obliterating the volume of the oral cavity, surgeons need to ensure that some of the volume is concentrated anteroorally.
- **Optimize residual finger function of the tongue.** Finger function is the ability of the tongue to sweep and clear the buccal, labial, and alveolar sulci and protrude past the coronal plane of the incisors. It is important to optimize the residual function of the remaining tongue tip.
- **Maintain movement of secretions from the anterior to the posterior aspect of the oral cavity.**
- **Optimize sensation of the remaining native tissue and the revascularized free tissue transfer.**

The following principles help achieve the goals of tongue reconstruction:

- **Tissue of appropriate volume should be selected to adequately restore the volume of the defect.** To ensure that the volume of the reconstruction is satisfactory, the defect volume should be overcorrected, because volume can be lost slowly over several years, particularly in patients who undergo radiation therapy.
- **The tissue on the floor of the mouth is reconstructed with thin tissue, and tongue tissue is reconstructed with thicker tissue when the objective of the reconstruction is to facilitate protrusion.** This difference of tissue thickness is achieved by carefully choosing the position of the flap on the donor site or by customizing the flap. The flap is customized by either thinning the subcutaneous tissue in selected areas or by increasing bulk by folding over deepithelialized subcutaneous tissue in other selected areas.
The volume associated with the tongue and all the adjacent compartments is restored. The compartments include the extrinsic tongue musculature (submandibular and submental triangle), the mandible, and the parapharyngeal space. The volume of these tissues, if resected, is restored to prevent the tongue reconstruction from contracting laterally or inferiorly, which would compromise obliteration of the oral cavity and protrusion of the tongue.

If there is residual tongue tip, the flap design and inset must allow anterior and posterior excursion of the tongue to facilitate tongue protrusion.

There needs to be a smooth gutter from the anterior floor of mouth to the posterior floor of mouth to facilitate the clearing of secretions. The reconstruction should not block the glossoalveolar or buccoalveolar sulci, nor blunt the labioalveolar sulci.

**Classification of Tongue Defects**

A universal classification system that divides the various tongue defects into several clinically manageable types has not been developed, although several systems have been described. These classification systems are excellent for cataloging the extirpated tissue, but can be cumbersome for daily clinical use.

The classification of tongue defects is based on embryology. There are two fusion planes in the tongue: a midline fusion plane runs the entire length of the tongue, and a coronal division runs between the anterior two thirds and posterior one third. The anterior two thirds of the tongue consist of two identical functional units that are mirror images of one another. Together these paired functional units obliterate the volume of the oral cavity and provide the finger function of tongue. The anterior two thirds are part of the oral preparatory phase of swallowing and form food into a bolus for the pharyngeal phase of swallowing. The finger function is responsible for (1) sweeping food from the labial and buccal sulci, (2) forming and shaping the food bolus by cradling and pressing it against the premaxilla and anterior aspect of the secondary palate, (3) assisting with oral competence, and (4) cleaning the lips. The tongue tip is required at least on one side to maintain all of these functions. Almost any tongue resection affects the finger function of the tongue—but it is more difficult to determine at what point the impaired function becomes a disability. Radiation and the associated xerostomia also make finger function more difficult. Because of the importance of the tip of the tongue for finger function, surgical removal of this portion of the tongue figures prominently in the defect classification and considerations for reconstruction.

The base of the tongue is the posterior one third of the tongue and is also paired. It is classified as part of the oropharynx because its embryology, functional role, and pathophysiology are different from those of the anterior two thirds. The oropharynx is involved in the pharyngeal phase of swallowing, and the base of the tongue drives the food bolus through the oropharynx. The base of the tongue is frequently involved in tongue cancer resection, and it is important to know how to classify and manage the base of tongue in this context. The oropharynx is a complex organ that
initiates the pharyngeal swallow, separates the nasopharynx, and protects the larynx. This requires motor and sensory neurointegration that, in my opinion, is best managed if the sphincter is intact neurologically and circumferentially. Therefore, whenever possible, one of the goals of tongue base reconstruction is primary closure that results in a neurologically intact sphincter, even if this approach leads to stenosis. With my approach, defects that include up to half of the base of the tongue are not classified separately, because primary closure is always performed to the lateral pharyngeal wall in an effort to reconstitute the oropharynx and maintain a neurologically intact, functional sphincter.

The five defects described here can be divided into the following classification system (Fig. 30-1):

Type 1. Subtotal hemiglossectomy. This defect is also called a wide local excision or cookie bite.
Type 2. Hemiglossectomy. This includes an oral hemiglossectomy and a complete hemiglossectomy, including up to half of the base of the tongue.

![Fig. 30-1](image)

**Fig. 30-1** A, Type 1: subtotal hemiglossectomy. B, Type 2: hemiglossectomy.
Type 3. Extended hemiglossectomy. The extensions include the anterior floor of the mouth, and/or the anterior tonsillar pillar, and/or the midline tongue raphe.

Type 4. Oral glossectomy. This defect includes the entire tip of the tongue and can include up to half of the tongue base. It is also called a near-total oral glossectomy.

Type 5. Total glossectomy. This defect includes the tongue tip and tongue base wherein primary closure of the tongue base is not possible.

Fig. 30-1, cont’d  C, Type 3: extended hemiglossectomy. D, Type 4: near-total oral glossectomy. E, Type 5: total glossectomy. The blue areas represent the location and extent of the defect. The yellow areas show possible extension of the defect. The red areas indicate extension to include either the contralateral anterior floor of the mouth or the ipsilateral anterior tonsillar pillar, tonsil, and/or retromolar trigone.
A hemiglossectomy is the homolateral excision of one side of the tongue. As previously mentioned, the hemitongue is divided into three parts: the anterior one third (the tip of the tongue), the middle one third (the lateral tongue), and the posterior one third (the base of the tongue). The hemiglossectomy defect includes at least the anterior two thirds of the tongue and may extend to include the posterior one third. When half of the base of the tongue is excised, the remaining base is closed in a primary fashion to the lateral pharyngeal wall, which converts the defect into one that involves the anterior and lateral thirds of the tongue. The subtotal hemiglossectomy includes less than two of the thirds of the tongue and cannot include both the right and left sides of the tongue tip. The extended hemiglossectomy includes areas that compromise the results of a hemiglossectomy reconstruction and require considerable attention to optimize the outcome. The mucosal extension in the anterior floor of the mouth to the contralateral side of the defect often requires additional tissue to facilitate tongue protrusion. The mucosal extension up the anterior tonsillar pillar along the palatoglossus, with or without involvement of the retromolar trigone, is also common. This situation can require additional tissue to prevent tethering of the base of the tongue and allow flow of secretions through a reconstructed glossotonsillar sulcus to the oropharynx. The extension to include the midline raphe does not include the contralateral hypoglossal nerve but can include the most medial part of the contralateral genioglossus. Extension to include these tissues is commonly seen in large invasive lateral tongue tumors and can result in decreased tongue strength and limited tongue protrusion.

The oral glossectomy includes the tip of the tongue and can extend to involve the entire oral tongue (the anterior third and the middle third on both sides) as well as the right or left half of the base of the tongue, but not the entire base of the tongue. Once the tip of the tongue is resected, finger function is lost, and the focus of the reconstructive effort is to restore the volume of the tongue and obliterate the oral cavity. The base of the tongue is used as a motor driver to move the tongue mound anteriorly and posteriorly, which is most useful for speech and management of liquids. The total glossectomy defect includes the tongue tip and a tongue base resection that precludes primary closure. This defect represents a total resection of the tongue from a functional perspective. The primary objective in these defects is obliteration of the oral cavity for management of secretions and protection of the airway.

Some part of the tongue tip and tongue base is preserved in defect types 1, 2, and 3. But, as the classification moves from defect type 1 through defect type 3, there is a progressive negative impact on finger function and progressive enlargement of the volume of the defect. The focus of reconstructing defect types 1 through 3 is using the remaining tongue to facilitate the finger function while maintaining appropriate volume. Defect types 4 and 5 include loss of the tongue tip and, in addition, defect type 5 includes loss of the base of the tongue. In these defect types, the focus of the reconstruction is on restoring the volume of the tongue to obliterate the oral cavity. Tongue defects can extend to involve the mandible, oropharynx, larynx, and skin.
Even with extension to these areas, the goals, principles, and classification with respect to the tongue portion of the defect remain the same. A discussion of the surgical options and decision-making with respect to these larger defects is beyond the scope of this chapter.

**Surgical Options**

Although autogenous transplantation is not the best approach for all tongue defects, it is preferred for defects that could adversely affect tongue protrusion and finger function, and for defects that result in large volume losses that compromise obliteration of the oral cavity. Fig. 30-2 shows a decision-making algorithm for various tongue defects.

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**Fig. 30-2** Decision making for tongue defects. *Defect 1,* Subtotal hemiglossectomy; *defect 2,* hemiglossectomy; *defect 3,* extended hemiglossectomy; *defect 4,* oral glossectomy; *defect 5,* total glossectomy. *ALT,* Anterolateral thigh flap; *BMI,* body mass index; *STSG,* split-thickness skin graft.
Healing by secondary intention allows the tongue to heal without any form of reconstruction. If this approach is taken, good oral hygiene and early mobilization are important to minimize contraction.

Primary closure involves reapproximation of the remaining tongue, sometimes in combination with healing by secondary intention. This approach requires creativity to optimize the finger function of the tongue and recruit adequate volume. This approach is very desirable, because it maintains native tissue in a near-anatomic location. With this approach, the dorsum of the tongue should still contact the hard palate, the tongue tip should be able to protrude past the incisors, and the remaining tongue has to obliterate the oral cavity.10

Skin grafting usually involves split-thickness skin grafts. Full-thickness skin grafts take longer to revascularize and often become overgrown by bacteria before effective vascular ingrowth can take place. A split-thickness skin graft is thinner and vascularizes faster, making it a better choice for the oral cavity. The split-thickness skin graft is ideal for thin, low-volume defects. Skin grafts need to be immobile, applied to the underlying vascular bed, and free of salivary contamination. To achieve these as well as possible, I use a large bolster of fine-mesh gauze impregnated with 3% bismuth tribromophenate in a petroleum blend. The disadvantages of skin grafts are contraction and a relatively high failure rate compared with tissue transplantation. To compensate for these disadvantages, skin grafts should be placed with the wound maximally stretched. This can be achieved by suturing the oral tissues over the bolster. A skin graft contracts by 50% to 75%. In addition, a skin graft should not be used if its failure will cause tethering that would result in compromised speech or the inability to consume a solid diet.

Local flaps such as melolabial or buccal mucosal flaps can be excellent reconstructive options for low-volume defects if a skin graft would cause excessive tethering of the lateral tongue or tongue tip.11 A patient must have adequate donor tissue to be a candidate for this reconstruction. Careful assessment of the recipient and donor sites is important to ensure that the donor site can provide sufficient tissue. Older patients with large melolabial folds are ideal candidates for this reconstructive approach. They have ample tissue and their donor site heals with little cosmetic consequence. These are two-stage procedures; the first stage is the inset and the second stage is pedicle division. Both of these local flaps are well suited to lateral tongue, anterior tongue, ventral tongue, and floor-of-the-mouth defects, but problems can occur when they are used to cross the anterior midline or extend posterior to the glossotonsillar sulcus. Precautionary steps need to be taken with surgical planning to prevent patients from biting through the pedicle, because it crosses the occlusal surface. For dentate patients, it can be helpful to fashion a bite splint to hold the jaw slightly open. The disadvantages of these reconstructions are a higher failure rate than tissue transplantation, limited donor tissue, and the risk of damage to the facial nerve. Damage to the
facial nerve and/or a weak buccinator muscle can cause problems in patients who have decreased sensation or weakness of the ipsilateral tongue, because the buccinator and orbicularis oris are used as accessory muscles to obliterate dead space and move secretions posteriorly. If these donor sites are ideal, the need to perform the procedure in two stages should not be considered a major disadvantage.

Tongue flaps for most clinical presentations are a reconstruction of last resort. In most situations, an alternative reconstruction offers a superior result in terms of socialization, complexity of the diet, and employment. Advancement of the tongue base can be a good reconstructive approach in patients with lateral defects, an intact tongue base, a mobile tongue tip, and the ability to obliterate the volume of the oral cavity with the remaining tongue tissue. A midline incision is made in the base of the tongue, the contralateral tongue base is sutured to the ipsilateral lateral pharyngeal wall, and the ipsilateral tongue base is advanced anteriorly into the lateral tongue defect. This reconstruction has the advantage of a very low failure rate and provides native sensate tissue. The disadvantage can be inadequate obliteration of the oral cavity, tethering of the tongue, the inability of the tongue to protrude, and loss of the tongue’s finger function.

Regional rotation flaps include the pectoralis, trapezius, and latissimus myocutaneous flaps, all of which can be used for higher-volume defects. The disadvantages of these flaps are the limited arc of rotation to the level of the hard palate, the limited arc of rotation to the anterior aspect of the oral cavity, and the relatively poor reliability compared with tissue transplantation.\cite{12} To reconstruct the tongue effectively, the residual tongue and its associated reconstruction need to be mobile, reach the palate and the premaxilla, and facilitate the finger function of the tongue. Regional rotation flaps can reach the oropharynx and the floor of the mouth. Regional flaps can limit oral cavity obliteration, because they do not easily reach the level of the palate, and contractions of the muscle pedicle tether the tongue, limiting protrusion.\cite{13} The pectoralis muscle flap can be useful in patients with very ptotic pectoral fat and skin. The extra ptosis reduces tethering so that, when inset, oral cavity obliteration and tongue protrusion are improved. The ptotic pectoralis flap can also be useful for oral glossectomy and total glossectomy defects, provided there is enough volume. The latissimus flap can be staged to recruit a portion of the tertiary angiosome to extend the distance of the arc of rotation, thus enhancing oral cavity obliteration and tongue protrusion. For experienced transplant surgeons, regional flaps are considered more morbid and less reliable, and involve substantially more tissue dissection. When using regional rotation flaps, the operating time is reduced, but the overall cost is comparable and the morbidity is increased.\cite{14,15}

Tissue transplantation requires specialized surgical training and is more time consuming than other available reconstructive options. But for most patients, tissue transplantation is the best solution after the excision of an invasive tumor 1.5 cm or
larger, if the goals of reconstruction are oral cavity obliteration and tongue protru-
sion.\textsuperscript{6,16–19} In the context of tongue reconstruction, the failure rate of tissue trans-
plantation is 1\% to 2\%. Depending on a patient’s body habitus, a variety of tissue op-
tions are available to help customize the reconstruction. The flexibility of tissue
positioning during inset, the option to template the reconstruction, and the rich vas-
cularity make tissue transplantation ideal, particularly in patients who will undergo
or have undergone radiation therapy.

Engineered human dermis is a bioengineered product that has also been explored as
a repair option.\textsuperscript{19} However, anything used to repair a defect requires three compo-
nents to form integument: a scaffold, cells, and growth factors, and, although engi-
eered dermis is an excellent scaffold, but it has no growth factors and is acellular. It
may have value as a biologic dressing to facilitate healing from secondary intention,
but if measured by its ability to form a functioning integument, it does not provide
the necessary building blocks.

**INDICATIONS AND CONTRAINDICATIONS**

Many factors must be considered when deciding whether an autogenous tissue trans-
plant is indicated, whether the defect should be closed primarily, or whether a skin
graft should be used. I always evaluate the shape of the recipient site, the type of the
defect, the anatomy of the tissue at the donor site, and the use of radiation.

Evaluation of the defect is the first step in developing a discipline with respect to
reconstruction.\textsuperscript{17} It is important to have detailed knowledge of the resected and
preserved mucosal subunits, muscle, nerve, and bone when choosing a reconstructive
approach. To determine whether the residual tissue will obliterate the oral cavity,
the following are assessed: the size of the tongue, the height of the palate, the rela-
tive location of the premaxilla, the contact of the posterior pharyngeal wall with the
base of the tongue, and the presence of teeth.

To obliterate the oral cavity, the tongue must contact all the mucosal surfaces. The
height of the palate is an important factor for the assessment of obliteration; a very
high palatal arch makes oral cavity obliteration more difficult to achieve. Patients
with a high, arched palate require a larger-volume reconstruction. The location of
the premaxilla is important, because the remaining native tongue or the reconstruc-
tion has to contact this area. This contact site is important for the production of
consonants and the creation of a seal anteriorly to initiate the oral phase of the swal-
low. The base-of-tongue contact is needed to help propel the food bolus through
the oropharynx and protect the larynx. If sufficient volume is not used to reconstruct
the oral cavity, contraction of the defect can pull the base of the tongue forward,
thereby losing pharyngeal wall contact. In this situation, food can be directed into the
oropharynx, which results in aspiration. Loss of posterior pharyngeal wall contact
combined with insufficient bolus control in the oral cavity, requires patients to have a limited diet. Dentition increases the volume that requires obliteration and can increase the complexity of the diet. To use the masticatory surface effectively, the volume of the tongue needs to be completely restored, and any remaining function of the tongue needs to be optimized.

Classification of the defect type involves deciding if there is enough residual tongue tissue to obliterate the oral cavity, if there is remaining tongue tip to achieve protrusion, and if there is sufficient tongue base to maintain posterior pharyngeal wall contact (see Fig. 30-2). Defect types 1 through 3 relate to the anterior one third of the tongue and its residual finger function, whereas defect types 4 and 5 relate to volume restoration of the tongue volume, because the tip has been resected.

The anatomy at the donor site is affected by body habitus and body mass index (BMI). The choice of donor site depends on a patient’s BMI. Most type 1 defects are reconstructed with a primary closure, a split-thickness skin graft, or a radial forearm free tissue transfer. For high BMI patients with type 1 defects, the radial forearm may be too thick if the body habitus includes fat deposition in the forearm. In this case, the forearm is not a good alternative. Most type 2 defects are closed with tissue from the radial forearm donor site. For low BMI patients, the forearm site may be too thin to obliterate the oral cavity. In this case, a lateral arm, septocutaneous anterolateral thigh, or a perforator-based rectus donor site is a better choice. Most type 3 defects are reconstructed with the same donor sites as those used for type 2 defects.

The demands on the soft tissue are more specific. Matching thin tissue to the floor-of-the-mouth portion of the reconstruction and thicker tissue to the tongue portion of the reconstruction is more important in these defects to maintain the finger function of the tongue while preserving oral cavity obliteration. In addition, innervation is important to consider for patients with type 2 or 3 defects that include the ipsilateral tip of the tongue. A donor site such as the forearm, in which innervation is axially oriented and the neurosome is conducive to reinnervation, should improve oral function as long as obliteration and protrusion are not compromised. Most type 4 defects are reconstructed based on each patient’s BMI and body habitus. These defects need volume but cannot accept extremely thick transfers. The most common donor sites are the rectus, lateral arm, anterolateral thigh, latissimus, and scapula. If a patient has a high BMI, hopefully a donor site less than 5 cm thick is available. In men the most likely site is the anterolateral thigh, and in women the most likely site is the lateral arm or the forearm. If a patient has a low BMI, deepithelialized components are necessary to increase the volume of the transplant.

Ideal donor sites are those in which long, thin paddles can be raised, with minimal muscle and good vascularity. These sites are usually the latissimus dorsi and the transverse rectus abdominis. Both are raised with muscle-sparing approaches. For
patients with an average BMI, a variety of sites can be used, including the rectus, lateral arm, anterolateral thigh, and the muscle-sparing latissimus. For type 5 defects, a large volume is required to obliterate the oral cavity, provide posterior pharyngeal wall contact, and protect the larynx. The most common donor sites are the rectus, latissimus, anterolateral thigh, and the scapula. Most frequently, patients with a type 5 defect have a low BMI and reconstruction is a problem, because there is insufficient tissue to obliterate the oral cavity. If a patient has a low BMI, the possible donor sites are the rectus in the periumbilical region, a large transverse rectus in parous females, a long latissimus with deepithelialized components and re-innervation of the latissimus muscle for volume, or a scapula. For patients with a high BMI, the ideal donor site is less than 5 cm. The donor site can vary greatly in these patients, depending on the pattern of fat deposition. The rectus is rarely an option, because this tends to be the thickest site. If a patient has relatively less fat deposition in the limbs, the sites that should be assessed are the lateral arm and the anterolateral thigh. If a patient has relatively substantial fat deposition in the limbs, the scapula or the latissimus may be good alternatives. For patients with an average BMI, the periumbilical rectus, the transverse rectus, or the latissimus are the donor sites that I use most commonly.

The anterolateral thigh has become a very popular donor site for reconstruction of oral cavity defects.20 There are several advantages to this site: the size can be large, the harvest can be performed by a second surgical team during the resection, and the circumflex femoral vessels are large. Despite these advantages, I rarely use this flap for tongue reconstruction. Patients who present to my institution with tongue cancer usually have an average or low BMI and are predominantly of European heritage. The pattern of the fat deposition tends to result in a very thin flap in men and a thicker, irregular flap in women. The fat tends to be floppy, without compartmentalization. In addition, anatomic variation of the perforators makes the composition of the transplant more variable.21 Depending on a patient's anatomy and a surgeon's chosen approach, the transplant can contain a substantial amount of muscle, or it can contain very small perforators that may not resist saliva or infection in a contaminated wound. These factors make long-term control of the volume of the transplant more variable.

As discussed previously, volume is a critical component of tongue reconstruction, and the anterolateral thigh donor site may lack advantages in this regard. Other donor sites that are more predictable for controlling volume may be a better choice. Future clinical experience and careful research are required. Wei (see Chapter 13) has had tremendous success with the anterolateral thigh donor site, harvesting the transplant as a perforator flap in an Asian population.

The anatomy of the tissue at a donor site is important when positioning a template for harvest. The portion of the tissue that is used to reconstruct the tongue should be thicker, and the portion used to reconstruct the floor of the mouth should be thin-
ner. This means that ideal donor sites consist of thin soft tissue adjacent to thicker soft tissue. This characteristic is important for defect types 1 through 3. For patients with an average BMI, the forearm and lateral arm have this characteristic. For patients with a low BMI, some flap customization may be necessary. The portion that is used to reconstruct the tongue is made thicker by deepithelialization of adjacent tissue, folding this tissue under the tongue portion of the defect, and suturing this tissue in place before inset into the tongue. For very physically fit patients with a low BMI, thicker tissue adjacent to thinner tissue can be difficult to locate. For physically fit men, an alternative is the rectus donor site, in which the periumbilical fat can be used for thicker tissue adjacent to thinner tissue. For physically fit women, the lateral arm is a good source for thicker tissue adjacent to thinner tissue. For patients with type 4 and 5 defects, the thickness of tissue, excluding muscle, must be carefully judged to obliterate the volume of the defect. In general, 2 to 4 cm is an ideal tissue thickness.

The wound healing capability of the recipient site is important to consider when choosing between tissue transplantation and other reconstruction approaches. Radiation and chemotherapy create the most significant adverse effects on wound healing. Previous radiation therapy not only adversely affects wound healing but breaks down the barriers to cancer spread. Postoperative radiation increases scarring and induces xerostomia. Radiation also diminishes the neuromuscular capabilities of the swallowing mechanism and, as a result, any deficiency in the reconstruction makes it more difficult for the patient to develop compensatory strategies. Concomitant chemotherapy makes the long-term side effects of radiation more severe. The effects of radiation are unfortunate; however, radiation therapy improves the survival of our patients and, for the foreseeable future, is an integral modality for the treatment of tongue cancer. It is important to design reconstructive approaches that function well in this environment.

When evaluating a defect that has been or will be irradiated, the goals, principles, and approaches discussed thus far apply. However, the decision-making process should be modified with respect to the reconstructive approach and technique. In general, this results in tissue transplantation being chosen more often, because it brings a new blood supply and nonirradiated tissue, and it restores volume. To compensate for the irradiated wound, the volume of the defect must be substantially overcorrected because of the eventual atrophy of the transplanted tissue. In an irradiated wound, the transplant loses significant volume in the first year, and the loss continues long term. Several mechanisms of volume loss are likely, and overcorrection is the only immediate solution. Cutaneous donor sites lack mucosal covering and have diminished sensation, which do not help solve the problems of xerostomia and radiation-related loss of neuromuscular function. To help ameliorate these problems, it is necessary to work with a multidisciplinary team that includes radiation oncologists specialized in treating the head and neck area. Too often, patients seek “destination”
care for the surgical modality but undergo radiation therapy in centers that lack specialization in head and neck oncology. This can diminish the overall functional outcome. Therefore reconstructive surgeons should discuss these issues with their patients and help them make decisions that will optimize their result. In summary, if a patient has had or will have radiation therapy, tissue transplantation should be the first choice for the reconstructive approach. The volume of the defect should be overcorrected, and radiation oncologists specialized in the head and neck area should be a part of the multidisciplinary team to minimize radiation-related complications.

**Preoperative Management**

Oral cavity cancer should be treated in a multidisciplinary setting. A thorough preoperative evaluation, including endoscopy and radiographic studies, must be performed to assess the extent of the primary tumor and detect the presence of regional or distant metastasis. These findings need to be discussed with a multidisciplinary oncology team. Patients should meet with a speech pathologist before treatment to shape expectations and discuss a rehabilitative plan. Tissue transplantation procedures require preoperative consultation with an anesthesiologist and a thorough evaluation of the cardiopulmonary status. If radiation is part of the treatment plan, a dental assessment is important. Teeth around the resection site should not be pulled until after the reconstruction has healed. Premature dental extraction around the resection site has two important disadvantages: it can result in granulation tissue being confluent with the carcinoma, which makes the resection margin difficult to assess, and it can damage local tissue that is important for optimal tongue reconstruction. Dental extraction around the resection site on the day of extirpation also has two important disadvantages: it can result in open tooth sockets, which extend the wound and make a complication from wound healing more likely, and it can create islands of mucosa between the extraction site and the resection site, which can result in necrosis of the mucosa and a wound-healing complication. The decision to extract teeth adjacent to the resection site needs to be made on a case-by-case basis.

The preoperative workup includes a history of previous treatment to the head and neck and an evaluation of the donor sites. Knowledge of any previous neck and cardiac surgery helps determine the possible sites of vascular access. I use a CT angiogram to assess the recipient vessels when a patient has a history of bilateral neck surgery. In the absence of good recipient vessels in the neck, the right internal mammary artery and vein can be used as recipient vessels. The left internal mammary vessel should not be used, because it is important for cardiac vascular bypass surgery. If a patient has a history of atherosclerotic disease, appropriate consultation with a vascular surgeon is needed to assess potential peripheral, carotid, aortic, and valvular disease. The carotid artery is not recommended for use if it has significant narrowing or a stent, or if the patient has undergone an endarterectomy.
Any head and neck procedure that involves tongue resection requires preoperative imaging. A variety of modalities are available to assess the nodal basins in the neck. The chest has to be imaged to determine the presence of a second primary disease, metastasis, and aspiration pneumonia. For patients with very large or recurrent tumors of the tongue who have hypesthesia of the mandibular nerve and/or suspicious findings from CT scans, an MRI with contrast of the trigeminal nerve is helpful to assess perineural invasion and resectability. An evaluation of the extent of the primary site disease is important, and a preoperative CT scan with contrast is a useful tool. The protocol should be designed to angle around the teeth so that a clear image of the tongue can be captured.

The midline raphe of the tongue, hyoglossus, genioglossus, mandible, palatoglossus, base of the tongue, and mandibular nerve need to be carefully evaluated to help judge the extent of the primary disease site. I have found the assessment of the hyoglossus and midline raphe to be particularly helpful for providing an estimate of the extent of the tongue resection. If a tumor is tracking along the hyoglossus, the volume of the needed resection increases, and a higher-volume reconstruction is required. The hyoglossus can be seen as a narrow line of tissue just lateral to the lingual artery. The lingual artery is an excellent landmark in an axial CT scan with contrast enhancement; it is a bright dot within the substance of the tongue. If the tumor is in contact with the midline raphe of the oral tongue, the likelihood of the tip of the tongue being resected is high, which results in a type 4 defect. If the tumor is in contact with the midline raphe of the oropharyngeal tongue (in combination with oral tongue involvement), then a type 5 defect is more likely.

Prophylactic medications include antibiotic agents, anticoagulants, and beta blockers. A single preoperative dose of an antibiotic followed by three doses postoperatively is appropriate; the regimen needs to cover anaerobes. A patient’s status with respect to methicillin-resistant *Staphylococcus* and other resistant organisms is also important. Almost all head and neck cancer patients are classified as a high risk for deep venous thrombosis (DVT) and should receive two prophylactic measures. Beta blockers are important for reducing the perioperative risk of myocardial infarction in patients with a history of hypertension or cardiovascular disease. Blood testing for thyroid stimulating hormone, hemoglobin, creatinine, liver function, and nutritional status should be obtained before surgery. The recommendations continue to change for the use of antiplatelet agents to maintain patency of intravascular stents. The risk of operative and perioperative bleeding must be balanced with the risk of stent occlusion.
Operative Technique

Defect type 1, the subtotal hemiglossectomy defect, includes less than two thirds of the tongue and cannot include both the right and left sides of the tongue tip (Figs. 30-3 and 30-4). The inset of this template is presented after a detailed discussion of the inset of the rectangle tongue template for defect type 3.

Fig. 30-3  A, The anatomic subsites of a subtotal hemiglossectomy defect in a 51-year-old man. B, A radial forearm transplant was used to reconstruct the right lateral tongue. The donor site was the contralateral forearm, based on the radial artery. Note that the tongue tip has not been resected. The excision did not extend to the midline but did involve the floor of the mouth. This type of defect does not need reconstruction or can be reconstructed with a split-thickness skin graft. I believe that the use of a thin, pliable transplant improves tongue protrusion and elevation. This patient is able to protrude his tongue 2 cm and elevate his tongue 3.8 cm. He was the president of a private manufacturing company and thought that he needed normal tongue function to lead meetings and run his company. He returned to his pretreatment employment and has no limitation of speech or swallowing function.
Fig. 30-4 A rectangle tongue template for a hemiglossectomy defect was designed on the left lateral arm of a 66-year-old patient. He had a low BMI but adequate fat on his lateral arm that could be used to obliterate the oral cavity. The elbow is on the left side of the figure, the shoulder is on the right side, and the biceps is at the top. The template was positioned so that the thicker tissue could be used to reconstruct the tongue, and the thinner skin over the lateral epicondyle would be used to reconstruct the floor of the mouth. The large unlabeled triangle of tissue adjacent to the proximal part of the template was discarded. The tab over the elbow adjacent to the distal part of the template was used to reconstruct the contralateral anterior floor of the mouth.

Fig. 30-3, cont’d  C and D, He demonstrates good tip mobility by contacting the ipsilateral and contralateral oral commissures. This amount of mobility facilitates an oral sweep of the gingival buccal sulcus, which is difficult unless thin pliable soft tissue has been interposed into the defect.
Defect type 2, the hemiglossectomy defect, is the archetypical defect for restoration of the tongue’s finger function while maintaining adequate volume. I use the rectangle tongue template (Fig. 30-5; see also Fig. 30-1, B). The rectangle is sized by measuring the edges of the defect. The length is determined by measuring from the most dorsal and medial aspect of the defect to the tip of the tongue while the tongue is gently placed in tension in the plane of the midline raphe. This forms the long, medial edge of the rectangle, is usually 8 to 9 cm, and is represented by side A in Fig. 30-5, B. The width of the rectangle is determined by measuring from the tongue tip to the most anterior midline portion of the defect while the tongue is gently placed in tension in a superior direction. This forms the shorter, anterior edge of the rectangle, is usually 5 to 6 cm, and is represented by side B in Fig. 30-5, B. The width is verified on the rectangle by measuring from the posterior medial aspect of the defect, over the BOT, through the glossotonsillar sulcus (GTS) onto the lateral-posterior aspect of the defect. This measurement is represented by side C in Fig. 30-5, B, and should be the same width as side B of the rectangle. Finally, the length of the rectangle is verified by measuring from the most posterolateral aspect of the defect, forward along the curvature of the mandible to the anterior midline portion of the defect. This measurement is represented by side D in Fig. 30-5, B, and should be the same length as side A of the rectangle.

Fig. 30-5  A, The anatomic subsites of a total hemiglossectomy defect in a 30-year-old woman.
Fig. 30-5, cont’d  

B, A rectangle tongue template was designed on her right forearm. The top of the figure is the radial side of the forearm, and the lower part of the figure is the ulnar side. The right side of the figure is proximal. The anterior two thirds of the tongue (TON), the posterior one third of the tongue (BOT), the floor of the mouth (FOM), and the ventral tongue (VENT TON) were marked. The crosshatched portion of the template was deepithelialized and sutured on the deep surface of the BOT and TON. The template was positioned on the forearm in a manner that used the thicker brachioradialis fat pad for the tongue portion and the thinner skin over the flexor tendons for the floor of the mouth and the ventral tongue. The line of tension followed the length of the template. 

C, The radial forearm transplant was used to re-create the left hemitongue. Two years postoperatively, tongue protrusion is 1 cm, with some deviation to the left. The native tongue tip is the most anterior part of the reconstruction, and this is the desired result. 

D, Six years postoperatively, the reconstruction obliterates the volume of the oral cavity while she is in repose. E, She is shown elevating her tongue and contacting her premaxilla. Her maximal tongue tip elevation is 1.5 cm.

The template of the rectangle is placed on the donor site. In the forearm donor site, a fat pad overlies the brachioradialis with adjacent, thinner skin of the flexor carpi radialis and palmaris longus tendons (see Fig. 30-5). The line of division between these two different tissue sites is used as the edge of the lateral tongue reconstruction. If more bulk is required for the tongue, additional subcutaneous tissue is harvested adjacent to side A and folded over to bulk up the lateral tongue. If additional volume is required for a large-volume loss deep to the axial plane of the floor of the mouth or
in the area of the body of the mandible, additional subcutaneous tissue is harvested over the brachioradialis pedicle of side C. The forearm can be too thin in patients with a low BMI, and other sites may need to be considered that have thicker tissue adjacent to thinner tissue (Fig. 30-6; see also Fig. 30-4).

Fig. 30-6  A rectangle tongue template for a hemiglossectomy defect is designed on the left lower abdomen on the rectus donor site. This 51-year-old man had a very low BMI and no other donor sites with sufficient subcutaneous tissue. The right side of the figure is cephalad and the left side is caudad. The umbilicus is in the upper part of the figure. The template was positioned so that the thicker tissue adjacent to the periumbilical region would be used for the tongue, and the thinner tissue would be used above the pubis. BOT, Bottom; FOM, floor of the mouth; GTS, glossotonsillar sulcus; RMT, retromolar trigone.

The inset of the flap is performed in a segmental fashion similar to the method that was used to measure the template. The posterior aspect of the flap is tacked in first. This is on side C, at the line of tension, to the most inferior portion of the GTS (see Fig. 30-5, B). The corner between side A and side C is tacked to the dorsum of the tongue at the most posterosuperior aspect of the defect. The tongue is maintained in gentle tension along the midline raphe. Next, the anterior corner between sides A and B is tacked at the tip. At this point it is determined whether the flap is draping properly into the tongue portion of the defect, and adjustments are made. Then, two or three more tacking sutures are placed along the dorsum of the tongue. The line of tension is created from the GTS to the junction between the ventral tongue and anterior floor of the mouth along side B. The line of tension is considered appropriate once the tongue portion of the reconstruction is pushed superiorly into the oral cavity and the dorsum of the tongue is aligned in an axial plane. This step flips up the remaining flap that is to be used to reconstruct the anterior and posterior floor of the mouth along side D. A natural-appearing glossomandibular sulcus is created along
the inner table of the mandible. The closure is completed along sides C, A, and B, and then D. Frequently, the anterior and posterior corners along side A require a small amount of trimming to finesse the final result.

Defect type 3 is an extended hemiglossectomy defect that can include an area that extends posteroorally to the anterior tonsillar pillar/retromolar trigone or an area extending anteroorally to include the contralateral anterior floor of the mouth (see Figs. 30-1, C, and 30-4). Tabs are added to each of these additional subunits and to the previously described rectangle tongue template. The first tab is 2 by 1 cm, located at the corner between C and D, which is oriented at a 45-degree angle and used to resurface the retromolar trigone or the anterior tonsillar pillar. The second tab is 2 by 1 cm and extends parallel to side D by 2 cm and is used to resurface the anterior floor of the mouth. The inset of this template is more difficult than that of the rectangle tongue template. The steps of inset are the same as those outlined for a type 2 defect. For defect type 3 it is more important (and more difficult) to set the line of tension correctly. It can be helpful to inset the tabs after setting the line of tension.

Defect type 1 is a subtotal hemiglossectomy that includes less than two thirds of the tongue and cannot include both the right and left sides of the tongue tip (see Figs. 30-1, A, and 30-3). Conceptually, this template is a part of the rectangle tongue template. I measure for a rectangle tongue template and then reduce the template, based on the areas of the tongue that are remaining. The template is positioned over the donor site in the same manner as the rectangle tongue template, with particular attention to the thin and thick areas of the donor site. If it is difficult to judge the shape of the template, a rectangle tongue template can be harvested, tacked onto the remaining tongue, and trimmed to fit the defect. The objective of this reconstruction is to obliterate the oral cavity, optimize the finger function of the tongue, and maintain the normal anatomic position of the tongue.

Pitfalls of reconstruction for defect types 1 through 3 are: not achieving the anatomic location of the remaining tongue, not reconstructing thin tissue with thin tissue and thick tissue with thick tissue, not taking time to establish the line of tension, not trimming the template for the best fit, not restoring sensation when possible, and not taking into account all the compartments that need volume restoration. An additional tip relates to defects that extend over the alveolus. It is fairly common to find a focal area of disease near or on the alveolus, with a portion of the alveolar subunit resected. In this case, it is best to add a tab onto side D in the appropriate location so that the line of tension is not distorted.

Defect type 4 is the oral glossectomy defect (the entire tip of the tongue and up to half of the base of the tongue) and defect type 5 is the total glossectomy defect (the tongue tip and tongue base defect that precludes primary closure of the tongue base) (see Fig. 30-1, D and E, respectively). The two critical aspects of reconstruction for these defects are management of the base of the tongue and obliteration of the oral
cavity. When managing the tongue base, even if the oropharynx is microstomic, any residual base of the tongue should be closed to the contralateral, lateral pharyngeal wall. The limiting factor for primary closure of the tongue base is long-term obstruction of the airway. An intact tongue base can move the reconstruction (the tongue mound), provide sensation above the airway, and maintain the pharyngeal swallow. If the oral cavity is not obliterated, the patient cannot control secretions, which results in oral pooling, drooling, aspiration, and spitting of oral contents while speaking. Achieving oral cavity obliteration is difficult in defect type 4, and even more difficult in defect type 5. The reconstruction needs to fully contact the pre-maxilla and secondary palate (Figs. 30-7 and 30-8). Several factors make this difficult. The reconstruction is more difficult for patients with a low BMI, because they may have insufficient tissue to restore the volume, and for patients with a high BMI, because it can be difficult to fit the template in the oral cavity. The reconstruction can lose volume if a patient’s BMI drops during radiation therapy, and scarring can make it difficult to restore. The reconstruction can also lose volume if the surrounding tissue is poorly vascularized—it seems that the surrounding tissue can “steal” blood supply and reduce the volume of the reconstruction. The reconstruction can lose volume in the late phases of healing if the pedicle undergoes thrombosis and the transplant maintains its viability through inosculation. These issues make good long-term results more difficult to achieve in patients with type 4 and 5 defects.

Fig. 30-7  A, The anatomic subsites of a subtotal glossectomy defect in a 49-year-old man.
Fig. 30-7, cont’d  B, A D-shaped tongue template was designed on the right lower abdomen on the rectus donor site in the periumbilical region. Thick tissue was required to obliterate the volume of the oral cavity and compensate for volume loss from postoperative radiation therapy. The left side of the figure is cephalad and the right side of the figure is caudad. The umbilicus is at the top of the figure. A primary closure was performed between the left tongue base and the right lateral pharyngeal wall. As a result, the tab that is seen just inferior to the umbilicus was not needed and was removed before inset. C, The tongue mound is shown 6 years after surgery and radiation therapy. The patient is able to move the mound superiorly and inferiorly 5 mm. He can obliterate the volume of his oral cavity and retains premaxillary contact. He is a professional in a large company and has retained his pretreatment employment.

Fig. 30-8  A, The anatomic subsites of a subtotal glossectomy defect in a 45-year-old man.

Continued
Fig. 30-8, cont’d  B, The anterior composite resection is shown with the oral tongue. C, A double rectangle tongue template for an oral glossectomy defect was designed on the inferior abdominal wall and harvested as a transverse rectus abdominis transplant. The umbilicus is at the top of the figure and the pubis is at the bottom of the figure. The anterior two thirds of the tongue (DOR TON), the floor of the mouth (FOM), the ventral tongue (VENT TON), and the mandibular alveolus (ALV) are marked. The superior edge of the transplant was folded and sutured to itself in a sagittal plane. The line of tension was along the floor of the mouth. The alveolar tabs were sutured over the alveolus. This template is for patients with a moderate BMI who have less than 3 cm of subcutaneous fat to improve oral cavity obliteration, palatal contact, and premaxillary contact. D, Tongue retrusion 12 months postoperatively. E, Tongue protrusion. The difference in the tongue mound between retrusion and protrusion is 5 mm. F, The patient has returned to work as an air traffic controller. His speech is understandable to people who do not know him, and he eats a solid, minced diet.
To obliterate the oral cavity in patients with defect types 4 and 5, as much volume as is technically possible should be placed in the oral cavity. To determine if the size of the template is appropriate, it is measured in a sagittal plane, from the back to the front of the defect while following the arch of the palate. In most cases, this measurement is 8 to 10 cm. The next measurement is carried out in a coronal plane from the midbody of the mandible to the contralateral midbody of the mandible while following the arch of the palate. In most cases, this measurement is 10 cm. From these two measurements, a D-shaped template can be fashioned for defect type 4, and a circular template can be designed for defect type 5 (see Fig. 30-7).

The tongue is reconstructed using a technique whereby the travel on each suture on the transplant side is three times that of sutures on the defect side. This results in a pincushion effect, a high mound, and contact with the palate. To support the inset, the rectus fascia is sutured to the mandible to re-create the mylohyoid muscle. This reconstruction has worked well for patients whose BMI is average or above average and who have 4 to 5 cm of fat in the rectus donor site and do not lose weight during treatment. I have also used the lateral arm site in the same patient population with good results, but the lateral arm needs to be a little thicker, and great care must be taken when judging pedicle length and position on the lateral arm. If a patient has a lower BMI, tabs can be added to the circle in positions that resemble ears on a cat. The tabs are sutured together in the anterior midline, and a vertical (sagittal) closure increases the height of the reconstruction anteriorly and improves premaxillary contact.

In patients with a low BMI, a double rectangle tongue can be used to orient the reconstruction in a more sagittal plane to improve premaxillary and palatal contact (see Fig. 30-8). This template is linear and facilitates the use of large, deepithelialized, fold-in tabs to increase the volume of the reconstruction. For defect types 4 and 5, hyoid suspension is an integral part of enhancing airway protection. The hyoid suspension is accomplished with two Gore-tex sutures placed around the hyoid bone and through holes along the inferior edge of the mandible, anterior to the mental foramen. The hyoid is suspended to a distance of 3 cm from the mandible. The suspension changes the anatomy of the pedicle of the transplant, and this should be taken into account before anastomosis.
COMPICATIONS
Dr. Suresh Mukherji once said, “Good judgment comes from experience and experience comes from bad judgment.” Optimization of functional outcome is linked to meticulous preoperative planning, patient education, assessment of the defect type, appropriate donor site selection, careful inset, prevention of complications, and early rehabilitation. The most significant complication of tongue reconstruction is the inability to speak or eat at a functional level. Both activities are needed for employment and social interaction.

Complications that limit the functional outcome are necrosis of the transplant, necrosis of the remaining tongue tissue, fistula, scar, and atrophy. If the transplant appears to have impaired circulation, then early, aggressive salvage is indicated. Necrotic tissues of the oral cavity or the intraoral transplant should be debrided early and aggressively. The wound should be reclosed to minimize salivary contamination of the neck. Fistulas are controlled with irrigation and a neck pressure dressing. The neck incision should not be opened at the bedside, unless it is the most dependent part of the wound and the great vessels are not exposed. Two catheters are inserted through the drain site. Regular irrigation should be instituted until the fistula clears.

If the fistula is too large or if severely contaminated deep tissue needs to be debrided, then the patient should be taken to the operating room for cleaning and wound debridement. The neck should be wrapped and an irrigation regimen started. I do not use packing as a treatment for fistula. Scarring is prevented with early rehabilitation that continues through radiation therapy, until the patient has completed late-stage healing. Atrophy is prevented by careful flap selection, compensation for radiation, good radiation planning, and good nutrition. Oncologic care should effectively treat the disease and return the patient to a functional level that facilitates integration into society. A surgeon who does not focus on small details, performs resections with close margins, and does not commit to the reconstructive effort may present the most dangerous complication to effective care. If a surgeon is not a contributing member of a team who strives for excellence in resection and reconstruction, complications will occur.

OPTIMIZING OUTCOMES (TIPS AND TRICKS)
Patients should know that resection and reconstruction of tongue cancer is a team effort and that they are the most important member of the team. They will need to contribute effort to obtain a good outcome and will need to endure a difficult treatment course. Patient education, the shaping of realistic expectations, and support by the care team are essential for helping patients through their treatment.
Chapter 30  Tongue Reconstruction

The defect volume should be overcorrected, particularly in patients who have undergone or will undergo radiation therapy. The larger the defect, the more important the restoration of adequate volume. The result on the operating table appears bulky; however, the volume of the reconstruction stabilizes in approximately 1 year, at which time the tissue will have evolved into its intended shape.

All of the reconstructive subunits that have been resected must be assessed and accounted for in the template.

Patience is important when insetsing the transplant. It should be draped into the wound, with tacking sutures and trimming to optimize fit and function. Because of the mobility of the tongue and surrounding tissue, it is easy to force a circle into a rectangular hole. However, the tendency to “make it fit” should be resisted, and the goal of the reconstructive process should be functional restoration.

Tongue cancer resection can affect the suspension of the larynx, particularly in defect types 4 and 5. Resuspension of the larynx is important to prevent aspiration.

Residual tongue tissue should be carefully restored to its anatomic position. This tissue is important for mobility and sensation. Careful preservation and reconstruction of residual tongue tissue improves the functional result. Errors can occur when trying to make the residual tissue to do too much and, equally, trying to make the residual tissue do too little.

The administration of antibiotic agents in the perioperative setting is evolving. A short course of prophylactic antibiotics has been shown to have benefit. Further use of antibiotics should be guided by the results of culture and sensitivity assays. The incidences of nosocomial infection, resistant microbes, and invasive fungi are increasing. Care must be taken to treat these complex infections with appropriate prophylaxis rather than contribute to them by overuse of prophylactic antibiotics.

Preoperative and postoperative nutrition is important for promoting wound healing and preventing volume loss. Patients who have a negative caloric balance should establish a positive balance before surgery and maintain it during the postoperative course and throughout radiation therapy. A negative nutritional balance causes the transplant to lose volume, and it is unlikely that the volume loss can be recovered. In addition, the likelihood of a complication is higher with poor nutrition, and if a complication develops, the speech and swallowing outcome will be compromised.
Hematomas are treated aggressively, particularly because they can lead to fistulas. The incidence of hematomas has increased with more aggressive prophylaxis of DVT. The likelihood of hematoma can be reduced by controlling residual bleeding at the end of the procedure, irrigating the neck and the neck drains during closure to prevent accumulation of blood, placing drains in dependent locations, securing drains after vacuum seal has been established, and wrapping the neck in the early postoperative phase. If a hematoma forms in a location where it could lead to a fistula, the patient is taken to the operating room and the wound is drained.

The impact of a fistula can be minimized by placing a drain at the site most likely to result in a fistula. This can result in placement of the drain along a portion of the pedicle. However, the drain should not cross the pedicle. If a fistula results, the oral secretions are directed along the drain to minimize contamination. To treat a fistula, two red rubber catheters are inserted along the drain and used to irrigate the tract three times a day until there is no evidence of saliva. At this point, both drains can be removed over 5 to 10 days.

All patients are educated on the importance of rehabilitation. The speech pathologist becomes involved preoperatively to counsel, create expectations, and emphasize the importance of rehabilitation for the overall outcome.

Early rehabilitation is important to prevent contracture and mobility loss. Passive range of motion is a very important component of the rehabilitation program for this reason.

**Postoperative Management**

Postoperative management includes medications, oral care, nutritional support, transplant monitoring, and rehabilitation. Medications should include antibiotic agents, anticoagulants, and antiemetics. The antibiotic regimen should cover anaerobes. At present, amoxicillin and clavulanate potassium (Augmentin) is the first drug of choice and, if a patient is allergic to penicillin, clindamycin (Cleocin) is the second drug of choice. A single dose is administered 1 hour preoperatively; then every 6 hours until four doses have been administered in the postoperative period. All head and neck cancer patients require anticoagulants to prevent DVT. Because of the length of the operative procedure and the presence of malignancy, these patients are in the high-risk category for the formation of DVT and the complication of pulmonary embolus. As a result, this group requires two prophylactic agents, an anticoagulant such as subcutaneous heparin and an intermittent compression device. Antiemetics are important for preventing damage to the reconstructive site and need
to be used at the first report of nausea. Oral care varies widely among institutions. A clean mouth improves the hygiene of the surgical wound. However, the instrumentation used to keep it clean can cause disruption of the closure line and contribute to a fistula. I use 30 ml of 0.9% NaCl solution mixed with 30 ml of 3% H$_2$O$_2$, administered by a nurse through a red rubber catheter every 8 hours. Patients are also allowed to brush dentition that is not adjacent to the reconstruction with an infant toothbrush and regular toothpaste. Toothette foam brushes are not recommended, because they tend to break down the closure line.

Nutrition should be started on the first postoperative day to prevent resorption of the intestinal microvilli. Trophic feeds should be started at a rate of 25 ml per hour. If a patient tolerates the enteral nutrition for the first 24 hours, then the rate should be increased to a goal amount recommended by a dietitian.

Transplant monitoring is not standardized, and there is wide variation in practice. The options for monitoring are visual examination, Doppler imaging, a pinprick test, and internal oxygen saturation sensors. I use a monitoring regimen that includes physician checks every 4 hours and nursing checks every 1 to 2 hours in the first 48 hours. The technique involves a dermal needlestick with a 30-gauge needle and measurement of the time from the pinprick to evidence of bleeding. If the pedicle of the transplant is not near other vessels that can be erroneously monitored, a Doppler unit is used. An assessment of color and capillary refill is strongly emphasized but is not used as the sole monitoring technique when there is a variation of experience among the clinical staff evaluating the viability of the transplant. Close monitoring is important so that early and aggressive salvage can be instituted if needed. Leech therapy is used for transplants with an unsalvageable venous obstruction.

Rehabilitation is a critical component of treatment that contributes to the success of the reconstruction and the overall psyche of the patient. Speech pathologists work with the patient preoperatively and return to evaluate the patient in the hospital. A regular plan of weekly visits is established. Early mobilization and strengthening of the tongue is emphasized for patients with defect types 1 through 3. Alternative oral diet consistencies and protection of the airway with swallowing are emphasized with defect types 4 and 5. A program that emphasizes consonant production and punctuated speech improves speech intelligibility and, depending on the defect, can take months. A patient's functional status will be reduced if the reconstructive surgeon has a casual approach to the effective integration of speech pathology and/or the speech pathologist lacks training and experience with postsurgical head and neck cancer patients.
CRITICAL POINTS

Must Know
• Oral cavity obliteration is the most important goal of tongue reconstruction. 
• The critical decision point of oral cavity obliteration, tongue tip protrusion, and residual floor-of-the-mouth mucosa is to decide if a transplant is required to optimize oral cavity function.
• The donor site for the transplant is determined based on the defect type, the patient's BMI, and the pattern of fat deposition in the donor site.
• Tongue reconstruction needs excess volume in patients who have undergone or will undergo radiation therapy.
• The members of the multidisciplinary team must provide speech and swallowing rehabilitation, nutritional support, social support, radiation therapy, and chemotherapy.

Should Know
• Surgeons should understand the goals and principles of tongue reconstruction.
• Knowledge of the classification of tongue defects is essential to assess, plan, and perform reconstructive surgery in this area.
• A successful outcome requires an accurate measurement, design, and inset of tongue templates.
• Patients must be prepared and managed appropriately perioperatively to minimize risks and manage complications.
• Prevention of wound problems and meticulous attention to detail help to improve the outcome.
• An important goal of surgery is for patients to return to their pretreatment occupation and socialization, and remain disease free.

Synopsis
• The tongue will heal without major reconstruction. Because of its mobility, durability, and vascularity, it can be sutured to almost any skin graft, rotation flap, or even itself to facilitate healing and prevent complications.
• Reconstructive microsurgery offers more to a patient than successful wound healing. Reconstructive microsurgeons need to assess both the defect and the patient to choose the optimal reconstruction.
• Surgical oncologists must understand that careful resection with finessed reconstruction of the tongue is the future of tongue carcinoma treatment.
• If the surgeon understands the function of the tongue, considering goals and principles when designing the reconstruction can lead to better choices. Template-based reconstruction offers an organized approach that accounts for anatomic subsites and the compartments that were resected.
• Surgeons should understand comorbidities, the wound complexity, and the plan for future treatment to manage the patient in the perioperative period.
• Respect for the critical role the tongue fills in the human experience will reward patients with engaged and socially integrated roles.
Chapter 30  Tongue Reconstruction

References


   The authors compare the abilities of two methods of tongue reconstruction to preserve tongue function. Patients with the free flap had more intelligible speech. The questionnaire study showed no significant difference between the two groups in regard to swallowing. Motility caused by flap pliability increased speech intelligibility more than swallowing function. Their experience in a few selected patients shows that the functional outcome of tongue surgery is related to the reconstruction methods used (for speech) and the extent of tongue resection (for swallowing).


   By combining the principles of nasolabial and buccal mucosal flaps, the authors describe a new axial musculomucosal flap based on the facial artery. This flap is designated the facial artery musculomucosal (FAMM) flap. The flap has proved reliable either superiorly based (retrograde flow) or inferiorly based (antegrade flow). It is versatile and was used 18 times in 15 patients, with no failure and two partial losses. It was used successfully to reconstruct a wide variety of difficult oronasal mucosal defects, including defects of the palate, alveolus, nasal septum, antrum, upper and lower lips, floor of the mouth, and soft palate.


   Using videofluoroscopy, swallowing function was studied in patients who underwent hemiglossectomy with either primary closure of the defect or radial forearm flap reconstruction. Patients with primary closure were unable to lift the tongue tip and had poor tongue-to-palate contact on initiating swallowing, premature spilling of the bolus into the pharynx, a large amount of barium stasis on the floor of the mouth, and prolonged oral transit time. After flap reconstruction, patients could easily lift the tongue and make good contact with the entire palate. Although reconstructed...
flaps are nonfunctional, they provide bulk and help the remaining tongue complete the swallow process. The authors suggest it is better to reconstruct primary defects with a free radial forearm flap when more than 50% of the tongue is resected.


This study was performed to determine if a rectangular template free tissue transfer is effective for the reconstruction of the hemiglossectomy defect. In a total of 13 patients, there were no major complications; 2 patients had minor complications. The average patient resumed intake of a full range of liquids and solids with minimal restrictions and believed that their speech was mostly understandable with occasional repetition. The template-based rectangle tongue flap effectively restored speech and swallowing function in this group of patients. Tongue protrusion greater than 0.8 cm is associated with better swallowing results.


The free anterolateral thigh flap is becoming one of the most preferred options for soft tissue reconstruction. In this large series, consistent anatomy of the main pedicle of the anterolateral thigh flap was observed. In cutaneous and fasciocutaneous flaps, the skin vessels (musculocutaneous perforators or septocutaneous vessels) were found and followed until they reached the main pedicle, regardless of the anatomic position. There were only six cases in this series in which no skin vessels were identified during the harvest of cutaneous or fasciocutaneous anterolateral thigh flaps. In 87.1% of the cutaneous or fasciocutaneous flaps, the skin vessels were found to be musculocutaneous perforators; in 12.9%, they were found as septocutaneous vessels. The anterolateral thigh flap is a reliable flap that supplies a large area of skin. This flap can be harvested whether the skin vessels are septocutaneous or musculocutaneous. It is a versatile soft tissue flap in which thickness and volume can be adjusted for the extent of the defect, and it can replace most soft tissue free flaps in most clinical situations.


Reconstruction of the Hypopharynx and Cervical Esophagus

Peirong Yu, Geoffrey L. Robb

HIGHLIGHTS

- Pharyngoesophageal reconstruction is among the most challenging reconstructions for head and neck defects, particularly in patients who have had surgery and radiation therapy and in those with postlaryngectomy pharyngocutaneous fistulas.
- Partial defects are commonly reconstructed with a fasciocutaneous free flap, whereas circumferential defects can be reconstructed with a fasciocutaneous flap and a jejunal flap.
- Although the jejunal flap provides rapid healing with a low incidence of anastomotic leakage or fistulas, fasciocutaneous flaps provide better speech and swallowing functions with less donor site morbidity.
- Careful planning for complex through-and-through defects and the possible absence of recipient vessels may maximize surgical success.

The pharynx is anatomically divided into the oropharynx, nasopharynx, and hypopharynx. The hypopharynx extends from the level of the hyoid bone to the lower border of the cricoid cartilage, which is congruous with the cervical esophagus below it (Fig. 31-1). This is a critical area that is responsible for airway protection, swallowing, and speech functions.
Pharyngoesophageal defects are most commonly the result of a total laryngopharyngectomy for squamous cell carcinoma in the laryngeal region or hypopharynx (Table 31-1). Radiation therapy has become the primary treatment for early stages of squamous cell carcinoma in these regions. Therefore reconstructive surgeons now face more difficult cases of recurrent cancers that have failed radiation therapy and, in some cases, previous surgery. In our practice, approximately half of such patients have had primary radiation therapy, with or without surgery. These defects are among the most difficult to repair in head and neck reconstruction. Pharyngoesophageal reconstruction now accounts for 15% of all head and neck free flap reconstructions in our institution. The number of cases has not changed much in the past 5 years, averaging 25 cases per year, whereas the numbers of other types of free flap reconstruction have increased significantly. Because of the relatively low case volume, gaining experience with this type of reconstruction outside major medical centers can be difficult. Pharyngoesophageal reconstruction requires great attention to detail. A small mistake can cause progressive problems and eventually lead to difficult complications and poor function.

Fig. 31-1 The hypopharynx is located behind the larynx, in continuity with the oral pharynx superiorly and the cervical esophagus inferiorly. It is arbitrarily divided into three areas to facilitate tumor classification: the pharyngeal wall, the piriform sinuses, and the postcricoid area.
Complication rates with pharyngoesophageal reconstruction can be high and functional outcomes disappointing. Every effort should be made to maximize function, minimize donor site morbidities, and improve aesthetic results. Providing basic tissue coverage without considering the functional, donor site, and aesthetic outcomes is no longer acceptable in current practice. Proper reconstruction of such defects may prevent life-threatening complications, restore essential functions, and improve the quality of life and self-image of patients. In addition to being nonvocal following a total laryngopharyngectomy, patients may depend on tube feeding because of reconstruction complications such as pharyngocutaneous fistulas and anastomotic strictures. Patients and their families should be made fully aware of these functional deficits and the impact they have on the quality of life.

**Table 31-1 Characteristics of Pharyngoesophageal Defects Requiring Reconstruction**

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Defect Location</th>
<th>Type of Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary SCC in the laryngeal region or hypopharynx</td>
<td>Hypopharynx and cervical esophagus</td>
<td>Most commonly partial</td>
</tr>
<tr>
<td>Recurrent SCC in the laryngeal region or hypopharynx</td>
<td>Hypopharynx and cervical esophagus</td>
<td>Most commonly circumferential</td>
</tr>
<tr>
<td>Advanced or recurrent thyroid cancer</td>
<td>Hypopharynx and cervical esophagus</td>
<td>Most commonly circumferential</td>
</tr>
<tr>
<td>Isolated esophageal tumors</td>
<td>Cervical esophagus</td>
<td>Most commonly partial</td>
</tr>
<tr>
<td>Pharyngoesophageal or tracheoesophageal fistulas</td>
<td>Cervical esophagus or hypopharynx</td>
<td>Most commonly partial</td>
</tr>
<tr>
<td>Anastomotic strictures</td>
<td>Cervical esophagus</td>
<td>Most commonly circumferential</td>
</tr>
<tr>
<td>Radiation-induced strictures</td>
<td>Hypopharynx or cervical esophagus</td>
<td>Partial or circumferential, depending on the degree of stricture</td>
</tr>
</tbody>
</table>

*SCC, Squamous cell carcinoma.*
PREOPERATIVE EVALUATION

Surgical History and Radiation Therapy
Patients with recurrent disease after previous surgery and radiation therapy are likely to have a circumferential defect in the cervical esophagus. Knowledge of the type of neck dissection previously performed prepares the reconstructive surgeon for the possible absence of recipient blood vessels. The reelevation of previously operated and irradiated neck skin may cause necrosis of the neck skin flap and create a through-and-through defect.

Donor Site Evaluation
Common donor sites such as the forearm, anterolateral thigh, abdomen, and anterior chest should be evaluated for skin quality and thickness, any history of surgery or trauma, and vascular disease. Previous abdominal surgery, particularly gastrointestinal surgery, and severe comorbidities may preclude the use of the jejunal flap. An Allen test is commonly used to assess the adequacy of hand perfusion through the ulnar artery when reconstruction with a radial forearm flap is planned. A bracelet with the words “NO IV” is placed on the potential donor site arm, which is usually the non-dominant side. Careful planning is essential for successful reconstruction. An alternative reconstructive option (or options) should always be planned for complex cases.

Medical Evaluation
Major head and neck surgery and free flap reconstruction pose significant perioperative risks for patients. A thorough medical evaluation before surgery is required. Pulmonary function should be evaluated in patients with chronic obstructive pulmonary disease, and a cardiovascular workup should be performed as indicated. Many patients with head and neck cancers have a history of tobacco and alcohol abuse. These patients are encouraged at the time of presentation to cease tobacco use and are referred to smoking cessation clinics as needed.

Other Preoperative Evaluations
Patients with a benign stricture or pharyngocutaneous fistula following previous treatment for cancer should undergo imaging studies to rule out local recurrence or distant metastasis before proceeding with reconstructive surgery.
INDICATIONS AND CONTRAINDICATIONS

Indications

- All patients with cancers in the larynx and hypopharynx, or with thyroid cancers involving the larynx and esophagus, who undergo surgical resection with defects beyond primary closure are surgical candidates for reconstruction (Fig. 31-2).
- Patients with benign strictures in the hypopharynx and cervical esophagus caused by radiation, chemical ingestion, and other benign causes are candidates for reconstruction.
- Patients with a pharyngocutaneous fistula following a total laryngectomy with or without reconstruction that is unlikely to heal spontaneously are candidates for reconstruction.
- Patients with isolated cervical esophageal defects caused by tumor resection or trauma require reconstruction, even if the defects are small.

Fig. 31-2  A, A circumferential pharyngoesophageal defect following a total laryngopharyngectomy for squamous cell carcinoma of the larynx. The superior limit is the base of the tongue and the inferior limit is the esophagus, above the sternal notch. The prevertebral fascia is posterior (deep) to the defect. B, A partial pharyngoesophageal defect with a narrow strip of posterior pharyngeal mucosa intact.

Contraindications

The only absolute contraindication is severe comorbid disease in patients who are unable to tolerate a lengthy reconstructive surgery. Patients who become hemodynamically unstable on the operating table and require pharmacologic resuscitation should not undergo free flap reconstruction. In patients with benign strictures or fistulas, the risks and benefits of complex reconstruction should be carefully weighed, and patients and their family members should be well informed.
**Flap Choices**

Currently four flaps are commonly used for pharyngoesophageal reconstruction: the anterolateral thigh (ALT) flap, the jejunal flap, the radial forearm flap, and the pectoralis major myocutaneous flap. The pectoralis flap gained popularity in the early 1980s but is used less frequently now because of advances in free flap reconstruction. The advantages and disadvantages of each flap are listed in Table 31-2.

*Table 31-2  Advantages and Disadvantages of Commonly Used Flaps*

<table>
<thead>
<tr>
<th>Flap</th>
<th>ALT</th>
<th>Jejunum</th>
<th>Radial Forearm</th>
<th>Pectoralis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flap elevation</td>
<td>Moderately difficult</td>
<td>Moderately difficult</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Flap reliability</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Variable</td>
</tr>
<tr>
<td>Flap thickness</td>
<td>Can be too thick</td>
<td>Good</td>
<td>Good</td>
<td>Too thick</td>
</tr>
<tr>
<td>Primary healing</td>
<td>Good</td>
<td>Best</td>
<td>Good</td>
<td>Can be poor</td>
</tr>
<tr>
<td>Donor site morbidity rates</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Recovery time</td>
<td>Quick</td>
<td>Can be slow</td>
<td>Quick</td>
<td>Quick</td>
</tr>
<tr>
<td>Fistula rates</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Stricture rates</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>TEP voice</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Unknown</td>
</tr>
<tr>
<td>Swallowing</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Use for circumferential defects?</td>
<td>Yes</td>
<td>Yes</td>
<td>Second choice</td>
<td>No</td>
</tr>
<tr>
<td>Use for partial defects?</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Contraindications</td>
<td>Obesity (with a very thick thigh)</td>
<td>High-risk disease, severe COPD, prior abdominal surgery</td>
<td>Thin patient with a small arm, radial dominance</td>
<td>Female, obesity, smoking, circumferential defects</td>
</tr>
</tbody>
</table>

*ALT*, Anterolateral thigh flap; *COPD*, chronic obstructive pulmonary disease; *TEP*, tracheoesophageal puncture.
In the past, circumferential pharyngoesophageal defects were most commonly reconstructed with a free jejunal flap, and partial defects were reconstructed with a radial forearm flap. The ALT flap was first used for pharyngoesophageal reconstruction at our institution in early 2002, quickly gaining popularity and largely replacing the jejunal and radial forearm flaps. If the ALT flap is not an option because perforators are not available, the jejunal flap is the next choice for the repair of circumferential defects in otherwise healthy patients with low surgical risk. The radial forearm flap is the next choice in patients with a history of abdominal/gastrointestinal surgeries or a partial defect and in those who are obese or have a high surgical risk because of significant comorbid conditions.

The pectoralis major flap is generally reserved for partial defects in male patients, salvage after failed free flap reconstruction, or very high-risk patients. In my experience (P.Y.) with 70 pharyngoesophageal reconstructions in the past 5 years, the ALT flap was used in all but three patients. One patient had no perforators in either thigh, and a jejunal flap was used. The other two patients were morbidly obese, and reconstruction was performed with a radial forearm flap.

If a patient is not considered a good candidate for reconstruction or does not wish to go through another major surgery after a failed reconstruction, a spit fistula is created in the upper neck for drainage, the cervical esophagus is closed, the neck defect is covered with a pectoralis major muscle flap, and a permanent feeding gastrostomy or jejunostomy tube is placed.

TECHNIQUE

ALT THIGH FLAP

Flap Design and Harvesting

The right thigh is the preferred donor site of ALT flaps for right-handed surgeons, because it allows easier dissection of the vascular pedicle. However, either thigh can be used regardless of the type of defect. During surgery the leg should be in a neutral position, without rotations. When a patient is under general anesthesia, the leg has a natural tendency to rotate outward. Therefore before preparing and draping a patient, attention should be paid to avoiding this rotation, because it may cause misplacement of perforator locations and ultimately failure to capture the cutaneous perforators. An easy way to keep the legs from rotating outward is to wrap each foot with a towel and clip the towels together.
Once a patient’s legs are in the correct position, the anterior superior iliac spine (ASIS) and the superolateral corner of the patella are marked, and a straight line (the A-P line) is drawn connecting the two landmarks (Fig. 31-3).1 The midpoint of the A-P line is marked. One to three usable cutaneous perforators are usually available in the ALT flap territory. These are marked A, B, and C. The middle perforator, perforator B, is located an average of 1.4 cm lateral to the midpoint of the A-P line.2 Perforator A is located approximately 5 cm proximal to perforator B, and perforator C is 5 cm distal to perforator B. The flap design is centered on the presumed location of perforator B. Doppler examination can be used to help locate the cutaneous perforators. However, the accuracy is only fair. The false-positive rate can be high, and more than 25% of the Doppler signals are more than 10 mm away from the actual location of the cutaneous perforator. The accuracy is particularly poor in obese patients.

The flap elevation is performed simultaneously with tumor ablation using a two-team approach. For circumferential defects, a flap 9.4 cm wide is used to construct a tubed neopharynx with a 3 cm diameter (3 × π), which is slightly larger than the native cervical esophagus.1 For partial defects, the width of the flap is calculated by subtracting the width of the remaining pharyngeal mucosa from 9.4 cm. The flap design is tentatively centered on the presumed location of perforator B. A straight anterior incision approximately 15 cm long is made across all three cutaneous perforators down to the fascia. This incision corresponds to the anterior midline of the thigh in most cases. Including a wider area of fascia is desirable for second-layer closure during flap insetting, therefore the fascial incision is made 1 to 2 cm more medial than the anterior skin incision. Subfascial dissection proceeds laterally until the
cutaneous perforators are identified. The exact locations of the perforators are marked on the skin surface with a 5-0 polypropylene suture. The flap is recentered if necessary, based on the actual perforator locations. To accommodate the wide opening in the base of the tongue for the proximal anastomosis, an extended lip of skin is designed at the proximal end of the flap so that an elongated oblique opening can be created when the flap is tubed (Fig. 31-4). Dissection of the perforators and the main pedicle can be performed through the anterior incision. The rest of the flap is incised only after the cutaneous perforators and the main vascular pedicle are located or dissected out. Two cutaneous perforators are included whenever possible so that the flap can be divided into two skin paddles (Fig. 31-5).

Fig. 31-4  The flap is rolled into the shape of a tube, and a larger, oblique opening at its proximal end is formed by including the extended portion of the flap (P).

Fig. 31-5  The flap is divided into two skin paddles based on separate cutaneous perforators, A and C. The forceps indicates the location of the division line.
The proximal paddle is usually based on perforator A or B and used for reconstruction of the pharyngoesophageal defect; the distal paddle is usually based on perforator C and used for flap monitoring or anterior neck and tracheal reconstruction\(^3,4\) (Fig. 31-6). If only one perforator is present and an anterior neck defect needs to be reconstructed, a segment of the superficial half of the vastus lateralis muscle is included in the ALT flap to support skin grafts that resurface the neck, eliminating the need for a second flap.\(^5\) This layer of muscle is usually no more than 1 cm thick and is typically a better option than a pectoralis major muscle flap (Fig. 31-7).

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**Fig. 31-6**  A, The second skin paddle, based on perforator C, can be used for neck resurfacing. B, The second skin paddle is based on perforator C. C, Using two skin paddles obviates the need for a second flap and adds minimal bulk in the neck to avoid obstructing the tracheostoma. D, Alternatively, the second skin island can be used for posterior tracheal wall reconstruction or solely as a monitoring segment, which is removed before patients are discharged from the hospital. E, The healed flap with hair growth.
Fig. 31-7  When only one perforator is present, the superficial half of the vastus lateralis muscle is included to support skin grafts. A, The descending branch travels alongside the medial edge of the vastus lateralis muscle. B, The superficial half of the muscle is separated from the deep half, immediately below the muscular branches. C, A thin and broad muscle is obtained to cover the neck defect. D, Skin grafting provides additional coverage. E, Such a thin muscle produces minimal bulk to avoid obstructing the tracheostoma.
**Flap Insetting**

The flap can be thinned as needed by direct excision of subcutaneous fat at the periphery of the flap. Ample subcutaneous tissue is left around the cutaneous perforators, and 2 to 3 mm of subcutaneous tissue is left on the dermis to protect the subdermal plexus (Fig. 31-8). The proximal anastomosis between the flap and the base of tongue is performed first, using 3-0 polyglactin interrupted sutures, with the longitudinal seam oriented posterolaterally at the 4 or 8 o’clock position. The anastomosis starts with two corner sutures at the 3 and 9 o’clock positions. The posterior wall is completed first, and the anterior wall second. Large bites are recommended with inversion of the skin and mucosal edges into the lumen. Care should be taken to avoid catching the hypoglossal nerve when suturing the flap to the base of the tongue. The longitudinal seam is completed toward the distal end of the flap. For partial defects, the proximal end of the flap is sewn to the base of the tongue and the lateral edges to the remaining posterior pharyngeal wall mucosa (Fig. 31-9).

![Image](image-url)

**Fig. 31-8** Thinning of the ALT flap. A, The flap is thicker proximally. B, After entering the flap, the cutaneous perforator gives off several branches to the fascia, subcutaneous tissue, and subdermal plexus. Flap thinning can be performed by direct excision of the subcutaneous fat away from the main perforator and the subdermal plexus (dotted lines). The fascia can be left intact if needed.
Fig. 31-9  A-C, For partial pharyngoesophageal defects, the flap is sewn to the lateral edges of the posterior pharyngeal mucosa. D, The fascia of the flap and a small segment of the vastus lateralis muscle can be used to cover the reconstruction.

Fig. 31-8, cont’d  C and D, Several millimeters of subcutaneous tissue are left below the dermis to protect the subdermal plexus.
A Montgomery salivary bypass tube with a diameter of 14 mm is placed inside the tubed flap during circumferential reconstruction in selected patients. The indications for using the Montgomery tube include a thick flap, difficult flap insetting, a very low location of the transected cervical esophageal end, a small cervical esophagus, and poor tissue quality after radiation injury. The placement of the bypass tube may help reduce the incidence of fistula formation and possibly stricture formation in this group of high-risk patients. The tube is inserted through the mouth before the longitudinal seam of the flap is completed (Fig. 31-10). The proximal flange of the bypass tube is placed above the proximal anastomosis and the distal end is placed in the esophagus, below the distal anastomosis. A no. 1 polypropylene suture is attached to the flange of the tube, brought out through the mouth, and taped to the cheek to prevent distal migration and facilitate easy removal of the tube. If a feeding tube has not been placed, a Dobbhoff feeding tube is placed through the nose, the flap, or inside the Montgomery salivary bypass tube, and the cervical esophagus to the stomach.

The neck is repositioned from a hyperextended to a neutral position by removing the shoulder roll. It is not necessary to flex the neck. The anterior wall of the cervical esophagus is split longitudinally for approximately 1.5 cm to accommodate a triangular lip created on the flap. This spatulation is important to enlarge the distal anas-

Fig. 31-10  A Montgomery salivary bypass tube with a diameter of 14 mm can be used to temporarily stent the neopharynx for 2 to 6 weeks.
tomosis and minimize the risk of ring stricture (Fig. 31-11). The tubed flap is slightly twisted so that the longitudinal seam at the distal anastomosis is facing posteriorly at the 6 o’clock position. This positioning of the tubed flap places the perforator vessels anteriorly between the 11 and 1 o’clock positions to avoid compression of the perforators against the prevertebral fascia. If necessary, the width of the flap is tapered to match the size of the cervical esophagus for the distal anastomosis. The flap is pulled straight to avoid redundancy but should not be stretched, which is commonly done with the jejunal flap, and anastomotic tension should be avoided. After completion of the distal anastomosis, the fascia of the flap is used to cover the suture lines\(^3\) (Fig. 31-12).

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**Fig. 31-11**  
A, The distal anastomosis is spatulated to minimize ring strictures. A triangular lip is created on the flap (D). B, The anterior cervical esophagus is incised longitudinally for approximately 1.5 cm. The flap is tubed, and the triangular lip of the flap (D) will fit into the spatulated cervical esophagus.

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**Fig. 31-12**  
A, A wider fascia is designed to cover the suture lines as a second layer after flap insetting. B, The perforator vessels are positioned anteriorly to avoid compression against the prevertebral fascia.
The neck wound is irrigated with ample warm normal saline solution (2 to 3 L), taking care not to squirt the saline directly on the vascular pedicle to avoid vessel spasm. Meticulous hemostasis is essential to avoiding a postoperative hematoma, which can compress the vascular pedicle. All areas should be carefully examined, even if they have already been examined by the ablative surgeons. A 15 Fr Blake drain is placed on each side of the neck, lateral to the internal jugular vein. The shoulder roll is removed, the neck is slightly flexed, and the vascular pedicle is examined again. Because the neck is usually hyperextended during surgery, flexing the neck to a normal position can significantly change the position of the vascular pedicle, causing kinking or compression. The pedicle is repositioned as needed to avoid these problems.

The second skin paddle is turned outward to resurface the neck for flap monitoring or used to reconstruct the trachea or any neck skin defects (see Fig. 31-6). Externalizing a portion of the distal flap by deepithelializing a strip of skin around the distal anastomosis is not recommended, because it results in a high fistula rate. To monitor a buried flap without an external skin island, an implantable Doppler probe can be secured to the vein and carefully fixed to the neck skin. Alternatively, a handheld Doppler device can be used to monitor the perforator or the main vascular pedicle through the neck skin. Neither method is very reliable, however. The implantable Doppler probe has a high false-positive rate, because any movement of the neck, including coughing, can potentially dislodge the probe and result in an unnecessary surgical exploration. Also, tiny blood clots can lodge between the Doppler probe and the vessel wall, causing the disappearance of the Doppler signal. The handheld Doppler unit usually detects only the arterial signal, resulting in delayed exploration in the event of the more common venous failure. It is still possible to detect a Doppler signal with both devices when the flap has a venous thrombosis. Externalizing a small skin island based on a second cutaneous perforator is thus strongly recommended. If neck skin coverage is not needed, this second skin island can be brought out through the neck incision for monitoring purposes only (see Fig. 31-6, D) and removed 5 to 7 days later, before patients are discharged from the hospital.

At the time of neck closure, the tracheostoma is sutured to the surrounding neck and anterior chest skin, and a size 8 Shiley tracheostomy tube is placed in the tracheostoma and secured to the chest skin. In patients with a short and thick neck, the superior flange of the Shiley tube is trimmed to avoid compressing the neck skin and underlying flap. Skin necrosis and even fistulas can result from this compression.

**Recipient Vessel Choices**

Branches of the external carotid artery and internal jugular vein are commonly used as recipient vessels if they are readily available (Fig. 31-13). However, using the transverse cervical vessels, which are discussed in the following section, may avoid difficult and risky dissection around the carotid artery in patients with severe neck fibrosis after previous surgery or radiation therapy.
Postoperative Management

After reconstructive surgery, patients are usually sedated and cared for in the surgical intensive care unit overnight. They are placed on a ventilator and weaned off the next morning. If patients are stable on the afternoon of the first postoperative day, they are transferred to a floor dedicated to monitoring patients after flap surgery. Healthier patients may be awakened at the end of surgery if it is still early in the afternoon. Delirium tremens prophylaxis should be given to patients who are known to be chronic alcohol users, which is common among patients with head and neck cancers. In patients with a history of alcohol abuse and narcotic dependence, postoperative confusion and agitation are common and may cause hypertension, hematoma, anastomotic breakdowns, and avulsion of the vascular pedicle. Therefore prompt management of these issues with the critical care and neuropsychiatric staff is important.

Routine prophylaxis for deep venous thrombosis starts in the operating room with stockings and sequential compression devices. Pharmacologic prophylaxis should be considered in high-risk patients. Most commonly, subcutaneous injections of heparin or low-molecular-weight heparin are used. Anticoagulation after free flap reconstruction is not routinely performed. In patients with postoperative vascular thrombosis requiring thrombectomy and difficult revisions of vascular anastomosis, an intravenous heparin bolus of 2500 to 3000 units is usually given intraoperatively when the patient is taken back to surgery, followed by a low-dose heparin infusion, usually 500 units per hour for 3 days, and then aspirin 325 mg per day for 1 week.
Tube feeding begins on postoperative day 1. Ambulation usually starts on postoperative day 2. The administration of broad-spectrum antibiotic agents is usually continued for 3 days or longer as indicated. The flap is checked hourly for 2 days. In most cases, this can be reduced to every 2 hours for 2 days thereafter and then every 4 hours until patients are discharged.

A modified barium swallow (MBS) study is performed by a speech pathologist 2 or 6 weeks after reconstruction in patients without or with a history of radiation therapy, respectively, to evaluate swallowing function and to determine whether leaks are present. The MBS study is delayed because of the risk of late fistula formation with the use of a fasciocutaneous flap for pharyngoesophageal reconstruction. If used with the reconstruction, the Montgomery salivary bypass tube is removed before the MBS study. In patients with no evidence of leaks or fistulas, a liquid diet is started and quickly advanced to a soft or regular diet as tolerated. In patients with a leak or fistula, oral intake is withheld, tube feeding is continued, and an MBS study is repeated in 2 weeks or later as clinically indicated. Most leaks heal spontaneously within 2 weeks.

Outcomes and Complications
In my experience (P.Y.) with 65 consecutive ALT flaps used for pharyngoesophageal reconstruction, the mean length of hospital stay was 8 days. More than 90% of the patients tolerated an oral diet without the need for tube feeding. Fluent tracheoesophageal speech was achieved in one third of the patients with a primary tracheoesophageal puncture (TEP) and in 80% of the patients with a secondary TEP.

Pharyngocutaneous Fistula
In this same series, pharyngocutaneous fistulas occurred in 6% of patients. Fistula rates were similar in partial and circumferential reconstructions. Proximal fistulas are rare with the ALT flap. It is speculated that the longitudinal seam of a tubed fasciocutaneous flap or two longitudinal suture lines in a partial defect may have contributed to a higher incidence of fistula formation with the radial forearm flap. However, in my experience (P.Y.), the fistula rate with the ALT flap is no higher than with the jejunal flap, and no fistulas have occurred through the longitudinal suture lines. Fistulas usually develop 1 to 4 weeks postoperatively and manifest as leakage of saliva or liquids and in some patients as a neck infection. Therefore any neck infection or abscess that occurs after a pharyngoesophageal reconstruction should raise suspicion for anastomotic leakage. Risk factors for fistula formation include improper suturing techniques, poor tissue quality at the anastomosis site, previous radiation therapy, and a turbulent postoperative course (that is, excessive coughing, vomiting, or neck mobility). At the time of surgery, any questionable tissue in the proximal pharynx and cervical esophagus should be trimmed until only well-vascularized tissue is seen.
We use single-layer, simple interrupted 3-0 polyglactin sutures for flap insetting, taking relatively big bites, inverting the skin/mucosa edges into the lumen, spacing sutures 5 mm apart, and avoiding excessively tight knots.

Once a fistula is identified, oral intake is withheld and local wound care is initiated. Small fistulas, in the absence of tumor recurrence or distal obstruction, usually heal spontaneously within 2 weeks with conservative management. Therefore an MBS is repeated 2 weeks later if the leakage has stopped. Larger fistulas and those with infection should be evaluated using CT to rule out an abscess and to assess the proximity of the fistula/abscess to the carotid artery. Any dead space or abscess around the carotid artery, especially in patients who have undergone previous radiation therapy or chemoradiation therapy, should be thoroughly but carefully debrided without jeopardizing the carotid artery and obliterated with a muscle flap such as a pectoralis major muscle flap. This should be done as soon as possible to reduce the risk of carotid artery rupture. Attempting to repair the leak or dehiscence at this stage is not generally successful and may cause more tissue damage. The muscle flap is usually adequate to obliterate the fistula tract and remucosalizes quickly. It is extremely important not to delay the debridement when an infection/abscess is identified. Early intervention may achieve rapid healing and prevent life-threatening complications.

With proper management, as described previously, persistent fistulas are rare. However, patients with a persistent fistula should be evaluated for possible tumor recurrence and distal obstruction/stricture. Longstanding fistulas eventually cause stricture because of scar tissue formation, which in turn results in nonhealing of the fistula. In these cases, reconstruction with a radial forearm flap may be indicated in select patients who are in good general health and have a good prognosis.

**Anastomotic Strictures**

With the ALT flap, anastomotic strictures rarely occur at the proximal anastomosis site, unless the flap was compromised at the time of reconstruction. Distal anastomotic strictures usually occur several months or years after reconstruction. Spatulation and the use of the Montgomery bypass tube may reduce the risk of stricture formation. In our experience, strictures are only seen with circumferential defect repair. Therefore removing the strip of remaining posterior pharyngeal mucosa and thereby converting a noncircumferential defect into a circumferential one, which was commonly done with the jejunal flap, should be avoided. As mentioned previously, the additional longitudinal suture lines do not seem to contribute to fistula formation.

If a patient develops dysphagia several months after reconstruction, anastomotic strictures should be suspected and an MBS study performed to confirm the diagnosis. In the past, surgical dilation with patients under general anesthesia was per-
formed to repair anastomotic strictures, and serious complications such as esophageal perforation occurred. In the past several years, endoscopic balloon dilation has become the preferred treatment. This is usually performed by a gastroenterologist. Repeated dilations may be required in some patients. In refractory cases, surgical repair can be achieved with a radial forearm free flap.

Medical Complications
The most common medical complications are respiratory and cardiac problems. These include pneumonia, respiratory failure, arrhythmia, myocardial infarction, and congestive heart failure. Therefore multidisciplinary care of high-risk patients in the immediate postoperative period is essential to prevent and treat life-threatening complications.

Radial Forearm Free Flap
The radial forearm flap is our second choice for primary pharyngoesophageal reconstruction after a laryngopharyngectomy. It is used in obese patients whose ALT flap is too thick. However, it is the first choice for treating pharyngocutaneous fistulas and strictures following a previous free flap reconstruction (ALT or jejunum), because a very thin flap is preferred.

Flap Design
The design of the radial forearm flap is similar to that of the ALT flap. The flap can be designed with an extended lip in the proximal forearm to accommodate the larger opening in the base of the tongue, as with the ALT flap. The circumference of the distal forearm at the wrist crease is 15 to 16 cm in average patients. For circumferential defects, the required flap width of 9.4 cm would require the removal of nearly two thirds of the forearm skin, creating an unsightly donor site scar. Pharyngoesophageal defects are usually no longer than 10 cm. In shorter defects, the flap can be rotated 90 degrees from the conventional design orientation on the forearm to minimize donor site morbidity. For instance, for a circumferential defect 6 cm long, the radial forearm flap would be 6 cm wide (lateral to medial) and 9.4 cm long (proximal to distal). When the flap is tubed, it is rolled from distal to proximal instead of from lateral to medial (Fig. 31-14). Defects caused by persistent fistulas and strictures after free flap reconstruction are usually only 3 or 4 cm long but are most likely circumferential. A radial forearm flap rotated 90 degrees only needs to be 3 or 4 cm wide, significantly decreasing donor site morbidity.
Flap Harvesting

The radial forearm flap elevation is well described in the literature, with the following modifications. In most cases, the venae comitantes of the radial forearm flap are adequate for venous drainage, without including the cephalic vein. However, the venae comitantes can be extremely small and inadequate in some patients. Therefore our approach is to tentatively outline the flap, centering it on the radial vessels, and make a small transverse incision at the wrist crease to explore the venae comitantes first (Fig. 31-15). If one of these veins is at least 1 mm in diameter, the cephalic vein is not used. Otherwise, the flap design is shifted laterally to capture the cephalic vein. Suprafascial dissection is preferred, and flap elevation is performed with a tourniquet in place. The venae comitantes are usually 1.5 mm or smaller before they converge; therefore the vein is usually taken above the convergence of the venae comitantes, where the diameter is greater than 2.5 mm in most cases. Once the flap and vascular pedicle are completely dissected, the tourniquet is released to perfuse the flap and hand for several minutes before dividing the pedicle.

Fig. 31-15 A small exploratory incision is made at the wrist crease to confirm the size of the venae comitantes of the radial forearm flap vascular pedicle. If both venae comitantes are less than 1 mm in diameter, the flap design is shifted laterally to include the cephalic vein.
A second skin island can also be fashioned with the radial forearm flap and externalized to resurface small neck skin defects (Fig. 31-16).

Flap insetting and postoperative care are similar to those performed with the ALT flap. The radial forearm flap has a reputation of having high fistula rates, up to 50%, and delayed fistulas. Some of these reports were from the 1980s and early 1990s and are likely the result of a learning curve. More recent reports have shown that the fistula rates are similar to those of the jejunal flap. A fasciocutaneous flap may not heal as quickly as a jejunal flap once it is immersed in saliva 24 hours a day. This may explain the high incidence of delayed fistula formation. If an oral diet is started early (for example, 7 days after surgery as with the jejunal flap), fistulas are likely to develop with the unhealed radial forearm flap. As with the ALT flap, we routinely delay oral intake for 2 weeks in nonirradiated patients and for 4 to 6 weeks in patients who have undergone radiation therapy.
JEJUNAL FLAP

Flap Harvesting

Through an upper midline abdominal incision, the mesenteric arcade of the proximal jejunum is examined with fiberoptic backlighting to transilluminate the mesentery (Fig. 31-17). The jejunal segment, usually based on the second mesenteric arcade vessels from the ligament of Treitz, is chosen. Surgical dissection begins with isolation of the mesenteric branch vessels to their origins at the superior mesenteric artery and vein. The mesentery between the adjacent arcade vessels is divided to the serosal border. The desired jejunal segment, usually about 15 to 20 cm long, is divided using a linear cutting stapler. The proximal end of the jejunal segment is marked with a serosal suture to maintain an isoperistaltic orientation during flap insetting. Once the recipient site is ready, the mesenteric vessels are ligated and divided. The jejunal flap is removed and placed on a side table, and its lumen is flushed with cold normal saline solution until clear.

Fig. 31-17 During jejunal flap harvesting, the mesenteric arcades of the jejunal flap are transilluminated with fiberoptic backlighting to facilitate vessel dissection. A short bowel segment (M) based on one or two terminal branch vessels are to be externalized and used for flap monitoring.

Flap Insetting

Because of the size discrepancy between the jejunum and the proximal pharyngeal defect, an incision 2 cm or longer is made in the proximal end of the jejunum, along the antimesenteric border. The proximal anastomosis is performed using interrupted 3-0 polyglactin sutures before revascularizing the flap. Some surgeons prefer a second-layer Lembert serosal closure. The hypoglossal nerve must be avoided at the base of the tongue during the second-layer closure.
Microvascular anastomoses are performed. To avoid jejunal redundancy and elongation over time, which may cause dysphagia, the anastomoses are performed with a patient’s neck in a neutral position. The jejunal flap is slightly stretched in a caudal direction while the flap for the distal anastomosis is marked (Fig. 31-18).\textsuperscript{13,14} The cervical esophagus is opened longitudinally to spatulate the distal anastomosis, as described previously with the ALT flap. The distal anastomosis is performed using a single layer of interrupted 3-0 absorbable sutures.

![Fig. 31-18](image)

\textbf{Fig. 31-18} During jejunal flap insetting, the flap is slightly stretched in a caudal direction to reduce redundancy.

A monitor segment 3 to 4 cm long is created from the remaining jejunum based on branches of the pedicle vessels (Fig. 31-19). The monitor segment is brought out through the lateral neck incision to avoid obstruction of the tracheostoma and is covered with petroleum jelly–impregnated gauze (Xeroform) to prevent desiccation. Both ends of the bowel segment are left open to avoid distention. The monitor segment can also be completely open longitudinally. A 2-0 silk suture may be placed around the segment’s small vascular pedicle at the skin level so that the pedicle can be easily tied when it is time to remove the monitor segment. In the mean time, jejunal continuity is reestablished, a feeding jejunostomy tube and a gastrostomy tube are inserted, and the abdomen is closed.
Postoperative Management

Postoperative care is similar to that following reconstruction with an ALT flap, with some exceptions. The gastric tube is kept on low suction, and jejunal tube feeding begins once active bowel sounds return. Food is administered through the gastrostomy tube using gravity, and the tube is clamped once bowel function returns fully and output is diminished. Some patients develop ileus, which can last for several days. It is important to monitor their gastrointestinal function carefully to avoid frequent vomiting, because this may disrupt the jejunopharyngeal anastomosis.

The monitor segment is usually removed before a patient is discharged from the hospital. An MBS is performed on postoperative day 7 in patients without previous radiation therapy or on day 14 in patients with previous radiation therapy (Fig. 31-20). A clear liquid diet is initiated and advanced as tolerated if no leakage or fistula is detected.

Fig. 31-19 A short bowel segment is created and externalized as a monitoring segment, which is removed before patients are discharged from the hospital.

Fig. 31-20 A modified barium swallow study performed 7 days after jejunal flap reconstruction shows a patent neopharynx.
Outcomes and Complications

In a recent study, we reported an average hospital stay of 13 days and an average intensive care unit stay of 3 days. The incidence of ileus and bowel obstruction was 9%, abdominal hernia 6%, and anastomatic stricture 19%. The incidence of pharyngocutaneous fistulas has decreased from 19% to 10%. The fistula rate was even lower (only 3%) when “inexperienced surgeons” were excluded from the series, suggesting the importance of meticulous attention to technical details in such complex reconstructions. Unlike results with the ALT flap, approximately half of the fistulas occur at the proximal anastomosis, possibly because of slight stretching of the thin walls of the jejunal flap during flap insetting.

Overall, 65% of patients tolerated an oral diet without supplemental tube feeding, and 23% were partially and 12% were totally tube-feeding dependent. Fluent tracheoesophageal speech was achieved in 22% of patients who received a TEP. The quality of tracheoesophageal speech following jejunal flap reconstruction is usually characterized as “wet” compared with that following a fasciocutaneous flap reconstruction or a total laryngectomy without reconstruction.

VOICE REHABILITATION

TEP is the preferred method of voice rehabilitation. It is commonly used after a total laryngectomy without flap reconstruction. However, an increasing number of patients who undergo a flap reconstruction are rehabilitated with TEP, which can be performed at the time of surgery (primary TEP) or several months after surgery with use of endoscopy (secondary TEP). Because of the higher failure rate of primary TEP with ALT and jejunal flaps, we now prefer secondary TEP, which is usually performed 4 or 5 months after reconstruction in patients without complications.

TEP is performed by puncturing the common wall between the esophagus and trachea 1.5 to 2 cm below the rim of the tracheostoma. In patients with a very low resection of the cervical esophagus below the tracheostoma, the puncture needs to go through the flap and the posterior tracheal wall, which is slightly more difficult to do. Initially, a 14 Fr red rubber catheter is inserted through the trachea to the esophagus and secured in place. The catheter is replaced with a voice prosthesis 2 to 4 weeks later by speech pathologists (see Fig. 31-6, C). Patients are followed up regularly by speech pathologists. Complications include a widened puncture site with leakage around the voice prosthesis, frequent mucus plugs inside the prosthesis, and fungal infections. Our experience suggests that TEP success rates and the resulting voice quality are significantly better with a fasciocutaneous flap than with a jejunal flap. Because of mucus production, frequent redundancy, and softness of the bowel wall that prevents adequate vibration, the speech of patients with a jejunal flap is often wet and labored. Speech rehabilitation requires patient motivation and commitment. Careful patient selection is therefore important.
MANAGING A FROZEN NECK DURING PHARYNGOESOPHAGEAL RECONSTRUCTION

A so-called frozen neck, usually defined as severe fibrosis in the neck without tissue planes, is the result of neck surgery such as neck dissection, combined with radiation therapy. Longstanding pharyngocutaneous fistulas usually result in the worst cases of frozen neck. Three major problems are associated with managing a frozen neck during reconstruction: (1) the risk of carotid artery rupture, (2) the absence of recipient vessels, and (3) concomitant neck skin or tracheal defects.

In a frozen neck, the carotid artery and internal jugular vein are usually encased in fibrotic tissue. Surgical dissection around these great vessels during fistula and scar tissue excision and preparation for recipient vessels can easily cause these previously damaged vessels to rupture, resulting in high rates of morbidity and mortality. The best approach to avoiding carotid artery rupture is to simply stay away from it. Our preference is to use the transverse cervical vessels as recipient vessels (Fig. 31-21). In this way, surgical dissection around the carotid artery and internal jugular vein can be avoided altogether if it is not required for oncologic reasons.

Fig. 31-21  A, This patient had a postlaryngectomy fistula and a frozen neck. B, The scar tissue was excised without exposing major vessels. The transverse cervical vessels were located lateral to the sternocleidomastoid muscle and immediately above the clavicle. C, An oblique incision is usually made toward the midclavicle area. D, A multiisland ALT flap was used to reconstruct the complex defect.
I (P.Y.) have previously shown that the transverse cervical vessels are available in 92% of patients and are very similar in size to those of the flap vascular pedicle. The supraclavicular area/posterior triangle is usually spared during modern neck dissections and is infrequently heavily irradiated. Therefore exposure of the transverse cervical vessels in the supraclavicular area lateral to the sternocleidomastoid muscle is possible with little risk. On the left side of the neck, particular attention should be paid to avoiding injury to the thoracic duct. Dissection should start high, above the supraclavicular fat pad, and proceed deep to it. The external jugular vein usually joins the transverse cervical vein before entering the subclavian vein. This part of the external jugular vein is more deeply located and of good quality. If both veins are unavailable, as in patients who have undergone a radical neck dissection, the internal jugular vein stump immediately above the subclavian vein is usually long enough for an end-to-side anastomosis.

The use of the transverse cervical vessels solves the first two problems associated with a frozen neck. Successful management of the third problem, concomitant neck skin or tracheal defects, is also possible. Elevating an anterior neck skin flap from a previously operated and irradiated area often causes skin necrosis. Releasing the neck contracture and removing the scar tissue creates a larger neck skin defect. Therefore a second flap is usually required to reconstruct the external defect when the jejunal flap or radial forearm flap is used for pharyngoesophageal reconstruction further complicating an already difficult case. The pedicled pectoralis major myocutaneous flap is probably the most frequently used flap for this purpose. The main disadvantage of this flap is its bulk; even when the muscle alone is used, it often produces contour deformity in the neck and sometimes causes obstruction of the tracheostoma. Donor site morbidity with the pectoralis major flap is particularly undesirable in women. Although the deltopectoral flap is thinner, its use is limited by the need for skin grafting to the donor site, the unreliability of the distal portion of the flap, and sometimes the need for flap delay.

The ALT flap provides simultaneous pharyngoesophageal reconstruction, neck resurfacing, and tracheostoma reconstruction. Seventy-eight percent of patients have more than one cutaneous perforator in the flap. Therefore the ALT flap can be divided into two independent skin islands based on separate perforators. One skin island is used for pharyngoesophageal reconstruction and the other for neck resurfacing. If only one cutaneous perforator is present, various amounts of vastus lateralis muscle can be included in the flap to support skin grafting to resurface the neck. A thin, broad muscle is desirable for neck resurfacing to avoid bulkiness. The vastus lateralis muscle can be safely split into halves, with only the superficial half harvested to obtain a thin, broad flap (see Fig. 31-7). The thickness of the superficial half of the muscle flap is usually 1 cm or less. The descending branch of the lateral circumflex femoral artery usually travels within the muscle, and the surgical plane of dissection is immediately deep to the descending branch, splitting the muscle. When only a small amount of muscle is needed, a cuff of muscle around a muscular branch from
the main descending branch is taken. The muscle portion of the ALT flap can be separated from the fasciocutaneous portion with only the cutaneous perforator attached, providing more flexibility in flap insetting.

In summary, the use of the transverse cervical vessels and multi-island ALT flap can convert an extremely difficult case with a frozen neck into a relatively straightforward one, reducing surgical risks and donor site morbidities and improving a patient’s quality of life.

**RECONSTRUCTION OF POSTLARYNGECTOMY PHARYNGOCUTANEOUS FISTULAS**

Since radiation therapy became the primary treatment for early stages of laryngeal and hypopharyngeal cancers, physicians have faced a new problem in these patients: higher rates of pharyngocutaneous fistulas after salvage total laryngectomies for recurrent cancers. Local and regional recurrences following radiation therapy for laryngeal and hypopharyngeal cancers can exceed 30%, depending on the tumor location and initial tumor stage. Although the overall incidence of postlaryngectomy pharyngocutaneous fistulas has decreased significantly in the past decade, it remains very high in previously irradiated patients. McCombe and Jones reported that the incidence increased from 4% to 39% when radiation was included in multimodal therapy.

Once fistulas develop, the radiation effects are compounded by salivary contamination of the neck, leading to chronic inflammation and hypoxia of the neck skin and vasculature, which places a patient at risk for loss of neck skin and the remaining pharynx, tracheostoma compromise, and even carotid artery rupture. Longstanding fistulas inevitably promote scar formation, leading to pharyngeal stricture. These more severe cases create a very difficult challenge for even the most experienced reconstructive surgeons. Conservative management is usually ineffective, and outcomes with local and regional flaps are often disappointing. Therefore many of these patients do not undergo reconstruction.

Recent studies have shown that the mean overall survival of patients after salvage total laryngectomy was 7.2 years. The mean 2-, 5-, and 10-year overall survival rates were around 70%, 55%, and 40%, respectively. These data demonstrate that this patient population still has a reasonable survival expectation. Therefore every effort should be made to restore functions and improve the quality of life for these patients. Major postoperative morbidities and death are mainly related to cardiopulmonary and cerebrovascular accidents, including carotid artery rupture. The goals of surgical reconstruction should be to minimize surgical morbidity and mortality and provide reliable reconstruction that achieves primary healing and a reasonable appearance and restores swallowing and speech functions.
Because all patients who have undergone total laryngectomy have also had radiation therapy, a frozen neck is always present (see Fig. 31-21, A). Therefore the strategies for reconstruction are the same as those for managing a frozen neck. During surgery, the fistula tract and scar tissues are excised, without exposing the great vessels in the neck if they are cancer free (see Fig. 31-21, B). All patients have various degrees of pharyngeal stricture, particularly those who have a longstanding fistula. The hypopharynx is opened superiorly to the base of the tongue, where the pharyngeal inlet is incised laterally and widened to approximately two to three fingers wide. This is important, because primary closure of the pharynx after a total laryngectomy inevitably narrows the pharyngeal inlet. In patients with a relatively normal pharynx and cervical esophagus and no complications, a small degree of narrowing may not cause dysphagia. After pharyngoesophageal reconstruction, however, food transit through the reconstructed conduit is compromised no matter what type of flap is used. Any narrowing in the pharyngeal inlet or weakness of the base of the tongue further compounds the problem and causes dysphagia. Inferiorly, the posterior wall of the tracheostoma is carefully separated from the cervical esophagus just far enough, usually 1 cm, for the flap-esophageal anastomosis. Minimal dissection should be performed to avoid compromising the blood supply to the remaining cervical esophagus and tracheal stoma. Meticulous tissue-handling techniques must be exercised in such difficult cases with no room for error. Once the pharyngoesophageal defect is re-created, the transverse cervical vessels are explored and a multiisland ALT flap is used to reconstruct the defects, as described previously (see Fig. 31-21, C and D).

Using this approach in nine consecutive cases of postlaryngectomy fistulas in the past 4 years, we achieved 100% primary wound healing without the recurrence of fistulas and with minimal donor site morbidity and excellent functional outcomes. The average intensive care unit stay was 1 night and the average hospital stay was 7 days (range 4 to 10 days). All patients achieved 100% oral intake without the need for tube feeding. Eight patients resumed a regular diet that included fish and chicken but no tough meat, and one patient was limited to a pureed diet because of extensive resection of the base of the tongue. No patients had developed pharyngoesophageal strictures at a mean follow-up of 28 months (range 11 to 48 months). All five patients with a secondary TEP or existing TEP achieved fluent and loud speech. One patient with a primary TEP did not achieve fluent speech because of poor phonation. Because of noncompliance or neck lymphedema, the other three patients were considered poor candidates for TEP.

In this series, the first five patients were managed in a conservative fashion for more than 5 months. During that time period, more scarring and fibrosis developed, worsening the frozen neck and causing severe strictures of the pharynx and cervical esophagus. At the time of surgery, three of the five patients had complete fibrosis and obstruction of the pharynx, resulting in a circumferential defect. The other two patients had near-circumferential defects, with only a 1 cm wide portion of the posterior pharyngeal wall intact. Therefore the last four patients in this series were managed more aggressively. Reconstructive surgery was performed shortly after the development of the fistula (as early as 3 days later if scheduling allowed), before severe
fibrosis set in. Surgical dissection in the neck was therefore much easier than in patients with a longstanding fistula, and the resulting defects in the pharynx and cervical esophagus were smaller. Although the tissues were still somewhat edematous, anastomoses could be safely and reliably completed with proper tissue-handling techniques.

Thorough debridement of infected and necrotic tissues and aggressive irrigation of the neck wound are critical in the reconstruction of defects caused by postlaryngectomy fistulas. The use of various amounts of the well-vascularized vastus lateralis muscle to repair neck defects in these cases might have helped to achieve primary healing. Because of the absence of well-vascularized neck tissue in this patient population, large pharyngocutaneous fistulas, unlike intraoral fistulas, do not respond to conservative management. Therefore early surgical intervention to reconstruct the neck in these patients once large fistulas develop is strongly recommended.

**ISOLATED CERVICAL ESOPHAGEAL DEFECTS WITH AN INTACT LARYNX**

The vast majority of tumors arising in the cervical esophagus are malignant, and laryngectomy is required to achieve tumor-free margins and to prevent aspiration when the cricopharyngeus muscle is resected.\(^{33}\) For benign tumors such as schwannomas and granular cell tumors, smaller margins are acceptable, but resection of a portion of the cricopharyngeus muscle increases the risk of reflux and aspiration. Therefore the reconstruction of isolated cervical esophageal defects can be challenging. With an intact larynx and trachea, exposure of the cervical esophagus is limited, making reconstruction technically difficult. Given the small space around the esophagus, a free tissue transfer offers the best flexibility for insetting the flap; a thin flap is required for the same reason. The radial forearm flap is therefore our flap of choice for partial and circumferential defects. These defects are usually only a few centimeters long, thus the radial forearm flap can be oriented 90 degrees to the conventional flap design so that the width of the flap becomes the length of the neoesophagus. The longitudinal length of the flap is rolled along the vascular pedicle to form a tube (see Fig. 31-14).

Because defects of the cervical esophagus are usually located lower in the neck, the external carotid artery is often not exposed. Either the transverse cervical artery or the superior thyroid artery can be used as the recipient artery. The transverse cervical vein and the internal jugular vein are the common recipient veins. The vascular pedicle is often longer than needed and should be carefully looped to avoid kinking or twisting.

Postoperative care is similar to that following reconstruction for laryngopharyngectomy defects. Oral intake is withheld for 2 weeks, at which time an MBS study is performed to evaluate swallowing function and to rule out aspiration and leakage. Slight leakage through the anastomosis usually heals spontaneously within 2 weeks.
CRITICAL POINTS

Must Know

- Complex pharyngoesophageal reconstruction requires a well-thought-out surgical plan and surgical precision.
- Medical complications often delay patient recovery, discharge, and ultimately affect the outcome. A thorough medical workup with optimization of cardiopulmonary functions and meticulous perioperative care may prevent life-threatening complications.
- Spatulation of the flap-esophageal anastomosis, meticulous tissue handling and suturing techniques, and avoidance of anastomotic tension may minimize surgical complications.
- A careful inspection of the vascular pedicle before closing the neck skin may prevent many microsurgical failures, because mechanical obstruction is the most common cause of venous failure.
- The use of transverse cervical vessels and a multiisland ALT flap may prevent carotid artery blowout and significantly simplify reconstruction in patients with a frozen neck.
- Early surgical intervention and free flap reconstruction (within 4 weeks) for large postlaryngectomy pharyngocutaneous fistulas, before a frozen neck sets in, may greatly reduce surgical difficulties, achieve high functional outcome, and prevent life-threatening complications.
- Early recognition and surgical intervention for neck wound infection may achieve primary healing without delaying crucial adjuvant therapy.
- TEP is the preferred method for voice rehabilitation. Secondary TEP has a much higher success rate than primary TEP.

Should Know

- In patients who undergo pharyngoesophageal reconstruction, complication rates can be higher than in the general population of reconstructive patients.
- It is no longer acceptable to provide necessary tissue coverage and ignore the importance of functional, donor site, and aesthetic outcomes.

Synopsis

- The reconstruction of pharyngoesophageal defects is among the most critical of head and neck procedures because of the necessity of airway, feeding, and speech functions.
- The pharyngoesophageal area is one of the most challenging to reconstruct, because these patients often present after failed primary treatments (that is, radiation therapy or previous surgery) and the recurrence of disease.
- In choosing among the options for pharyngoesophageal reconstruction, surgeons must evaluate each patient and custom-tailor treatments to maximize clinical and functional outcomes.

The authors evaluated outcomes following pharyngoesophageal reconstruction with the ALT flap in 41 consecutive patients. Total flap loss occurred in one patient, and one patient had partial flap necrosis because of an ischemic bowel and sepsis. Fluent speech was achieved in all 13 patients who had successful tracheoesophageal prosthesis placement. Among the 34 patients available for diet assessment, two patients (6%) required partial tube feeding because of extensive tongue resection; all other patients tolerated a regular diet (88%) or a pureed diet (6%). The authors conclude that the ALT flap offers comparable complication rates, superior speech and swallowing functions, minimal donor site morbidity, a quick recovery, and a short hospital stay.


The reconstruction of combined pharyngoesophageal, tracheal, and anterior neck defects is challenging and usually requires two flaps, which is sometimes accompanied by significant morbidity. Between March 2002 and February 2004, 18 consecutive patients with combined defects of the pharynx and cervical esophagus, trachea, and/or anterior neck skin underwent reconstruction with a single ALT flap. All patients had complete healing of reconstruction of their anterior neck and tracheal defects with good aesthetic results and only minor complications. The author concludes that complex neck reconstruction can be accomplished with a single ALT flap with good clinical and functional results, minimal morbidity, and a quick recovery.


The authors discuss hypopharyngeal and cervical esophageal defects and various flaps used to treat these challenging problems, including the free jejunal flap, radial forearm flap, gastric pull-up, and pectoralis flap. Reconstruction can offer most patients successful swallowing while minimizing complications.


A major challenge in head and neck reconstruction in patients with a frozen neck is the limited availability of recipient vessels, including the carotid artery system. The aim of this study was to investigate the suitability of the transverse cervical vessels as recipient vessels for free flap reconstruction in head and neck cancer patients. Thirty-three sides of necks in 26 patients requiring free flap reconstruction were explored. The transverse cervical vessels were suitable as recipient vessels in 92% of patients and should be the first choice in difficult head and neck reconstructions.


CHAPTER 32

Voice
Reconstruction

Hung-Chi Chen, Hasu D.L. Patel

HIGHLIGHTS

- Esophageal and laryngeal defects can be reconstructed with conventional and microsurgical techniques. Conventional methods use pedicled tissue transposition and artificial material. With the advances of microsurgery, free tissue transfer has become widely accepted when it is necessary or when it provides better results.

- Pharyngolaryngectomy defects following tumor resection or severe corrosive injury pose a complex challenge. Several techniques are available for reconstruction. Many factors should be taken into account, such as survival prognosis, which may determine reconstruction of the swallowing function with or without a prosthesis, or the complex autologous reconstruction of swallowing and voice function.

- Techniques for reconstructing the pharynx and larynx include:
  1. A free jejunal flap transfer for esophageal defects to restore swallowing function, with the use of prostheses for voice restoration,
  2. A jejunal flap alone for the esophageal defect and autologous voice (two segments of jejunum based on the same vascular pedicle),
  3. Our preferred technique of a free ileocolic flap for both,
  4. The appendix for reconstruction of the voice only, and
  5. Skin flaps for esophageal reconstruction and a voice prosthesis for voice restoration.

- Among the various techniques for esophageal and voice reconstruction, microsurgical procedures offer an excellent choice. For replacement of the upper alimentary tract, the intestine is clearly the best substitute. With the advances of reconstructive surgery, voice reconstruction should always be considered for patients undergoing laryngectomy or pharyngolaryngectomy.
Esophageal and voice reconstruction may be needed to treat patients with tumors, corrosive injuries, and congenital diseases. Esophageal reconstruction is required to restore gastrointestinal function. Restoration of voice function is one of the most challenging goals of reconstruction.

In 1502, Leonardo Da Vinci, in his drawing of the tongue, lip, and trachea, marvelled at the ability of the voice box to produce a range of sounds. He began: “Though human ingenuity by various inventions and with different instruments yields the same ends, it will never devise an invention more beautiful, ready, or shorter than does nature, because in her inventions nothing is lacking and nothing is superfluous.”

Before discussing the various options available for voice reconstruction, it is essential to understand the basic concepts related to these forms of reconstruction, which include psychological aspects of voice loss, the anatomy of phonation, and the principles behind reconstructing the voice box.

**Psychological Impact of Voice Loss**

The psychological impact of laryngectomy on a patient’s quality of life is quite significant. Patients are already trying to come to terms with the diagnosis of cancer and the reconstruction. The functional change and social stigma may cause intense distress, leading to depression, low self-esteem, and withdrawal from social interactions, with significant impairment in their quality of life. Early results of prospective psychological studies on the impact of voice loss are currently being conducted in our unit.

Typically, in daily life, patients need to talk to family members, friends, and strangers. Ease of communication is proportional to the familiarity of the relationship, so that communication with strangers is the most difficult and stressful. When their language is intelligible to everyone, including strangers, patients have the least frustration and depression. They feel the most frustration if their ability to communicate is impaired so that even their family members do not understand them. Patients stay at home if only their family members can understand them, or they may go out to meet friends who can communicate with them (Table 32-1).
It is our opinion that voice reconstruction with bowel transfer will become more and more popular in the future, because several factors have extended the life expectancy for patients with cancer, including earlier detection, improved adjuvant therapy, and improved postoperative intensive care. Therefore, with longer life expectancy, more patients will consider voice reconstruction as a priority and may favor autologous reconstruction over a prosthesis.

**Table 32-1  A General Classification of Voice Function**

<table>
<thead>
<tr>
<th>Intelligibility</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understood by everyone</td>
<td>Excellent</td>
</tr>
<tr>
<td>Understood by friends</td>
<td>Good</td>
</tr>
<tr>
<td>Understood by close family only</td>
<td>Fair</td>
</tr>
<tr>
<td>Not understood by anyone</td>
<td>Poor</td>
</tr>
</tbody>
</table>

It is essential to know the normal anatomy of the larynx, pharynx, and upper esophagus before attempting reconstructive surgery in this area of the body.

Voice originates in the larynx and is modulated by the controlled movement of vocal folds, which in turn are manipulated by delicate muscular movements. This sound is converted to speech by the actions of the tongue, lips, palate, pharynx, and other related structures. The larynx is a highly specialized organ between the laryngopharynx and the trachea. Although it is an essential part of the air passage and acts as a valve for preventing swallowed food and foreign bodies from entering the lower respiratory tract, it is also particularly suited for phonation.

**Phonation** is defined as the utterance of sounds with the aid of the vocal folds. Through movements of its cartilages, the larynx varies the opening of the vocal folds, thereby varying the pitch of sounds produced by the passage of air through them. These sounds are translated into intelligible speech by articulatory and resonating structures such as the tongue and the mouth. The vibrating vocal cord is the major
source of periodic sound for phonation. When initiating phonation, the vocal folds must be approximated to the midline to start vibration. Vocal fold vibration is multidirectional and intricate, and the aerodynamic-myoelastic theory has been proposed to explain voice production. To reconstruct voice using autologous tissue, this intricate mechanism must be understood.

**SURGICAL OPTIONS**

Microsurgical free tissue transfer is a safe procedure that has a high success rate when performed by experienced surgeons. Over the last 35 years, it has undergone many improvements. The problem of flap survival has been overcome, and now an emphasis is placed on good functional outcome, positive aesthetic results, and minimal donor site morbidity.

In the past, the benchmark for reconstruction following total pharyngolaryngectomy was the use of free skin flaps for esophageal reconstruction and a prosthesis for voice reconstruction. This technique presented two major categories of complications.\(^1\,^2\) First, the complications associated with the long-term use of a voice prosthesis included tissue maceration resulting in dilation of the tracheoesophageal (TE) fistula and aspiration. With time, the fistula could become so enlarged that it required closure. Second, the presence of a long suture line along the skin flap resulted in a higher chance of leakage in the immediate postoperative period.\(^3\) Other problems included fungal growth, stenosis of the tracheostoma, and esophageal perforation.

The selection of procedures for esophageal reconstruction depends on the location (that is, cervical esophagus or whole esophagus), the length of the defect, the patient’s age and associated comorbid medical problems, and the long-term survival prognosis.

Reconstruction of the cervical esophagus and pharynx can safely be carried out using jejunum\(^4\,^7\) or colon to provide good swallowing function and simultaneous voice reconstruction. Total pharyngolaryngectomy reconstructive options for deglutition and voice need to be carefully assessed in a holistic manner, taking into account all the pertinent factors and needs.
Several options are available for simultaneous reconstruction of the esophagus and restoration of voice function (Table 32-2):

- The traditional fasciocutaneous skin flap, such as the radial forearm flap, anterior lateral thigh (ALT) perforator flap, or tensor fascia lata flap, and a voice prosthesis. This method has been in use for many years and is suitable for patients with a shorter life expectancy. Autologous tissue for voice reconstruction is preferable and prevents complications associated with a voice prosthesis.
- A free jejunal flap for the esophagus and a voice prosthesis
- A free or pedicled colon flap for the esophagus and a voice prosthesis
- A jejunal flap for esophageal reconstruction, with a second segment of jejunum for voice reconstruction based on the same vascular pedicle
- The transfer of a segment of ileocolon for esophageal reconstruction and voice production, with the aid of the ileocecal valve
- A complex reconstruction based on a segment of bowel for esophageal reconstruction and appendix for voice restoration

<table>
<thead>
<tr>
<th>Table 32-2 Decision-Making in Reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruction of Swallowing Only</td>
</tr>
<tr>
<td>Indications</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Preferred organs</td>
</tr>
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</tbody>
</table>

*Pedicled colon or stomach is favored over jejunum with distal revascularization.
These operative techniques are described here in detail. The advantages and disadvantages are summarized in Table 32-3.

### Table 32-3  Advantages and Disadvantages of Common Techniques for Esophageal and Voice Reconstruction

<table>
<thead>
<tr>
<th>Skin Flap and Prosthesis</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Radial forearm flap and prosthesis | Tolerates long ischemia time  
No need for laparotomy  
Does not need a specialist in bowel transfer  
Better voice quality than jejunum with prosthesis  
More resistant to radiation therapy | Sacrifices a main artery supplying the hand  
Donor site is obvious with skin graft  
Higher rate of leakage than with intestinal flap  
Higher stenosis and stricture rates  
No autologous secretions; therefore occasional swallowing difficulty  
Skin flap undergoes nerve regeneration; therefore discomfort occurs with salty and spicy food  
Hair growth |  |
| ALT and prosthesis | Same as above, but donor site is hidden | Same as above, but anatomy of the ALT flap is less constant, and the flap is thicker than the radial forearm flap |  |
| Jejunum and prosthesis | Lower leakage rate  
Lower stricture rate  
Good swallowing with secretions and motility | Needs a laparotomy, which has associated complications  
Voice quality not as good as with a skin flap with prosthesis  
Develops redundancy; may even develop intussusception  
Less resistant to radiation therapy than a skin flap in some cases  
Initial dysphasia because of uncoordinated activity between the cervical and thoracic esophagus (The jejunum tries to digest food with constricted movement, whereas the esophagus acts to propel food through.) |  |
| Two segments of jejunum for the esophagus and voice | Same as jejunum and prosthesis | Same as jejunum and prosthesis  
Leakage rate is higher than jejunum and prosthesis because of more anastomoses  
Wet voice, worse than jejunum with prosthesis  
Higher aspiration rate than with ileocolon flap |  |
| Ileocolon for the esophagus and voice | Spontaneous, watery secretions  
Direction of peristalsis not important  
Nonmechanical voice, loud  
Wide anastomosis with pharynx  
Not hair bearing  
Built-in valve  
No aspiration | Laparotomy and its complications  
Temporary diarrhea from removal of ileocecal valve  
Atherosclerosis is more common in the elderly  
Stricture at the junction of the colon and thoracic esophagus because of leakage from mismatch (rare) |  |
| Appendix for voice only | Less donor site morbidity  
Small incision in harvesting  
No regurgitation of food | Voice is not loud because of shorter length, therefore limited turbulence  
Narrowing at the junction of the trachea and appendix  
Microsurgery is difficult because of the small vessels  
Still needs a minilaparotomy with possible associated complications |  |

ALT, Anterolateral thigh.
INDICATIONS AND CONTRAINDICATIONS FOR VOICE RECONSTRUCTION

Indications for Voice Reconstruction

- Cancer: laryngectomy or pharyngolaryngectomy
- Corrosive injury to the larynx and esophagus

In patients with corrosive injury, the damage to the upper alimentary tract is usually more severe than that of the larynx because of the reflex protection from closure of the epiglottis. There are two possibilities after these injuries: (1) In most cases, the voice function can be restored to maintain airway patency. (2) In severe cases in which the larynx is completely destroyed, the methods of voice reconstruction are the same as those for patients with cancer.

The following classification system is helpful in selecting the appropriate reconstructive approach (Table 32-4).

<table>
<thead>
<tr>
<th>Tissue Used</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only esophageal reconstruction and postoperative use of artificial larynx, external device, or esophageal voice for restoration of voice function</td>
<td>Senile patients, medical problems, patients with a short life expectancy</td>
</tr>
<tr>
<td>Skin flaps</td>
<td>Patients with risk of laparotomy</td>
</tr>
<tr>
<td>- Forearm flap or ALT flap for esophagus + voice prosthesis</td>
<td></td>
</tr>
<tr>
<td>- PM flap for esophagus + voice prosthesis</td>
<td></td>
</tr>
<tr>
<td>- Forearm flap for both esophagus and voice—result not good (abandoned now)</td>
<td></td>
</tr>
<tr>
<td>Intestinal flaps</td>
<td>Patients without risk of laparotomy and with a long life expectancy</td>
</tr>
<tr>
<td>- Jejunum for esophagus and voice</td>
<td></td>
</tr>
<tr>
<td>- Jejunum for esophagus + voice prosthesis</td>
<td></td>
</tr>
<tr>
<td>- Ileocolon for esophagus and voice</td>
<td></td>
</tr>
<tr>
<td>- Appendix for voice reconstruction</td>
<td></td>
</tr>
<tr>
<td>- Free appendix</td>
<td></td>
</tr>
<tr>
<td>- Pedicled ileocolon flap for reconstruction of the entire esophagus with appendix for voice</td>
<td></td>
</tr>
<tr>
<td>Laryngeal transplantation</td>
<td>Special conditions, patients agree with long-term use of immunosuppression</td>
</tr>
</tbody>
</table>

ALT, Anterolateral thigh; PM, pectoralis major musculocutaneous.
Contraindications of Autogenous Tissue for Voice Reconstruction

The use of autogenous tissue for voice reconstruction is contraindicated in elderly patients and in patients with severe medical problems, distant metastasis, or specific contraindications for intestinal flaps (such as a previous history of intestinal resection). For these patients, some forms of voice rehabilitation using an electrolarynx or external device can still be provided.

Preoperative Management

In addition to obtaining a detailed history and performing a thorough physical examination, the following items are important:

- Previous operations, especially laparotomies, should be reviewed.
- During the physical examination, abdominal scars or indurated skin of the neck should be given close attention, because they may have been caused by radiation therapy.
- Laboratory data to obtain:
  - Radiographs: esophagram, cervical spine
  - CT/MRI to determine the extent of cancer (or recurrent cancer), metastasis to lymph nodes in the neck, and distant metastasis.
  - Basic liver and kidney functions (bilirubin, glutamyl oxaloacetic transaminase [GOT], glutamyl pyruvic transaminase [GPT], albumin, prothrombin time [PT], activated partial thromboplastin time [aPTT], blood sugar, blood urea nitrogen [BUN], and creatinine)
  - Thyroid and parathyroid functions (serum triiodothyronine [T3], serum thyroxine [T4], thyroid stimulating hormone [TSH], calcium, and phosphorus)
  - Bone scan (especially of the cervical spine)
  - Endoscopy (pharynx, larynx, esophagus, and stomach)
  - Abdominal echography (any liver metastasis)
- Preparations to make before surgery:
  - Correction of nutritional status
  - Antibiotic agents for oral ulcer with infection
  - Care of teeth (dental care)
  - Colon preparation if ileocolon flap is planned
VOICE RECONSTRUCTION

Methods used for voice reconstruction can be either surgical or nonsurgical.\textsuperscript{12} The nonsurgical methods involve the electrolarynx, pneumatic artificial device, and esophageal speech. However, we focus here on the surgical approaches (Box 32-1).

**Box 32-1  Surgical Options**

<table>
<thead>
<tr>
<th>Surgery for Laryngeal Reconstruction Alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Voice prosthesis</td>
</tr>
<tr>
<td>• Transfer of ileocecal valve with a patch of cecum and a segment of ileum</td>
</tr>
<tr>
<td>• Appendix</td>
</tr>
<tr>
<td>• Laryngeal transplantation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surgery for Simultaneous Reconstruction of Pharyngoesophagus and Voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Free skin flap (ALT or radial forearm flap) or jejunum plus prosthesis</td>
</tr>
<tr>
<td>• Ileocolon for esophagus and voice tube</td>
</tr>
<tr>
<td>• Free jejunum (J1-J2) for esophagus and voice tube</td>
</tr>
</tbody>
</table>

**Operative Approaches**

Operative approaches include tracheoesophageal puncture and prosthesis; tracheoneoesophageal puncture and prosthesis in patients with a neoesophagus, which is created using a free fasciocutaneous flap or jejunum; or autologous voice reconstruction using a free ileocolon flap or two segments of jejunum based on a single vascular pedicle.
VOICE TUBE ANATOMY AND RECONSTRUCTION

The voice tube is an air shunt between the trachea and the esophagus, pharynx, neoesophagus, or neopharynx. It consists of a segment of bowel or a tubed fasciocutaneous flap (Fig. 32-1) and has three basic components:

1. The junction between the trachea and voice tube serves as an inlet for air into the voice tube.
2. The voice tube body transfers air from the trachea to the esophagus.
3. The junction between the voice tube and esophagus allows one-way air flow into the esophagus, using a valvelike mechanism that prevents food from entering the voice tube.

The voice tube can be created using jejunum or ileum (or a skin flap, which we no longer use because this method has many disadvantages). The upper end of the voice tube is inserted into the esophagus or neoesophagus. The lower end of the voice tube is attached in an end-to-end fashion to the tracheal stump or by an end-to-side anastomosis to the tracheal stump at the lateral wall of the trachea, about 1 cm distal to the tracheostoma.

Fig. 32-1  A skin flap is used for reconstruction of the esophagus and voice tube. This method is rarely used. E, Esophagus; S, skin flap; T, tracheostoma.
Free Jejunum Transfer for Simultaneous Reconstruction of Esophagus and Voice Tube

The free jejunum flap has become a standard technique for esophageal reconstruction following pharyngolaryngectomy. We describe a technique whereby a segment of the jejunum is divided into two parts based on the same vascular pedicle and used to reconstruct the esophageal defect and autologous voice\(^\text{13}\) (Fig. 32-2). A segment of the jejunum is harvested from the abdomen, starting 30 cm distal to the ligament of Treitz. After microvascular transfer onto a good recipient artery and vein, it is divided into two parts based on the same vascular pedicle. The first part is placed in an isoperistaltic direction and is used for reconstruction of the esophagus. The second part is fabricated into a voice tube that provides a conduit for air transfer between the airway and neoesophagus. This part also provides an antireflux mechanism to prevent food from entering the airway.

Fig. 32-2  A jejunum flap for reconstruction of the esophagus, with a second jejunal loop for the voice tube. \(E\), Esophagus; \(J_1\), jejunal flap for esophageal reconstruction; \(J_2\), jejunal flap for reconstruction of the voice tube; \(T\), tracheostoma.
During speech, the patient needs to occlude the tracheostoma so that air is driven from the lung through the voice tube into the pharynx and the mouth, where articulation is performed to form proper speech. This technique yields excellent swallowing function, and good but wet voice production. Because there is no inherent valve in this method, food regurgitation into the airway may occur occasionally, especially with a liquid diet. It can cause aspiration in some patients. Therefore the overall result is suboptimal. The aspirated material can be coughed out, because the trachea can induce a cough reflux. However, the risk of aspiration still exists. Therefore patients need to be educated to consume semisolid food. When they drink water, they should drink slowly.

**Simultaneous Reconstruction of Esophagus and Voice Using the Ileocolon Flap**

The ileocolon region provides ideal tissue for esophageal and voice reconstruction. The ileocolon flap is supplied by the ileocolic artery (a branch of the superior mesenteric artery), and venous drainage is through a concomitant vein. Fig. 32-3 shows the anatomy of the ileocolic flap and the ileocecal valve. The ileocecal valve is the key to the success of this technique of reconstructing defects after total pharyngolaryngectomy. The ileocecal valve should be plicated both internally and externally during surgery. The internal plication makes the valve smaller (0.5 cm), and the external plication creates a sharper angle of the voice tube in relation to the cervical esophagus to further prevent reflux of liquid or food. The ascending colon is used to reconstruct the esophagus and ileum to create a voice tube. The flap is inset so that the ileocecal valve provides a mechanism to allow one-way shunting of air from the trachea to the neoesophagus, while preventing regurgitation of food and liquid into the ileum and subsequently the trachea.

The colon part of the ileocolon flap can be inset in one of two directions, as either isoperistaltic colon (see Fig. 32-3) or antiperistaltic colon (Fig. 32-4). The decision of which direction to use is based on the size and level of the esophageal defect, the length of the recipient vessels and flap pedicle and their location, and the desired length of the voice tube. A shorter voice tube is generally more desirable, provided its mesentery is not kinked.
Fig. 32-3  Regular inset of an ileocolic flap (isoperistaltic). C, Ascending colon; Ce, cecum; E, esophagus; Ile, ileum; O-ph, oropharynx.

Fig. 32-4  Reverse design of an ileocolic flap (antiperistaltic). C, Ascending colon; Ce, cecum; E, esophagus; Ile, ileum; O-ph, oropharynx.
In patients who undergo laryngectomy only, without any significant defect of the esophagus, the options are either an ileocecal valve flap with a small patch of cecum (Figs. 32-5 and 32-6) or an appendix flap. The inset of the ileocecal valve flap is similar to that performed in patients with a partial esophageal defect, that is, with a small patch of cecum sutured to the esophageal wall. The flap inset is performed to create a one-way mechanism for preventing regurgitation of food into the trachea. It is important to maintain a balance between optimizing swallowing function and rehabilitation of the voice.

**Fig. 32-5** Side-to-patch anastomosis of an ileocolic flap transfer for voice reconstruction. **Ce**, Cecum; **E**, esophagus; **Ile**, ileum; **T**, trachea.
The appendix can be used to create a voice tube that will shunt air from the trachea to the esophagus or neoesophagus.

**Skin Flaps for Simultaneous Reconstruction of the Esophagus and Voice Tube**

Simultaneous reconstruction of the esophagus and voice is rarely performed in our unit. The skin flaps of choice are the radial forearm flap or the anterolateral thigh (ALT) flap. The ALT flap is favored, because it provides flexibility during inset, and if two or more perforators are present, it can be fabricated as a chimeric flap. One component is used for esophageal reconstruction and the other for a voice tube. It also has the option of including part of the vastus lateralis muscle to reinforce the vertical suture line, thereby decreasing the incidence of leakage. The main disadvantage is that the flap is thicker, and to create an optimal voice tube, it needs to be thinned to fashion a tube with a small caliber. In addition, secretions are not adequate to keep the tube clean and it is immobile, with resultant complete obstruction and retraction. For these reasons, skin flaps for voice reconstruction are not currently used in our unit. However, skin flaps with a voice prosthesis have been widely used with good results.
Laryngeal Transplantation: The Future
Tracheal transplantation in select patients is a promising option for the future.\textsuperscript{14-16} However, at the current stage of development, immunosuppression and the lack of donors have limited its use. Psychological problems may be a concern in some patients. Duque et al\textsuperscript{16} have shown good results with laryngeal transplantation.

COMPLICATIONS

Flap Loss
During surgery involving intestinal flaps, the ischemia time should be controlled.\textsuperscript{17,18} It is recommended that surgery be less than 2 hours. A common mistake is to use a small recipient vein, which results in congestion and swelling of the flap. It is essential to find a large vein such as the external jugular vein or even the internal jugular vein and use end-to-side anastomosis.

Loosening the Junction Between the Esophagus and Voice Tube
Patients may aspirate occasionally, but aspiration pneumonia will not occur. During surgery, the ileocecal valve should be plicated. Training for voice function should be postponed until 2 months after surgery to avoid loosening of the plicated ileocecal valve. The proper size for the esophagus–voice tube junction is 0.5 cm after plication.

Neck Scar
The scar that remains after surgery is often a concern for young patients or women. Secondary revision with excision of the neck scar or a skin graft may be necessary.

Redundant Esophagus and Dysphagia
The junction of the reconstructed cervical esophagus and thoracic esophagus is usually narrow. During the flap inset, intestinal flap tension is often worrisome for younger surgeons; therefore redundancy is a common problem in simultaneous reconstruction of the esophagus and voice. This problem can usually be avoided by performing the anastomoses in the following sequence: (1) an anastomosis between the pharynx and intestinal flap, (2) vascular anastomoses, and (3) an anastomosis be-
between the intestinal flap and thoracic esophagus. The time between the second and third steps should be 30 minutes to allow the intestinal flap circulation to stabilize before the final length is determined, because the final length results from the balance of the relative inflow from the artery and outflow of the vein. The junction between the pharynx and the reconstructed cervical esophagus is usually large enough and has no problem of stenosis. However, caution should be taken to prevent stenosis of the other end. A vertical incision should be made at the anterior wall of the thoracic esophagus to create a wider anastomosis between the reconstructed cervical esophagus and thoracic portion.

**Donor Site**

In our series of patients receiving ileocolon and jejunal flaps, three patients had symptoms of intestinal adhesion, but none required operative management. Careful dissection and manipulation of the intestine may help minimize this complication. Mild diarrhea often occurs for 1 month when the ileocecal valve is incorporated in the transferred intestinal flap. Iron and vitamin B₁₂ absorption is not affected in our studies, because only a short segment (15 cm) of ileum was harvested. In the regular follow-up, none of our patients have had vitamin B₁₂ or iron deficiency.

**Optimizing Outcomes**

Inset of the flap is important for obtaining a good result. The junction between the tracheal stump and voice tube (VT junction) is difficult to manage when the tracheal stump is short. In this situation, the VT junction is often small. If it is too small, the patient will have difficulty speaking, with a short maximal phonation time (MPT). Postoperative radiation therapy may even occlude the VT junction, necessitating revision as a secondary procedure.

Alternatively, if the VT junction is too large, the mucosa may prolapse into the tracheal lumen and cause partial airway obstruction. Management involves excision of the prolapsed mucosa or shortening of the voice tube. An optimal size for the VT junction is 0.5 cm. When an ileocolic flap is used, the optimal length of the voice tube depends on the defect of the cervical esophagus, the relative size of the cecum, and whether the colon segment is inset in an isoperistaltic or antiperistaltic fashion. We believe that an isoperistaltic inset is usually easier, because the length of ileum is more readily determined.
When the intestinal flap is inset (either a jejunal or ileocolic flap), it is important to prevent mesenteric kinking or twisting that could lead to swelling and circulatory compromise postoperatively (Fig. 32-7).

In some patients, the cervical esophagus is partially resected and the larynx is removed. In these cases, patch esophagoplasty can be performed using a piece of cecum for the esophagus and a segment of ileum for the voice tube (Fig. 32-8).

![Fig. 32-7](image1)

**Fig. 32-7** With the inset of an intestinal flap, it is important to prevent kinking or twisting of the mesentery of the different component segments, which can disrupt circulation and cause swelling in the postoperative period.

![Fig. 32-8](image2)

**Fig. 32-8** Patch esophagoplasty with a piece of cecum for the esophagus and a segment of ileum for voice reconstruction. It is indicated for narrowing of the cervical esophagus following laryngectomy. 

*Ce*, Cecum; *E*, esophagus; *Ile*, ileum; *T*, trachea.
To date, we have performed 92 cases of intestinal transfer for esophageal and voice reconstruction, 4 cases of appendix transfer for voice reconstruction, and 15 cases of jejunum transfer plus voice prosthesis for voice restoration. Among the patients in whom autogenous intestine was used, 68 had ileocolon flaps and 24 had jejunal flaps for simultaneous reconstruction of voice and esophagus. The functional outcome and associated problems and complications were analyzed (Table 32-5).

**Table 32-5  Results of Voice Reconstruction With Bowel Transfer**

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Swallowing Function</th>
<th>Voice Production</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jejunum for cervical esophagus and prosthesis for voice</td>
<td>15</td>
<td>Best</td>
<td>Good, but wet voice</td>
<td>Complications relating to voice prosthesis</td>
</tr>
<tr>
<td>Jejunum for cervical esophagus and jejunum for voice</td>
<td>24</td>
<td>Best</td>
<td>Fair</td>
<td>Early stage: leakage (three cases) Late stage: occasional reflux and aspiration*</td>
</tr>
<tr>
<td>Ileocolon (isoperistaltic) for esophagus and voice</td>
<td>61</td>
<td>Good</td>
<td>Best (40% excellent, 30% good, 20% fair, 10% poor)</td>
<td>Temporary diarrhea, requiring longer training time for swallowing</td>
</tr>
<tr>
<td>Ileocolon (antiperistaltic) for esophagus and voice</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free appendix for voice only</td>
<td>3</td>
<td>†</td>
<td>One case good Two cases fair</td>
<td></td>
</tr>
<tr>
<td>Pedicled ileocolon for whole esophagus; appendix for voice</td>
<td>1</td>
<td>Good</td>
<td>Fair†</td>
<td></td>
</tr>
</tbody>
</table>

*When jejunum is used for the esophagus and voice, patients may have occasional aspiration of liquid, which can always be coughed out. Proper education is necessary.
†Follow-up for these patients is only 3 months, which is not long enough to determine the final result.

**POSTOPERATIVE MANAGEMENT**

**ICU Care**

Patients are cared for in the ICU for the first few days after surgery. In addition to routine care for respiration and fluid therapy, the following are emphasized.

**Positioning**

The intestinal flap may have a short pedicle. The mesentery is soft and the intestinal flap is extensible, especially after congestion. These factors make it more vulnerable to vascular compromise than other free flaps. Caution is needed when reposi-
tioning these patients. The location of vascular anastomoses and other critical areas should be marked over the neck skin after wound closure. Proper instructions are given to nurses.

Cuff of the Endotracheal Tube
When the voice tube is made of an ileum loop, some secretion, which is not clean, may drain into the airway if the cuff is not filled with air. This stimulates and induces coughing. During the first few postoperative days, violent coughing can jeopardize intestinal flap survival. Therefore adequate care of the endotracheal tube cuff is necessary. Voice tube secretions eventually decrease and become cleaner with time. This is not a problem after the wound heals.

Blood Pressure Maintenance
Some patients have hypothyroidism and hypoparathyroidism after radiation therapy or surgical ablation of hypopharyngeal cancer that may cause low blood pressure and weakness. To ensure perfusion of the transferred intestinal flap, adequate blood pressure is needed. Ideally, the systolic blood pressure should be more than 100 mm Hg. Proper doses of thyroxin and calcium should be given when necessary. The thyroxin level may temporarily remain normal for weeks after partial or total thyroidectomy, which is performed with cancer ablation. However, the thyroxin and calcium levels will drop gradually and should be monitored after surgery.

Patient Care in the Ward
Patients are sent to the ward after their circulatory and respiratory conditions become stable.

Positioning
The nurses still need to pay attention to the neck position during the first postoperative week.

Diet
For patients who undergo reconstruction with an intestinal flap, an oral liquid diet can be started 2 weeks after surgery. It can be advanced to a soft diet and solid food gradually, depending on each case. If reconstruction involves a skin flap with a voice prosthesis, oral intake should be withheld until 4 weeks after surgery.

Training for Voice Function
If a jejunal or ileocolic flap is used for voice reconstruction, voice function training is started 2 months after surgery to avoid loosening. If a voice prosthesis is used, it is usually inserted between the trachea and esophagus, and voice training usually starts after swallowing has been reestablished (4 weeks after surgery).
CRITICAL POINTS

Must Know

- Current treatments for cancers of the larynx or pharynx should provide some form of voice rehabilitation or reconstruction. When possible, procedures to preserve voice function should be performed.
- When radical resection with removal of the larynx is necessary, all of the modalities of voice restoration should be explained to patients preoperatively.

Should Know

- Nonsurgical methods include the use of an external device, artificial larynx, and esophageal voice.
- Surgical methods include a voice prosthesis, skin flap, jejunal flap, ileocolon flap, and appendix flap.

Synopsis

- A free ileocolon flap for reconstruction of both esophagus and voice should be considered for patients who have a long life expectancy.
- A skin flap for the esophagus and voice prosthesis should be considered for patients with a short life expectancy and for elderly patients with some risk of laparotomy.
- For patients with high-risk factors, a pectoralis major musculocutaneous flap should be considered for esophageal reconstruction and the use of an external device or electronic larynx after surgery.

References


The authors present a detailed classification and technique for microsurgical reconstruction of the esophagus. Microsurgery is a new armament to fortify conventional methods. It provides a new approach to obtain better functions or to solve difficult problems in esophageal reconstructions. Microvascular transfer of jejunum, colon, and skin flaps is discussed according to their relative advantages and disadvantages. These are the basic tools required to master the techniques of voice reconstruction described in this chapter.
   The authors propose the selection criteria for larynx and trachea donors, including (1) between 18 and 50 years old, (2) gender and ABO blood type match, (3) not using addictive substances, (4) less than 3 days of tracheal intubation, and (5) less than 7 days in the intensive care unit. There were two cases of acute rejection, and the graft survival rate at 2 years was 90%.
   Good swallowing function is extremely important for most patients. With any complication in esophageal reconstruction, the swallowing function may be compromised, and voice function is always impaired. The nature of the tissue used for esophageal reconstruction also affects the quality of voice. For example, “wetness” of voice may be caused by profuse esophageal secretions into the lumen. Proper selection of and methods for esophageal reconstruction are described, with a discussion of possible pitfalls.
   This article is vital for anyone involved with voice reconstruction. Normal voice function is essential for a good quality of life. However, preservation of voice function should not compromise the extent of cancer ablation, unless the tumor is determined to be unresectable or the patient chooses to have a more conservative treatment. Many alternative methods to restore voice function are described, including operative reconstruction using bowel and skin flaps. Possible complications and their prevention are discussed.
Mandibular Reconstruction

Christopher G. Wallace, Fu-Chan Wei

HIGHLIGHTS

- Microsurgical free tissue transfer in conjunction with osseointegrated dental implants offers the potential for optimal results using segmental mandibular reconstructions.
- A single fibular osseoseptocutaneous free flap is usually sufficient for isolated bone defects, as well as for compound and composite segmental mandibular defects.
- Extensive composite segmental mandibular defects are better reconstructed with the fibular osseoseptocutaneous free flap combined with a soft tissue free flap such as the anterolateral thigh free flap.
- Nonmicrosurgical methods of segmental mandibular reconstruction are generally reserved for patients in whom a downgraded reconstruction is more suitable.
- The loss of a condylar process immediately downgrades the mobility and potential quality of any segmental mandibular reconstruction.
- Three methods are described that allow surgeons to use the free fibular osseoseptocutaneous flap to restore the height of the alveolar process for dental rehabilitation and the inferior mandibular margin for aesthetics, without using a less desirable osseo(myo)cutaneous free flap option.
The mandible is essential for normal mastication, swallowing, and speech. It is the largest, strongest, and the only mobile bone of the facial skeleton. The shape and height of the mandible are gradated to position the lower dentition optimally for occlusion. The height is essential for aesthetically pleasing facial proportions anteriorly and in profile. In addition, the mandible’s inferior margin defines the aesthetic curvature of the lower third of the face.

The most common indication for mandibular reconstruction is segmental bone loss following the wide resection of adjacent soft tissue neoplasms. The resection of an osseous or odontogenic neoplasm may also cause segmental loss, but these tumors are less common. Primary traumatic segmental bone loss is unusual, more often resulting from high-velocity, penetrating trauma such as from gunshots, rather than motor vehicle accidents or altercations. Sequelae such as osteomyelitis following trauma or osteoradionecrosis following radiation often require segmental bone resections.

**ANATOMY**

The mandible is formed by intramembranous ossification from two ossification centers, one for each side. It is present as two halves at birth joined at the midline by a fibrous symphysis, which completes ossification by the age of 2 years. The mandible consists of one horizontal component, two vertical components, and three processes. Its horizontal component includes the symphysis in the midline and the body on either side. Each vertical component, one on each side, consists of an angle, ramus, coronoid process, and condylar process. In adults, the mandibular dentition consists of two central incisors, two lateral incisors, two canines, two first premolars, two second premolars, and six molars. It is loaded into the alveolar process and occludes against the maxillary dentition (Fig. 33-1).
The masticatory system is mechanically redundant, allowing remarkable freedom of motion within the spatial limitations of the region. A variety of mandibular movements can be performed using an infinite number of muscle contraction patterns so that mastication can adapt constantly to the consistency of food between the teeth. Guided by the two temporomandibular joints, the mandible articulates within 6 degrees of freedom in relation to the skull. The principal movements at the temporomandibular joint produce elevation, depression, protraction, and retraction of the mandible. The two sides of the mandible alternate protract and retract to produce the grinding movements of chewing.

The masseter, temporalis, and medial pterygoid muscles close the mouth. The digastric, mylohyoid, geniohyoid, and genioglossus muscles open the mouth when the hyoid bone is fixed. The lateral pterygoid protracts the mandible and, assisted by the digastric and mylohyoid muscles, also opens the mouth. The posterior fibers of the temporalis muscle retract the mandible. The buccinator, which is not a muscle of mastication, controls the volume of the oral vestibule, thereby assisting the tongue in positioning the food bolus. It blends anteriorly with the orbicularis oris muscle, which also has a small attachment to the mandible. The mandible also provides attachment for a number of small facial muscles that play no role in mastication but help maintain oral continence.

The mandible is designed to withstand the extreme forces that these muscles collectively exert. It is a tubular bone with two cortices and intervening marrow. It is formed as a thick plate of predominantly cortical bone in areas that withstand mainly unidirectional forces (such as in the condylar neck), and where the bone must withstand multidirectional forces, it possesses trabeculae (such as in the condylar head and the alveolar process). The trabeculae span the medullary space and strategically align with the stress trajectories of the transmitted loads that they sustain. Any pressure from the dentition during mastication is transmitted directly to the trabecular bone, which remodels throughout life in response to dental movement/loss, and/or the individual’s masticatory characteristics and demands.

The blood supply of the mandible arises from the inferior alveolar artery, which courses through the mandibular canal with the inferior alveolar nerve. The surrounding periosteum contributes a supplementary blood supply. The mandibular canal is situated nearer the internal surface of the mandible in the posterior two thirds of the bone; in the anterior third, it is closer to the external surface. The inferior alveolar nerve arises from the mandibular division of the trigeminal nerve and enters the mandibular foramen in the ramus after providing motor supply to the mylohyoid and anterior digastric belly. The mental nerve exits the mental foramen to supply skin overlying the chin and encroaching onto the lower lip. Branches from the inferior alveolar vessels and nerve are distributed to the lower teeth from within the canal (see Fig. 33-1).
CLASSIFICATION OF SEGMENTAL MANDIBULAR DEFECTS

It is useful to have a classification system for segmental mandibular defects for a variety of reasons, including to improve communication, to audit and compare results, and to guide reconstructive treatment. Among the classification systems that have been proposed, we prefer the scheme devised by Daniel\textsuperscript{8} that describes the characteristics of any mandibular defect in a straightforward and easily understood manner:

- Isolated bone
- Compound (bone and oral lining or skin)
- Composite (bone, oral lining, and skin)
- Extensive composite (bone, oral lining, skin, and soft tissues)

In addition, the position and size of the defect are anatomically described according to the region (for example, lateral, anterior, or anterolateral) and/or process affected.

Some prefer the system devised by Jewer et al.\textsuperscript{9} which divides the mandible into H, C, and L regions (Fig. 33-2). A lateral defect of any length is classified as either an H defect (if the condyle is affected) or an L defect (when it is not). A complete hemimandibulectomy is therefore an H defect. A defect that involves the central segment, which spans from canine to canine, is a C defect. The various permutations of these three letters can reasonably describe any mandibular segmental defect. For example, an angle-to-angle defect is described as LCL, a mandibular body defect as L, and a ramus defect is also L. The presence of an associated soft tissue defect can be indicated by the letters \textit{o} for osseous defect only, \textit{m} for mucosa, \textit{s} for external skin, and \textit{ms} for combined surface defects.\textsuperscript{10} Other systems have been devised that are more detailed and comprehensive but have not gained popularity, mainly because of their complexity.\textsuperscript{11}

![Fig. 33-2](image_url)  
The HCL mandibular classification, where \( H \) denotes a hemimandibular defect, \( C \) is a central defect, and \( L \) is a lateral defect.
SURGICAL OPTIONS

We recommend that no mandibular segmental defect, however small, be shortened for primary fixation, because this will interfere severely with the symmetry of dental occlusion and mastication, and even the smallest cosmetic asymmetry will be clearly visible. If a segmental defect is not reconstructed or is inadequately reconstructed, unopposed muscle contractions will cause collapse toward the incongruent side, with unacceptable functional and cosmetic consequences. Ideally, the reconstruction should restore the functional shape, height, symmetry, and biomechanical features of the mandible, as well as its cosmetic symmetry, height, and curvature. These goals should be achieved expeditiously in as few surgical stages as feasible, without delaying adjuvant treatments such as radiation therapy. This is a major challenge. The options available can be divided into nonmicrosurgical methods and microvascular free tissue transfer.

Nonmicrosurgical Methods

Nonmicrosurgical methods include grafts, prosthetic materials, metalwork, and pedicled flaps in various combinations. Although these warrant review, surgeons should be aware that microvascular free tissue transfer almost always offers optimal outcomes for segmental mandibular reconstructions and is usually the first choice.

Nonvascularized bone grafts (NVBGs) still have their place in mandibular reconstruction, but only for the smallest of isolated bone defects situated in biomechanically favorable locations (ramus and body) within ideal soft tissues that will not undergo radiation therapy or become infected. We perform bone-containing microvascular free tissue transfers even for small defects if there is any chance that the area will be irradiated.

The remaining methods of nonmicrosurgical reconstruction for larger segmental defects are limited to patients for whom a downgraded reconstruction would be more suitable. These patients may be medically fragile, severely debilitated, and/or have short life expectancies (for example, from a second primary cancer or recurrence). One option is to bridge the bone defect with a substantial reconstruction plate and cover it with regional tissue. There are numerous options for regional soft tissue cover of the plate, including the trapezius, pectoralis major, and latissimus dorsi flaps, but these are universally suboptimal as donor sites for the mandible compared with free tissue transfer from distant areas such as the anterolateral thigh. In addition, their cutaneous component is not always reliable when transferred as a myocutaneous flap, because it often needs to be designed at the distalmost end of the flap to reach the mandible. To overcome these limitations, microvascular free tissue transfers, such as those from the forearm or thigh, have been used to cover bridging metalwork in the mandible. Whatever method of soft tissue cover is chosen, plate reconstructions have major disadvantages, such as plate fatigue and fracture, screw loosening, and plate extrusion—especially in the setting of irradiated tissue.
Some regional flap transfers can also import vascularized bone to the mandible (for example, pectoralis major with rib/sternum, sternocleidomastoid with clavicle, and trapezius with scapula) but with limitations in bone quality and volume and/or length, unreliability of the blood supply to the bone, limited freedom in insetting because of the orientation of bone and soft tissues, and higher donor site morbidity. Exceptional circumstances may exist when the pedicled trapezius with scapula or pectoralis major with rib/sternum are chosen, such as following multiple sequential free flap failures.

**Microsurgical Methods**

Microvascular free tissue transfer is now available ubiquitously, is highly successful, offers the best results for almost any segmental mandibular defect, and should be considered the procedure of choice. Free flaps with good quality bone and healthy soft tissues can be liberally imported to restore mandibular and soft tissue continuity immediately after segmental resections or debridements. Numerous large studies have demonstrated the reliability of microvascular free tissue transfer, with flap survival rates exceeding 95%, even in elderly cancer patients. Others have shown that, with regard to morbidity, free flaps compare favorably with traditional pedicled techniques.

The potential for applying microvascular free tissue transfer to mandibular reconstruction was recognized even as the earliest successful clinical free flaps were described. In 1974, Ostrup and Fredrickson reported some of the first experimental microvascular free vascularized bone transfers for mandibular reconstructions using ribs in canines. They additionally confirmed that these remained viable and healed even within radically irradiated tissue beds. Numerous descriptions of osseous free tissue transfers in humans for mandibular reconstruction followed, including the use of rib, the second metatarsal, scapula, radius, humerus, iliac crest, and fibula, with or without associated soft tissues. It is widely accepted that the best options today are microvascular free tissue transfers, with fibular bone as the first option and the iliac crest as the second.

**The Vascularized Iliac Crest Free Flap**

During the 1970s and 1980s, the vascularized iliac crest free flap based on the deep circumflex iliac artery became the most popular choice for microsurgical reconstruction of the mandible. The earliest vascularized iliac crest microsurgical transfers were based on a superficial circumflex iliac artery pedicle; however, Taylor et al recognized the superiority of the deep circumflex iliac artery over its superficial counterpart for providing a reliable blood supply to the ilium. This flap remains the workhorse for mandibular osseoseptocutaneous reconstruction in some centers.
The iliac bone possesses several beneficial characteristics for mandibular reconstruction. It can provide a good length of thick, sturdy, and tall bone of sufficient stock to support osseointegrated dental implants, reasonably matching the shape of the hemimandible. It is, however, less adaptable for composite mandibular reconstructions, because its associated skin paddle has limited mobility and is often excessively bulky, making insets difficult. Furthermore, the available length of the pedicle limits reach to the more proximal vessels in the neck if vein grafts are to be avoided. The skin paddle is not dependable when supported by the deep circumflex iliac artery pedicle. This can be overcome by transecting and additionally anastomosing the superficial circumflex iliac artery vessels either to another set of recipient vessels or, using supramicrosurgical techniques, as a flow-through to a branch of the deep circumflex iliac artery—but these methods are impractical. Finally, the functional donor site morbidities associated with harvest of the iliac crest are a deterrent: protracted gait pain and gait disturbance, lateral femoral cutaneous nerve injury, pelvic fractures, and abdominal wall structural problems, including hernia formation.

The Fibular Osseoseptocutaneous Free Flap

Most surgeons agree that the benefits offered by the free vascularized iliac bone transfer are superseded by those of the free vascularized fibular transfer. The use of the fibula offers important advantages, which have solidified its current position as the ideal flap for reconstruction of segmental mandibular defects. When the soft tissues carried by the free fibula flap are insufficient, a second soft tissue flap is often indicated; in some cases, this can be a regional soft tissue flap. This chapter focuses on the fibular osseoseptocutaneous free flap and the double free flap.

The design, harvest, and uses of microvascular free fibular bone transfer, with or without soft tissues, are described in Chapter 16. The fibula has a medullary and a segmental periosteal blood supply arising from the peroneal artery (Fig. 33-3). Since Taylor et al first described the free vascularized fibular flap in 1975, three vitally important features have been reported that led to its application and success in mandibular reconstruction. The first feature was originally reported by Yoo et al in 1982 and then by Jupiter et al in 1987. Their work showed that the fibula could be osteotomized into two struts and folded into a “twin-barreled” or “double-barreled” configuration without devascularization of either strut, as long as the intervening periosteal vasculature was kept intact. The second feature was reported by Hidalgo in 1989, who confirmed that the fibula could withstand several osteotomies in sequence when the periosteal supply was protected. This allowed him to angle the fibular segments sequentially to mimic the curvature of the mandible following segmental resections in a series of 12 reconstructions in patients. Hidalgo reported excellent results, particularly for defects involving only bone. He also transferred a skin paddle with the fibula in five of these cases (four for intraoral defects and one for a
facial skin defect) but concluded that the blood supply was generally inadequate to support the skin component. He therefore recommended using the free fibula only for bone-only mandibular defects. The third feature had actually been reported before Hidalgo’s landmark publication. In 1986, Wei et al39 published their anatomic investigations and clinical cases confirming the reliability of the skin paddle when based on a septocutaneous (or musculocutaneous) blood supply from the peroneal vessels. These findings were additionally confirmed by independent investigators around this time.61,62

Gradually, the free fibular osseoseptocutaneous flap has become widely accepted as the free flap of choice for mandibular reconstruction. The skin paddle can reconstruct soft tissues, facilitate wound closure, and serve as a sentinel marker of the underlying bone vascularity in reconstructions of isolated bone defects39 (Fig. 33-4).
The free fibular osseoseptocutaneous flap has several other features that make it an excellent choice for segmental mandibular reconstruction, including: (1) an unmatched supply of robust, straight bone of nearly uniform thickness, with a sturdy triangular cross-section of sufficient length (22 to 26 cm in adults) to reconstruct even angle-to-angle mandibular defects, (2) a borticocancellous structure that can reliably support osseointegrated dental implants, (3) a large and lengthy pedicle (2 to 3 mm in diameter, up to 15 cm long), (4) a thin, pliable, and sizeable skin paddle (up to 22 to 25 cm long and 10 to 14 cm wide) that is easily maneuvered into almost any architectural bony configuration, (5) a flexible design that can use the chimeric concept to incorporate additional skin or muscle components when required, (6) a large-diameter distal run-off from the peroneal vessels, ideal for supplying a second free flap in sequence if additional donor vessels are unavailable, (7) an ideally located donor site for sural nerve graft harvest when reconstruction of the inferior alveolar nerve is required, (8) a skin paddle that can be made sensate by including the lateral sural cutaneous nerve, and (9) a donor site location that allows the flap harvest and recipient site operation to be performed simultaneously by two surgical teams.

**INDICATIONS AND CONTRAINDICATIONS**

There are few circumstances in which the free fibular osseoseptocutaneous flap is not the first choice for segmental mandibular reconstruction. Its desirable characteristics, overall, are not matched by any other option. One contraindication to its use is an unfavorable blood supply to the foot once the peroneal vessels have been sacrificed for flap harvest (for example, arteria peronea magna).\(^69^,\(^70^\) It is important to evaluate the contralateral leg in these circumstances, because the vascular supply to the feet is not always symmetrical.\(^69^,\(^70^\) The fibula is unavailable in patients who refuse to have a scar on the leg and in those who have a significant history of peripheral vas-

*References 14, 25, 38, 39, 42, 52, 63–68.*
cular disease or previous bilateral limb trauma. The patient evaluation for fibular osseoseptocutaneous flap harvest is described in detail in Chapter 16, including the debate regarding the usefulness and necessity of routine preoperative angiography.

The only major drawback of the fibular osseoseptocutaneous free flap is the limited soft tissue volume that it can carry. It is possible to incorporate a strip of soleus or gastrocnemius muscle with the flap, but its positioning or volume may not be ideal or enough. This becomes a problem when reconstructing extensive composite defects or large compound defects, such as those that may result from T3 or T4 cancer resections. In these circumstances, the fibular osseoseptocutaneous flap should be used for the bone and oral lining, with a second free flap used for external skin coverage and cheek volume. Numerous options are available for the second free flap. Our previous preference was the radial forearm free flap, the rectus abdominis myocutaneous free flap, or the latissimus dorsi myocutaneous free flap, which we used less commonly because of its requirement for patient repositioning. However, we now prefer the free anterolateral thigh flap because of its numerous advantages, including superior donor site morbidity profile (see Chapter 13). The descending branch of the lateral circumflex femoral artery offers surgeons exceptional flexibility in flap design. The radial forearm, the latissimus dorsi myocutaneous, and rectus abdominis myocutaneous free flaps each leave more significant donor site morbidity than the anterolateral thigh free flap, and each is located too close to the ablative team for a comfortable two-team approach. In addition, the radial forearm free flap is usually too thin to cover the fibula bone and its fixation, leading to plate visibility, palpability, and ultimately plate exposure from contact pressure or radiation-induced soft tissue shrinkage. If a simultaneous second free flap is not feasible, a pedicled pectoralis major myocutaneous flap is a technically less demanding option that does not require repositioning the patient intraoperatively.

If the fibular osseoseptocutaneous flap is contraindicated, the next option for reconstructing the bone is the deep circumflex iliac artery flap with iliac crest (Fig. 33-5). When a double flap is required for an extensive composite segmental defect, the skin component of the iliac flap is better placed internally after thinning. If the skin component is placed externally, the intraoral second free flap needs to be inset first, but this interferes with the insetting of the neomandible construct; therefore this is not recommended. With the skin paddle placed intraorally, a fasciocutaneous anterolateral thigh flap can be used for external skin coverage and to augment the cheek volume. If radiation therapy is expected, it is essential to restore the cheek volume first, overcorrecting it to adequately compensate for radiation-induced soft tissue shrinkage, without jeopardizing coverage of the osseous flap or its metalwork fixation.
Other options include the scapular osseo(myo)cutaneous and radial osseocutaneous free flaps. The skin paddle of the scapular flap is a good match for the face and has great flexibility in its vascular axis to create chimeric configurations for extensive composite defects\textsuperscript{25} (Fig. 33-6). Its considerable drawback, however, is its location. There is no option for a two-team approach, and patients need to be repositioned twice intraoperatively; both of these factors prolong the operation substantially. The radial forearm free flap (see Chapter 14) has been used in many centers for segmental mandibular reconstruction. The bone quality of the hemiradius is poorer than that of the iliac crest, but the available length is greater. The major drawback of the radial osseocutaneous flap is its donor site morbidity. Postoperative fracture rates are approximately 12\%.\textsuperscript{45} Prophylactic plating of the radius has not proved cost effective.\textsuperscript{76} For these reasons, we almost never use this flap for bony restoration of segmental mandibular defects.
In summary, the first choice of bone for mandibular reconstruction is the fibula. It should always be harvested with a skin paddle to serve as a sentinel monitor of bone vascularity and to facilitate wound closure for isolated bone defects; for compound defects, the skin paddle is used to reconstruct the soft tissue component (Fig. 33-7). Composite defects that do not have a significant reduction in cheek volume may or may not require an additional free flap; the fibular osseoseptocutaneous flap skin paddle or paddles are often large enough to provide external skin and intraoral lining.

**Fig. 33-7** The reconstruction of a compound segmental mandibular defect with a single free fibular osseoseptocutaneous flap. **A,** Preoperative. **B,** A compound segmental mandibular ablative defect with the reconstruction plate in situ. **C,** The free fibular osseoseptocutaneous flap was inset after being contoured at the side table. The skin paddle will be inset to reconstruct the intraoral defect. **D,** The result after 6 months shows facial symmetry.
Extensive composite defects are best reconstructed using a second free flap that can augment cheek volume and provide good quality external skin; our preference is the anterolateral thigh free flap (Fig. 33-8). When neither fibula bone is available for mandibular reconstruction, the next choice is usually the iliac crest, followed by the scapula. A reconstructive microsurgeon should not hesitate to use a second free flap for extensive composite mandibular defects. A single free flap that is forced into solving all the reconstructive problems of extensive composite segmental mandibular defects will not offer the same functional and cosmetic results; a free fibular osseoseptocutaneous flap combined with a regional flap would be a better choice.

Fig. 33-8  Reconstruction of an extensive composite segmental mandibular defect with a double free flap procedure. A, This extensive composite segmental mandibular ablative defect shows the reconstruction plate in situ. B, The contoured free fibular osseoseptocutaneous flap was inset. The skin paddle will be inset to reconstruct the intraoral defect and the second free flap (from the anterolateral thigh) will be used to restore the facial skin and cheek volume. C, Result after 3 years. The aesthetic contour of the cheek has been retained, despite radiation therapy, and the soft tissues and the mandible show acceptable symmetry. D, Note the absence of trismus with functional mouth opening; the positioning of the intraoral skin paddle of the fibular osseoseptocutaneous flap; and the volume of the reconstructed cheek.
**Preoperative Management**

The preoperative assessment of any patient requiring mandibular reconstruction is multidisciplinary. The team should include experienced reconstructive and ablative surgeons working alongside anesthetists, medical oncologists, radiographers, pathologists, radiation therapists, psychologists, and various dental, prosthodontic, and rehabilitation specialists. These patients should therefore be managed in a center that specializes in head and neck reconstruction.

Preoperative assessment includes obtaining a full history and performing a thorough physical examination, focusing on the head and neck examination, liver function tests, a biopsy specimen of the lesion, panendoscopy, chest radiographs, and mandibular Panorex and CT imaging. The results of these tests will help grade and stage the disease preoperatively and influence the treatment plan. Important parts of this decision include whether the resection will be curative or palliative, the extent of any associated neck dissection or dissections and plans for adjuvant treatments such as radiation therapy. The ablative surgeon plans the site and dimensions of the mandibular segmental and soft tissue resections and communicates his or her intentions to the reconstructive team. It is important that members of the anesthetic department assess the patient before the operation to determine the need for any additional diagnostic procedures. A careful risk assessment for postoperative delirium tremens is particularly important in this patient population.

Potential flap donor sites should be clinically assessed and may require additional imaging. For example, abnormal pedal pulses, bilateral leg trauma, or significant evidence of peripheral vascular disease warrants angiography before fibular osseoseptocutaneous flap harvest (see Chapter 16). The reconstructive surgeon plans the quality and extent of the reconstruction, taking into account the curative or palliative intent of ablation and the wishes and expectations of the patient. In particular, patients should be made aware of any plan to use the radial forearm flap, because they will need to protect that arm from blood sampling or intravenous lines. Prosthodontists and oral surgeons are needed to assess and plan for potential dental rehabilitation.

Three-dimensional mandibular templates prefabricated from CT scans are useful for planning the bony reconstruction, particularly when primary osseointegration is to be performed (see Chapter 35). These templates are important for surgeons who prefer to osteotomize and shape the osseous flap at the donor site, rather than on a side table or at the recipient site. In addition, two-dimensional cut-out templates are simple to reproduce from lateral and inferior radiographs of the mandible.
**Operative Technique**

The ablative and reconstructive teams should work simultaneously to reduce operative time. Flaps such as the anterolateral thigh and fibular osseoseptocutaneous flaps are ideally located on the same lower extremity, as far away from the ablative team as possible, and can be harvested with the patient supine. Communication between the two teams and their experience working together will influence the stepwise approach to the ablation and reconstruction. The following provides a guideline for how this may proceed.

**The Recipient Site**

The recipient site is prepared for reconstruction once the ablative operation has been completed. Meticulous hemostasis should be verified first. Recipient vessels are ideally located on the ipsilateral side. A single vein and artery are usually adequate per free flap, but alternative vessels should also be sought as backup options. When using a second free flap, it is better to isolate a second set of recipient vessels instead of using the distal runoff of the fibular osseoseptocutaneous flap, although this is a useful option to keep at hand. Vessels in the contralateral neck are useful in patients who have had multiple previous ipsilateral operations in the region or previous radiation therapy, or when vessel changes such as severe atherosclerosis render them unsafe to use. When present, the internal jugular vein usually offers several side branches for end-to-end anastomosis and adequate flap drainage. The external jugular vein is also a useful option for end-to-end venous anastomosis. Branches of the external carotid artery are sought to provide flap inflow. Easily accessible options include the superior thyroid, lingual, facial, and superficial temporal vessels (see Chapter 11). The transverse cervical vessels are a good alternative in difficult necks. End-to-side anastomoses to the external carotid artery bring an attendant risk of fatal carotid artery blowout in the early postoperative period, and for this reason are left as a last resort in our center. Careful preoperative planning and flap design usually obviate the requirement for vein grafts. In addition, the continuity of the inferior alveolar nerve should be assessed in case a graft of the sural cutaneous nerve must be harvested to bridge the nerve gap before closure of the fibular donor site.

If dentition allows, maxillomandibular fixation should be performed to restore normal occlusal relationships. Subperiosteal dissection of the native mandibular bone ends should be adequate to allow fixation of the reconstruction plate without intervening soft tissue. This allows accurate shaping and fixation of the reconstruction plate in preparation for neomandible contouring at the recipient site. The curvature of the reconstruction plate is defined by the native mandible using a no-touch technique or against preoperatively fashioned mandibular templates. The reconstruction plate can be molded freehand, but care must be taken to ensure tandem
movement of the temporomandibular joints and correct positioning of the condyles in occlusion.85 This can be checked by releasing the maxillomandibular fixation once the reconstruction plate is fixed with screws to the native mandible. This also allows intraoral access for insetting the soft tissue component of the osseous flap.

The Donor Site

The reconstructive team will have a good indication of the recipient site defect dimensions and compositions from the ablative team and can therefore proceed to flap harvest during the ablative operation. The osseous flap should be harvested first, which is usually the fibular osseoseptocutaneous free flap.14,52 The anatomy, design, and dissection of the fibular osseoseptocutaneous flap are described in Chapter 16.39

The fibula should always be raised with a skin paddle, which has two functions: a sentinel flap monitor of bone viability and a source of skin for soft tissue reconstruction.39 The former function makes implantable monitoring devices redundant.38,39 The skin paddle is often designed to encompass strong arterial Doppler signals located 15 to 27 cm from the fibular head; these are usually septocutaneous vessels.39 A skin paddle of up to 14 by 25 cm can be reliably based on one or two of these arteries.39 Retrograde dissection of myocutaneous perforators, which are generally located more proximally, is rarely required.39 These can be sacrificed to facilitate flap harvest and increase mobility of the paddle once a reliable septocutaneous supply has been dissected. If only a small volume of additional bulk is required in a suitable location, a soleus muscle segment can be included in a chimeric fashion, but the patient should be warned of the possible additional donor site morbidity.67 Alternatively, soft tissue bulk can be increased by harvesting a larger-than-necessary skin paddle and burying the deepithelialized excess. Flap circulation should be confirmed by deflating the thigh tourniquet and allowing at least 20 minutes of reperfusion before transecting the pedicle.

Before the flap is rendered ischemic, the recipient site and vessels should be checked once again. The reconstructive surgeon should verify the length of the pedicle required to reach the recipient vessels, visualize the pathway of the inset pedicle, and ensure that adequate room is allowed in that pathway so that pedicle compression will not occur. Postoperative swelling and positioning should be assessed, especially if the pedicle is to pass through the musculature of the floor of the mouth.

Contouring, Insetting, and Fixation

Some surgeons prefer to contour the neomandible while the fibula is still attached to the donor site to reduce flap ischemic time.13,45 Osteocytes are not sensitive to a moderate period of ischemia, which in our experience is usually within 4 hours for this flap.86 It is therefore not necessary to contour the neomandible while still attached, even when performing additional primary osseointegration of dental implants. In addition, vascular attachment at the donor site hinders the freedom of the contouring process.78,80 To promote bony union, each fibular segment should intimately abut
neighboring bone without soft tissue interference. This requires a clear appreciation of angles in more than one plane, which is easier with the flap mobile in hand, rather than attached to its donor site. Furthermore, a perfectly placed osteotomy cannot be guaranteed every time, so it is helpful to verify completed osteotomy angulations and positions directly against the recipient defect in case fine adjustments are required. This is particularly important for reconstructions involving sequential osteotomies; even a minor error in angulation will be accentuated by increasing distances away from the osteotomy site and therefore introduces error to subsequent osteotomies. These errors are best corrected before proceeding to the next osteotomy, which is not feasible if the flap contour cannot be intermittently checked against the recipient site defect when the flap is attached to the leg. Two- or three-dimensional mandibular templates provide useful guides during flap contouring.

The contour of the neomandible is defined principally by the curve of the reconstruction plate, but can be rechecked with a no-touch technique alongside the resected specimen and the recipient defect. Fixation should be rigid to permit early postoperative movement of the temporomandibular joints. We use titanium mini-plates and screws for fixation if no osteotomy or only one osteotomy is required to form the neomandible. Monocortical screws are recommended over bicortical screws to minimize the risk of bone devascularization.

An important part of contouring the bone is choosing where to make the first osteotomy. This is largely determined by the pedicle length requirement and the location of the skin paddle, which, again, are easier to check with the flap in hand. The pedicle measurement can be determined accurately by placing the flap within the mandibular defect and aligning the pedicle with each of its potential recipient vessels within its planned pathway. The first osteotomy defines what length of proximal fibula can be dispensed with. The remaining length must fill the full length of mandible requiring reconstruction. It is recommended that excess distal bone length be included to account for bone length losses from osteotomy angulations and potential errors in osteotomy placement that require corrections (and therefore further length losses). The positioning of the skin paddle should also be verified before the first osteotomy by draping it into the soft tissue defect; this judgment must be made before the osteotomies are performed and is therefore largely intuitive. Once the site of the first osteotomy is decided, the pedicle should be carefully dissected in the subperiosteal plane off the proximal fibula. This increases the potential length of the pedicle and is an important part of the planning procedure that reduces the risk of requiring vein grafts. The placement of sequential osteotomies can then be verified against the mandibular defect while accounting for the angulations of the prior osteotomies.

In our practice, all osteotomies are performed at a side table under controlled conditions. The following points are particularly important. First, the fibula must be grasped gently with a damp swab instead of gloved fingers, because excessive grip strength is required to overcome the slipperiness of the periosteum and may cause periosteal crushing. Second, noncrushing, pointed instruments such as bone holders
or towel clips are used to stabilize the bone during osteotomies, not the fingers; this is more stable, does not crush the periosteal supply, and is safer for the operator. Third, an assistant is needed to perform the osteotomies safely: the operator stabilizes the bone with one hand and controls the saw with the other while the assistant stabilizes the other end of the bone and ensures protection of the periosteal supply with an intervening forceps. Fourth, the scrub nurse provides continuous irrigation with normal saline solution while the bone is being osteotomized to prevent any heating of the bone; additional irrigations of the pedicle and soft tissues prevent flap desiccation. Heating of the bone encourages bone necrosis and early screw loosening; heating to 40° C or more almost guarantees bone necrosis and screw failure. Fifth, osteotomies are better performed on a sterile, raised, custom solid plate covered with multiply folded surgical drapes; the plate protects against penetration of the drapes, which would contaminate the surgical field. Sixth, both arms of the operator and assistant should be supportively planted against the side table to perform each osteotomy stably. Finally, we recommend that no fibular segments are less than 3 cm long. Some surgeons use segments as short as 1 cm to improve contour, but this stretches the limits of the segmental periosteal blood supply to the bone.

The construct should be immediately inset once the osteotomies are completed. Some areas of the soft tissue defect may be closable directly without tension, particularly in its deepest aspect. The skin paddle should be temporarily and approximately inset before the bone. At this stage, it is possible to incise the septum on either side of the chosen septocutaneous supply to provide additional rotational mobility of the skin paddle. This should not be performed before inset, because the septum provides some protection against stretching of the vessels supplying the skin paddle when contouring and handling the flap. Probably the most important function of the skin paddle inset is to provide a watertight seal against salivary leakage from the oral cavity into the vicinities of the flap and neck, which may cause either a closed-space infection and jeopardize flap survival or an orocutaneous fistula. It is particularly difficult to achieve this seal if the gingiva has been completely resected. The ablative surgeon determines if complete gingival resection is necessary, but some resect it to increase the “safety” margin, not recognizing the importance of its presence for flap inset. This is one example of the importance of interdisciplinary communication for optimal reconstruction; the gingival tissues should be preserved as long as resection margins are not risked. When the gingiva is inadequate to achieve a stable suture line, the reconstructive surgeon can “hang” the skin paddle on the mandibular dentition, with each suture encircling a single tooth, but this depends on good-quality teeth. We usually use one of two approaches to achieve a watertight seal when the teeth are in poor health or when a patient is edentulous. First, the fibula can be harvested with a small segment of muscle that can be inset below the skin paddle to create a plug in any areas that may leak saliva. Second, it is possible to drill holes through the mandible, between the roots of the teeth (when present), for suture placement and plug the suture line with a strip of muscle or deepithelialized skin paddle. Neither option is foolproof; both rely on meticulous postoperative care to continuously siphon saliva away from the suture line until mucosalization is com-
plete. Other important aspects of skin paddle inset are anatomically defined. Principles of reconstructing the oral mucosa and tongue are presented in Chapters 29 and 30. The soft tissue reconstruction is just as important, probably even more important, than the bony reconstruction. If the segmental mandibular defect is a compound defect that involves only the external skin, the neomandible should be inset first. Chapter 25 addresses the principles of facial soft tissue reconstruction.

The fibula can be fixed with titanium miniplates and screws if the bone requires no osteotomies or only one osteotomy for contouring. Otherwise the neomandible is inset against the preshaped reconstruction plate. The minimum number of screws should be used per segment to ensure stabilization while minimizing disruption to its vascularity. Each screw should gain purchase of the second cortex but not disrupt its overlying periosteum. Screws placed in the native mandible must not disrupt the inferior alveolar nerve or the dental roots.

Microvascular anastomoses are performed once flap insetting and fixation are completed, unless primary osseointegration was planned. For primary osseointegration, the entire neomandible/metalwork construct is removed en bloc to the side table to position the implant fixtures (see Chapter 35). The neomandible is revascularized once the osseointegrated implant fixtures are accurately sited. If a second free flap is necessary, its harvest would have been completed during the inset of the osseous free flap (by a third surgical team) and would now be ready for pedicle transection and flap inset into the external face (see Chapter 25), and revascularization. After all anastomoses are completed, the head and neck should be gently mobilized in all directions while visualizing the pedicle or pedicles so that postoperative patient positioning and the limits of neck movements can be defined.

RECONSTRUCTING THE MANDIBULAR CONDYLE

Each temporomandibular joint has complex biomechanics and is elaborately shaped to provide remarkable freedom of movement to its hemimandible. The loss of a condylar process immediately downgrades the expected mobility of a mandibular reconstruction, and the patient should be warned of the additional increased risk of temporomandibular joint symptoms.

The best option for reconstructing the mandibular condyle is probably to excise and reinsert the condylar process into the joint as a NVBG, but this requires the condyle to be disease free; in addition, its survival after postoperative radiation therapy is uncertain at best. Any doubt regarding disease involvement renders this method unusable. Condyles that have been reinserted in this fashion have survived intact in some patients for at least 10 years, yet degrade with time in others. Despite this unpredictable survival, the use of the condyle as a NVBG has not resulted in pain, trismus, infection, ankylosis, or symptoms of temporomandibular joint syndrome. Fixation of the neomandible to the condylar NVBG should be performed with miniplates and screws rather than reconstruction plates, which are too large.
The second option for reconstruction of the mandibular condyle is to fashion a neocondyle. One method is to round off the end of the proximal fibular segment, cover it with excess periosteum or fascia, and insert this neocondyle into the joint. Alternatively, a costochondral graft can be shaped and attached to this end of the bone flap. A third option is to use a prosthetic condyle. Some reconstruction plates with a condylar extension are available. Neither of these latter two options is patient specific. Reported complications of alloplastic condyle replacements include sensorineural deafness, erosion into the middle cranial fossa, and joint dislocation. The final option is to not reconstruct the temporomandibular joint, but to rely instead on the pivot of the contralateral temporomandibular joint; however, the mandible will rotate obliquely during mouth opening.

**Optimizing Outcomes**

Although an exact replica of the native mandible is the goal, this cannot be achieved at the anterior segment where the mandible height far exceeds the diameter of a fibular strut. Contouring should balance an aesthetic inferior margin with a functional position for the neomandible, particularly when osseointegration of implants is anticipated. When the symphysis or parasymphysis is involved, the reconstructive surgeon is faced with a reconstructive dilemma. This region is subjected to the greatest moments of force during biting and is a critical determinant of aesthetic facial height. Because the cross-sectional height of the fibula is approximately half that of the anterior mandibular segment, if the facial height and mandibular curvature are restored from the aesthetic perspective, a functional price will be paid by the compromised lower position of osseointegrated dental implants. Otherwise, the facial height must be shortened to place the dental implants into the plane of the native alveolar ridge, but this compromises facial aesthetics.

We address this in select patients with one of three methods. The first method involves placing an additional reconstruction plate inferior to the fibula-implant construct in combination with primary osseointegration. This method is indicated only for patients who will not receive postoperative radiation therapy, which would confer an unacceptable risk of plate exposure and fixture loosening. The inferior mandibular contour is restored with a low-profile, 2.4 mm reconstruction plate that has been fashioned preoperatively against a three-dimensional mandibular template. The superior border of the fibula-implant construct is placed, aligned with and 10 to 15 mm inferior to the occlusal plane, and fixed to the native mandible to provide an adequate alveolar ridge for primary osseointegration. Microvascular anastomoses are performed after insetting.

The second method is to double barrel the fibular osseoseptocutaneous flap (see Chapter 16). As first described by Horiuchi et al in 1995, this method is useful for restoring mandibular height at the anterior segment. Osseointegrations can be placed into the upper barrel primarily or secondarily. The lengthier strut can then be aligned with the inferior mandibular margin and osteotomized to match the splay at the junction between the anterior and lateral mandibular regions. We recom-
mend that a 3 cm (not shorter) segment of bone be planned for discard so that folding does not stretch the intervening periosteal vascular connection.80

In the third method, vertical distraction osteogenesis is applied to the transplanted fibula to gain adequate alveolar height for secondary osseointegration of dental implants.96,99 Once consolidated, the neomandible can be osteotomized horizontally at its midpoint, spanning the region chosen for distraction, without injuring the periosteal blood supply, to produce upper and lower halves. The upper half receives one vertical osteotomy at each end, causing 2 mm bone gaps on either side to allow unimpeded distraction. An extraosseous vertical distraction device is set at the midpoint of the two halves with single cortex screws. After 10 to 14 days latency, distraction begins at a rhythm of two distractions per day (0.4 to 0.5 mm each) until the vertical discrepancy is corrected.99,100 A local anesthetic is administered and the device is removed after a retention period of 3 to 4 months to allow bony consolidation.99,101 Osseointegrated dental implants are then placed 4 to 6 weeks later.96 Greater control over the distraction vector, which is affected by the limited stretch in the intact periosteum, may be afforded in the future with multidirectional osseodistraction equipment.96,100,102

In the fourth method, osseous reconstruction is performed using iliac crest instead of fibula. The iliac provides the tallest bone available for reconstructing the mandible and has excellent bone stock for accepting osseointegrated dental implants.63 Its disadvantages were previously described. This method is only used in our center when both fibular donor sites are unavailable. We prefer to use one of the first three techniques described so that the numerous advantages of the fibular osseoseptocutaneous flap can be put to full use for optimal reconstruction.96 Double barreling the fibula in particular requires no techniques in addition to those used to contour the neomandible and can be used in patients irrespective of plans for radiation therapy.

**Complications**

The common pitfalls and complications encountered in mandibular reconstruction can be avoided by adhering to the principles previously outlined. Pitfalls include insufficient pedicle length (necessitating vein grafts), improper angulation of osteotomies, insufficient soft tissue incorporation with the flap or flaps, absence of gingival tissues for skin paddle inseting, and inadequate neomandibular height at the anterior segment.

Secondary reconstructions, especially those following radiation therapy, and reconstructions for radiation-related complications such as osteoradionecrosis create additional reconstructive pitfalls.103–106 The soft tissue resection is often difficult to predict with accuracy. When this is the case, it is sometimes better to delay the completion of fibular osseoseptocutaneous flap harvest until the defect dimensions are clearer. Primary microsurgical reconstruction in a single stage is the intended standard of care and, with the techniques that are currently available, secondary reconstructions are fortunately rarely performed.
Extensive mandibular reconstructions in very young patients are unusual. Both fibular donor sites must not be used in these situations—at least one should be spared. It is technically feasible to include the fibular ossification center into the reconstruction, but only that segment will increase in length and may jeopardize symmetry in neomandibles requiring one or more osteotomies for contouring. Distraction osteogenesis is another method available to increase the dimensions of the neomandible in concert with the growth of very young patients to maintain mandibular symmetry. In patients with a poor prognosis, such as those with advanced tumors, it has been suggested to delay definitive reconstruction until survival has been guaranteed and mandibular growth has progressed by placing a temporary bridging reconstruction plate with overlying soft tissue free flap coverage. It needs to be accepted, however, that the reconstruction plate is likely to interfere significantly with normal soft tissue growth, apart from that of the mandible, compromising functional symmetry in survivors who will undergo definitive reconstructions.

**Postoperative Management**

The skin paddle of the fibular osseoseptocutaneous free flap is ideal for monitoring the vascularity of the underlying bone. The inset of the pedicle or pedicles and the position of microvascular anastomoses must be considered when positioning a patient’s head and neck postoperatively. At our institution, antibiotic agents are administered routinely after mandibular reconstruction. Specific postoperative management of each flap donor site is addressed in other chapters of this book.

When a reconstruction plate has been used for neomandible fixation, the temporomandibular joints can be mobilized immediately to reduce the risk of temporomandibular joint ankylosis and maximize mouth opening. Conventional analgesics are prescribed to facilitate jaw mobilization exercises. The mandible should be splinted open with tightly rolled gauze when patients are resting. The oral cavity is moisturized with aerosolized sterile water until oral intake can be initiated. This occurs when the seal between the oral cavity and the flap and neck is certain. Regular examinations for unilateral neck swelling and/or erythema are essential, because these are early markers of salivary leakage around the intraoral reconstruction. Infection, hematoma formation, and chyle leakage also produce similar signs. All require exploration, irrigation, and correction of the underlying problem.

All patients undergoing mandibular reconstruction at our institution receive a temporary tracheostomy and nasogastric tube immediately before the resection. The tracheostomy can be removed after approximately 10 days if the postoperative course is smooth. The nasogastric tube can be removed once soft food intake is established.
CRITICAL POINTS

Must Know

- For effective communication and operative planning, segmental mandibular defects are classified as isolated bone, compound, composite, and extensive composite defects.
- For some patients, a downgraded reconstruction is more appropriate than a segmental mandibular reconstruction.
- The harvest, contour, inset, and fixation principles of the fibular osseoseptocutaneous free flap must be understood.
- The fibula is always raised with a skin paddle, even if a paddle is not required for reconstructive purposes, because it can be used to monitor fibular bone vascularity and facilitates wound closure.
- Surgeons must know how to achieve maxillomandibular fixation and shape the reconstruction plate.
- Some defects are best reconstructed with a double free flap procedure, and the indications must be understood.

Should Know

- The principles of primary and secondary osseointegration of dental implants should be understood.
- The iliac crest and scapular osseo(myo)cutaneous free flaps can be used for segmental mandibular reconstruction when neither fibular donor site is available for use.
- Surgeons should know methods to achieve an intraoral seal when little or no gingival tissue is available for flap inset.
- There are at least four methods for reconstructing the mandibular condyle.

Synopsis

- An inadequately reconstructed segmental mandibular defect can have devastating musculoskeletal functional, aesthetic, and psychosocial impacts on a patient. Microvascular free tissue transfer offers the best overall results.
- For most defects, the first choice is the fibular osseoseptocutaneous free flap. For extensive composite segmental mandibular defects, it is better to combine the fibular osseoseptocutaneous free flap with a soft tissue free flap to restore cheek volume; we recommend the free anterolateral thigh free flap.
- A quality reconstruction is not complete without dental restoration. Primary osseointegration of dental implants into the fibular osseoseptocutaneous free flap is a safe, reliable, and recommended option in select patients; for other patients, secondary osseointegration may be appropriate.
- Reconstruction of the condylar process remains a significant challenge that inevitably downgrades the mobility and quality of any mandibular reconstruction; no ideal method is currently available.
References


The author describes a useful and straightforward classification system for segmental mandibular defects that is easy to remember and communicate. It has become the standard classification system for segmental mandibular defects used at our institution, in particular for audit and research purposes.


In this landmark article, Hidalgo describes the first 12 cases of segmental mandibular reconstruction using the free fibular flap. He introduces some important principles in designing the fibula bone to mimic the mandibular contour but concludes that the skin paddle is unreliable, especially if placed intraorally. (He revokes this claim in later publications.)


In this series of 27 consecutive cases, all patients underwent fibular osteoseptocutaneous free flap reconstruction for segmental mandibular bone defects with soft tissue loss. All soft tissue defects were reconstructed using either one or two skin paddles of the fibular osteoseptocutaneous free flap; 13 also required a second soft tissue free flap. Only one total flap failure occurred (96.3% success); there were no instances of isolated, partial, or complete fibular osteoseptocutaneous free flap skin paddle necrosis.


By comparing the short- and long-term results of free iliac crest and free fibular flaps used for mandibular reconstructions, the authors conclude that the fibula yields generally superior results and should be considered the free flap of choice. They consider the iliac crest a useful complementary free flap.


This paper describes segmental mandibular resection and fibular osteoseptocutaneous flap reconstruction with primary osseointegration of dental implants to provide total rehabilitation expediently.
General Rehabilitation After Head and Neck Surgery

Peter C. Neligan

HIGHLIGHTS

- Nutrition is important for wound healing, but postoperative nutrition in head and neck patients may require significant additional therapy.
- Along with the need to establish proper nutrition, the function of speech and swallowing are vital; all of these functions are interwoven.
- Attention to physical rehabilitation, including mouth opening and neck and shoulder movement, is vital for the recovery of these patients.

Surgery of the head and neck is major surgery that has a significant impact on patients, more so than many other types of surgery. The head and neck is unique in its combination of form and function. The calvarium provides protection for the brain as well as providing contour for the head. The skull base is the region through which numerous vital structures, including vessels and nerves, pass from the cranium to the rest of the body. The midface houses several specialized structures, including the eyes and the sinuses, and it forms the upper arch of the dentition. The mandible makes up the lower arch. It is an extremely strong bone and, apart from forming the platform for the lower dentition, also plays a role in speech and swallowing. Surgery on any part of the head and neck therefore can have major implications for function, let alone for cosmesis and social participation. As a consequence, these patients
often require extensive rehabilitation. These issues underline the necessity that these patients be treated by a multidisciplinary team. Recovery from any major operation is a lengthy process that can be further complicated by the postoperative adjuvant treatment that these patients often must face. Although many of the processes that are necessary for full recovery are obvious, there are some special to the head and neck that demand attention.

**Nutrition**

It is not unusual for patients undergoing head and neck surgery to have some degree of nutritional deficiency before their surgery. This is particularly true in patients presenting with mucosal tumors, such as those in the tongue, the upper aerodigestive tract, and the floor of the mouth, because of the pain and discomfort that they cause, which is often exacerbated by the passage of foodstuff. Also, mobility may be impeded in the tongue, the palate, the pharynx, or the upper esophagus, making swallowing difficult. Patients with tumors elsewhere in the head and neck are less likely to suffer from these effects, though they may, of course, be debilitated from their tumor load in the same way that any other cancer patient may be. It is therefore imperative that patients be nutritionally supported throughout the perioperative period. This is best achieved by the placement of an enteric feeding tube, and a nasogastric tube is the simplest way to do this. However, for patients with bulky tumors in the upper aerodigestive tract, passage of a nasogastric tube may be physically impossible. In these cases a percutaneous tube placed in the stomach or jejunum works well (Box 34-1). Some patients will need permanent g-tube feeding, though the goal, whenever possible, is to restore the ability to swallow. Even in patients who are able to swallow, nutritional supplements administered by tube can make it easier to achieve adequate calorie intake for optimizing healing and recovery. Many patients require postoperative radiation, and it is frequently necessary to continue tube feeding or tube supplementation during radiation treatment, because the short-term effects of radiation may preclude swallowing. It is also important to remember that there may be certain supplements that these patients require, depending on the type of surgery that they have undergone. For example, calcium supplementation may be important for patients who have had their parathyroid glands removed.

**Box 34-1  Nutrition Facts**

- Consider necessity for tube feeding
  - Nasogastric
  - Percutaneous endoscopic gastrostomy
- Consider temporary tube feeding/supplementation during adjuvant treatment
- Consider need for dietary as well as electrolyte supplementation
**Speech and Swallowing**

As already mentioned, the goal of surgery is to restore function to normal as nearly as possible. Swallowing has already been discussed to some extent in the previous section, because it is integral to achieving adequate nutrition. The goal of surgery on the tongue, apart from tumor ablation, is to reconstruct the tongue in such a way as to maximize mobility. This is less of a challenge with partial glossectomy defects as it is with patients who have total and subtotal glossectomy. These patients are also particularly vulnerable to continual aspiration because of the inability to control secretions and protect the larynx. Various operations have been devised to mitigate this effect. The normal swallowing process is instigated by pressing the tongue against the palate—not being able to do this makes the initiation of swallowing very difficult. In these cases the floor of the mouth tends to act as a funnel, with secretions being swallowed as they overflow into the pharynx rather than being actively pushed back by the tongue. Maintaining bulk in the reconstruction helps restore a more normal swallowing process. Adding movement that allows the reconstruction to function more like a normal tongue is theoretically beneficial, and several such operations have been designed. However, as with any situation where several operations have been devised, there is no single operation that adequately does the job.\(^1\)\(^-\)\(^3\)

Regardless of the type of resection and/or reconstruction, patients with tongue defects can benefit from treatment by a qualified speech-language pathologist to help them relearn the mechanism of speech and swallowing.

Like swallowing, speech is a function of tissue pliability and mobility. Speech is particularly affected by larynx tumors and intraoral tumors involving the tongue, and speech rehabilitation is most pertinent in patients who have undergone laryngeal surgery (Box 34-2). Although the goal of laryngeal cancer treatment is disease eradication combined with organ preservation, this goal is not always attainable. For partial laryngeal defects, reconstructive procedures have been reported that functionally reconstruct the larynx and restore the ability to speak.\(^4\)\(^-\)\(^6\) Unfortunately, when such a procedure is not feasible, the patient may need to undergo a laryngectomy, which, by definition, removes the ability to speak. However, voice rehabilitation following laryngectomy is still possible.

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**Box 34-2  Speech and Swallowing**

- Early involvement by speech language pathologist
- Tracheostomy
  - Temporary
  - Permanent
- Consider need for adjuvant treatment and how it will affect speech
- Be aware of the possibility of aspiration
In the West, voice rehabilitation is most commonly achieved through a procedure called tracheoesophageal puncture (TEP), which is a very effective way to restore some form of speech.\textsuperscript{7-9} The tracheostome is punctured, which allows access to the esophagus immediately behind it, and a valve is placed in that aperture. Intensive therapy with the aid of a speech language pathologist is necessary after this procedure. In the East there is more of a preference for autologous voice reconstruction using flaps that incorporate a valve, such as the ileocecal valve, to reproduce speech.\textsuperscript{10,11} Apart from these techniques, there are also electronic devices that can produce an atonal kind of speech. These devices are held to the neck by the patient and, though they sound strange, they can nevertheless be very effective in helping these patients to communicate. Good care by competent nursing staff and respiratory technicians is essential during the early postoperative period.

**MOUTH OPENING**

Maintaining good oral hygiene is all part of the postoperative care and rehabilitation of the patient. Many patients go on to receive postoperative radiation therapy, and the combination of postoperative scarring with radiation-induced fibrosis has a tendency to produce trismus with intraoral tumors. It is therefore important to coach patients on maintaining an adequate mouth opening. Once again, the assistance of a qualified therapist makes this task easier. In cases where a degree of trismus is already established, the use of multiple tongue depressors can be helpful in improving the mouth opening. The patient simply inserts as many wooden tongue depressors as possible between the central incisors, sliding extra depressors into the middle of the stack to stretch the tissues. This is a cheap and effective way to improve mouth opening, and it helps that the patient is in control of it.

**AIRWAY MANAGEMENT**

Airway management is always an issue with head and neck patients, particularly in the perioperative period (Box 34-3). Patients with upper aerodigestive mucosal tumors almost always require a tracheostomy intraoperatively to facilitate tumor ablation. Even in patients with the most minor of resections, the endotracheal tube is often left in place until postoperative swelling has abated. When a tracheostomy is used, it is left in place during the early postoperative period, allowing the patient to recover from the initial postoperative edema with a secure airway. Once the initial postoperative swelling has abated, the cuffed tracheostomy tube is exchanged for a fenestrated tube, which is then corked to ensure that the patient can manage without the tube before being decannulated. It is important during this period that airway care be meticulous, that secretions be regularly aspirated, and that the site be kept clean. One of the most important things to remember is that many of these patients have had free flap reconstruction, and the pressure on the pedicle of a flap from a tracheostomy tie can cause obstruction and flap thrombosis. It is our practice to avoid tracheostomy ties and, instead, to suture the tracheostomy tube in place.
Box 34-3  Airway Management

- Temporary or permanent tracheostomy
- Tracheostomy ties and free flaps
- Meticulous airway care
- Involvement of nursing/respiratory therapy
- Be aware of the possibility of aspiration

NECK AND SHOULDER MOVEMENT

Extensive surgery in any body region can, of course, result in stiffness. The head and neck is no exception. We have already discussed the issue of mouth opening. Neck and shoulder mobility is equally important. Though injury to the accessory nerve in neck surgery is not especially common, it is not uncommon for patients to suffer some neck and shoulder stiffness or some element of temporary accessory nerve paresis. Patient comfort is enhanced by minimizing postoperative stiffness, and postoperative physical therapy is very helpful to that end.

CONCLUSION

Head and neck surgery is demanding for the surgeon because of the intricacy of the anatomy and because of the difficulty in achieving reconstructions that replace complex functional mechanisms. Not only does this difficulty require unique surgical solutions, but it also requires unique rehabilitative solutions.

CRITICAL POINTS

**Must Know**
- The swallowing reflex may be significantly compromised following treatment.
- Aspiration is a significant risk.

**Should Know**
- The involvement of a speech-language pathologist may be an important part of a patient's rehabilitation.
- The ability of the patient to communicate may be compromised after surgery, and this fact should be acknowledged.

**Synopsis**
- Treatment of most head and neck malignancies can affect a number of vital functions.
- It is important to reestablish the patient’s ability to eat and drink as well as to speak and communicate.
- Multidisciplinary care in rehabilitation is an important part of treatment.
References


The clinical records of 28 patients undergoing primary or salvage hemicricoid hemilaryngectomy for laryngeal cancer (26 patients) and pyriform sinus cancer (2 patients) were analyzed for function and local control. Functional reconstruction of extensive laryngeal defects can be achieved with an autotransplantation of cervical trachea, with favorable functional results and acceptable morbidity. This technique expands the limits of conservation surgery for selected laryngeal and hypopharyngeal tumors.


The authors describe their experience using the Provox voice prosthesis in patients undergoing free jejunal loop transfer following total pharyngolaryngectomy. The use of a voice prosthesis appears to be an effective method of speech rehabilitation in this group of patients.


Voice reconstruction and rehabilitation are important for quality of life after surgical ablation of tumors in the larynx or pharynx. In addition to the esophageal voice, the artificial larynx, and external voice devices, the following procedures have been developed: (1) after laryngectomy with preservation of pharynx, neoglottis or TEP can be performed; (2) after laryngopharyngectomy, either a forearm flap with TEP or a jejunal transfer with TEP or voice tube shunt can be selected; and (3) after laryngopharyngoesophagectomy, either pharyngogastrostomy with TEP or colon segment interposition with TEP can be employed. The voice tube shunt is improving, and allograft transplantation is currently under investigation.
Osseointegrated Implants

Yang-Ming Chang, Christopher G. Wallace, Fu-Chan Wei

HIGHLIGHTS

- Segmental mandibular (or maxillary) reconstruction is incomplete without dental rehabilitation.
- Whether primary or secondary osseointegration of dental implants is selected, the occlusal alignment of implants and native dentition must be accurate.
- In properly selected patients, a complete, single-stage functional and anatomic reconstruction can be safely achieved by combining primary osseointegration of dental implants with microsurgical transfer of the fibular osseoseptocutaneous free flap.
- Implant-related complications include implant failure, implant fracture, bone loss, mucosal irritation, and pyogenic granuloma. Methods to deal with these complications are discussed.

Microsurgical free tissue transfer provides the best chance of achieving optimal mandibular reconstruction when an appropriate vascularized bone-containing flap is used. A functional reconstruction is incomplete without dental rehabilitation, which is best achieved using osseointegrated dental implants. Traditionally, this has been performed as a secondary procedure. Recently, it has been demonstrated that an aesthetic and functional oral reconstruction is possible in a single operation by combining the free vascularized fibular osseoseptocutaneous flap transfer with simultaneous placement of osseointegrated dental implants. The success of this procedure depends on accurate placement and fixation of the implant-fibula construct to maintain interarch and interocclusal relationships.
CHARACTERISTICS OF VARIOUS VASCULARIZED OSSEOUS FLAPS FOR OSSEOINTEGRATION

The fibula, iliac crest, and scapula are commonly used sources of free vascularized bone flaps for mandibular reconstruction. Many factors influence the outcome of dental reconstruction with osseointegrated implants, including bone dimensions, bone quality, bone remodeling capacity, and the availability of soft tissues that can be imported with the flap. These factors vary with each source of vascularized bone.

Bone Dimensions

The vertical height and width of the harvested bone must be adequate for the placement of dental implants. In general, at least 1 mm of healthy bone must surround the implant to ensure adequate osseointegration. The minimum width of bone required for dental implant installation is 6 mm, and the minimum vertical bone height is 7 to 10 mm⁴⁻⁶ (Fig. 35-1). In addition, at least 1 mm of healthy bone is required beneath the implant. In a cadaver study, the dimensions of bone available for implant placement from the fibular, iliac crest, scapular, and radial flaps were measured.⁷⁻⁹ The results showed that the fibular and iliac crest flaps consistently had adequate bone dimensions for osseointegration. Most of the scapular flap specimens had adequate bone dimensions, but the majority of radial flaps had inadequate bone dimensions to support osseointegrated dental implants. Furthermore, when considering osseointegration, the difference in height between the vascularized bone flap and the native mandible should also be evaluated. The available bone height from iliac crest and scapular flaps is adequate, but is generally inadequate for fibular and radial flaps. Methods to overcome the inadequacy of fibular bone height are described in Chapter 33.

Fig. 35-1  A, Minimal fibular bone requirements for implant placement are a vertical bone height of 10 mm and a width of 6 mm. B, At least 1 mm of healthy bone is needed around the dental implant to prevent bone resorption in occlusal functional loading.
Cortical Bone Thickness and Bone Density
The cortical thickness of the donor bone plays an important role in osseointegration by providing initial stability for the implant fixture. Cortical bone is highly osteoconductive because of the haversian system and is more resistant to resorption. Cancellous bone density is also important, because it is rich in osteogenic cells. It is responsible for the biologic response and mechanical support of the implant fixture. The quality of the bone-implant interface may affect the initial stability that is crucial for obtaining osseointegration. A low bone density at the interface may be relatively unfavorable for osseointegration, because micromotion during the osseointegration period can impair early bone healing. Therefore, when an implant fixture is placed in thicker cortical bone, better initial implant stability is provided and a higher probability of successful osseointegration results. The fibula provides a relatively thick cortex and high bone-implant interface density, but its cancellous bone density is low. The iliac crest has abundant cancellous bone; however, its cortical bone is relatively thin, and the bone-implant interface stiffness is low. The scapula has a relatively low grade of cortical thickness and bone-implant interface stiffness.

Primary Stability
Impaired primary implant stability can jeopardize the osseointegration process. Removal torque (bottomed out in the implant site) is one of the most commonly used indicators of implant stability. Rohner et al inserted implants into the fibula, iliac crest, and scapula in six Yorkshire pigs to evaluate the removal torque of unloaded implants. The study showed that removal torque increased with healing time. The mean removal torque values were all well above 35 N/cm², the suggested value for abutment fastening. They concluded that the fibula, iliac crest, and scapula are adequate recipient sites for implant placement. A healing time of 3 weeks was deemed sufficient to allow adequate interfacial strength and to resist 35 N/cm² of fastening torque with a sufficient margin of error. Niimi et al placed implants in the fibula, iliac crest, and scapula in formalin-preserved cadavers (bicortical stabilization) and reviewed their removal torque values. They found a significant correlation between the removal torque value and cortical bone thickness, but no significant correlation between the removal torque value and total bone thickness. They suggested that the fibula offered the strongest removal torque value for a dental implant compared with the iliac crest and scapula. Akkocaoglu et al also compared the primary stability of dental implants placed in human cadaveric fibula, iliac crest, and scapula (unicortical stabilization). They concluded that the primary mechanical stability of implants placed in the fibula was higher than those placed in the iliac crest and the scapula, although the bone mass and density around the implants in latter sites were higher.

Interface
Rohner et al studied the interface strength in the bone-implant surface with the bone under unloaded conditions. They described a good interface strength at the bone-implant surface in the fibula, iliac crest, and scapula of pigs. Bicortically an-
chored 8 mm implants in the fibula were biomechanically as stable as monocortically anchored 12 mm implants in the scapula and iliac crest. The length of the implant and the amount of bone-to-implant contact were the determinants for interface strength within cancellous bone. They concluded that bicortical anchorage determined implant stability in the fibula, whereas interfacial strength seemed to define stability in the scapula.

Although these and similar experiments have determined that no single source of vascularized bone flap can provide perfect conditions for osseointegration, we and others have found that the fibular osseoseptocutaneous flap offers predictable outcomes for osseointegrated dental implants performed primarily or secondarily.9-11

PRINCIPLES OF DENTAL RESTORATION IN THE FIBULAR OSSEOSEPTOCUTANEOUS FREE FLAP

Patient Selection and Primary or Secondary Osseointegration

The choice of primary or secondary osseointegration depends on whether the lesion is benign or malignant, the status of adjacent skin and soft tissues, and patient motivation. Primary placement of osseointegrated implants is beneficial for earlier restoration of oral function and psychosocial stability, but requires a careful selection of candidates. Patients with traumatic mandibular defects are ideal for primary osseointegration, because they are typically young and active physically and socially. Even smaller segmental bone defects that were commonly reconstructed with conventional grafts previously can benefit from free vascularized bone grafts with primary dental implants.12 Patients with benign tumors such as ameloblastoma of the mandible also can benefit from primary osseointegration, as can patients with osteomyelitis, osteoradionecrosis, or low-malignancy tumors that do not require postoperative radiation and have a minimal risk of recurrence.10

Patients with trismus, severe periodontal disease with stomatitis, or advanced caries should be excluded from consideration for primary osseointegration, because these factors can compromise the process.13,14 Primary placement of implants facilitates surgical access to the bone, eliminates one surgical procedure, and helps create adequate dental arch relationships, avoiding inclination of implants. Disadvantages include prolonged operative time, although the placement of three to four implants usually requires less than 1 additional hour.

Secondary placement of dental implants is technically less demanding if the bone defect has been replaced adequately. A disadvantage of secondary osseointegration teeth implantation is a prolonged reconstruction period with at least one additional surgical procedure.
Patients who have malignant tumors with a risk for recurrence or who require postoperative radiation therapy are, in our experience, not suitable candidates for primary osseointegration. In select patients, however, secondary insertion of dental implants can be a reasonable alternative 1 to 2 years after ablative surgery, as long as no sign of tumor recurrence or osteoradionecrosis is present. For complex mandibular reconstructions using multiple osteotomies and incorporating multiple implant insertions, primary osseointegration is more challenging than secondary osseointegration.15

THE THREE STAGES OF IMPLANT PLACEMENT

First Stage: Implant Fixtures

The first stage of osseointegration can be performed primarily (that is, at the same operation as the microsurgical mandibular reconstruction with vascularized bone transfer) or secondarily during an additional procedure. Primary osseointegration involves a reconstructive microsurgery team working in conjunction with oral maxillofacial surgeons. Intermaxillary fixation is performed to achieve accurate occlusion after mandibulectomy. A titanium reconstruction plate is contoured preoperatively to simulate the shape of the mandible according to a stereolithographic mold (Fig. 35-2). This plate is temporarily fixed to both ends of the remaining native mandible, leaving a 20 to 25 mm space between the superior border of the reconstruction plate and the occlusal plane of the inferior edge of the maxillary teeth.

Fig. 35-2  A, Marking normal contour on a stereolithographic wax mold. B, The reconstruction plate is contoured according to the normal mandible outline.

A vascularized free fibular osseoseptocutaneous flap is harvested, and osteotomies are performed at a back table to provide bone segments for definitive reconstruction. The fibula segments are then temporarily fixed to the inner side of the reconstruction plate, with the upper border of the fibula bone placed at least 5 mm above the superior edge of the reconstruction plate.2,11 Implant positions in the fibula are determined according to the positions of the opposite maxillary teeth.
The fibular segments are removed from the plate, and endosteal implants are inserted at a back table. To maintain the vascularity of the free fibula bone, a maximum of two endosteal implants are placed in a bone segment at least 3 cm long, and a single screw is used for fixation to the reconstruction plate. Implant waxing screws (12 mm) are connected to the fixtures to guide adjustment of the vertical axis and to direct the occlusal loading force when the bone is replaced at the recipient site (Fig. 35-3). Waxing screws are prosthodontic components that are normally placed on implant impressions to wax the prosthesis. The use of waxing screws in this procedure prevents the fibular segments from being fixed in a tilted position (resulting in misalignment of the final implant positions), which is important because the long axis of the occlusal loading force allows a maximal divergence of only 15 degrees. After confirmation of accurate positioning of the fibula-implant construct, the waxing screws are removed and replaced with implant cover screws.

If the inferior alveolar nerve has been included in the mandibular resection of a benign tumor, the sural nerve is used as an interpositional graft to restore nerve continuity before the bone graft is finally fixed to the recipient site. After insetting the skin island, microvascular anastomoses to the recipient vessels are performed. The warm ischemia time is usually less than 4 hours for this procedure.

Primary placement allows easier access to the mandible, provides the best opportunity to obtain an optimal dental ridge relationship, and decreases the number of surgical procedures and time required for complete dental rehabilitation.
Second Stage: Healing Abutments and Palatal Mucosal Graft

Placement of the palatal mucosal graft is performed as a secondary procedure about 6 months after insertion of the endosteal implants. An incision is made along the top of the fibular bone (forming the neomandible), and buccal and lingual flaps are elevated in a supraperiosteal plane (Fig. 35-4, A). The buccal and lingual flaps are trimmed and sutured to the underlying periosteal surface at a lower level to expose the superior border of the bone. A subperiosteal incision is made around the implants to replace them with healing abutments (8 mm high). Self-curing acrylic resin is molded into this newly created vestibulum at the dough stage, and povidone-iodine (Betaiodine) solution is used to irrigate and cool the tissue during polymerization. The stent margins are smoothed with an acrylic bur.

A split-thickness palatal mucosal graft that extends at least 6 mm beyond the implants is harvested, grafted to the recipient site, and sutured to the underlying periosteum using 4-0 Vicryl suture (Fig. 35-4, B). A periodontal dressing material is placed inside the stent to stabilize the underlying mucosal graft, and the healing abutment is used to retain the acrylic stent (Fig. 35-4, C). This technique helps avoid the need for circumferential wiring or screw fixation of the stent. This stage can be performed under local anesthesia.

Fig. 35-4  A, Supraperiosteal dissection of the neomandible. B, A fabricated self-curing stent. C, Palatal mucosal graft sutured to the periosteum around the implants.
The stent and periodontal dressing are temporarily removed after 10 days, and the adequacy of mucosal adaptation is checked.

The stent should be worn for 4 weeks, until the final prosthesis is fabricated, but it must be taken off for cleaning every day. This procedure prevents the mucosa from creeping up as a result of lateral or lingual muscular reattachment.17

Third Stage: Fitting the Prosthesis

Segmental mandibular reconstruction can provide acceptable cosmesis, but normal mastication and deglutition are difficult to achieve with conventional removable dentures. Since 1988, our treatment protocol has been modified to use endosseous root-form implants to support dental prostheses, instead of the conventional removable prostheses in these patients. Two types of prosthesis can be constructed over dental implants: (1) a removable implant overdenture and (2) a fixed detachable prosthesis. In general, patients tend to select the latter option during consultation; however, a fixed detachable prosthesis may present problems such as phonetic discrepancies, food impaction, difficult home care, and poor aesthetics for patients with a high lip line (gummy smile). In addition, it is not easy to fabricate accurately in the laboratory. To help overcome these problems, a double-coping technique can be used to fabricate dentures.16

A study cast is taken and transferred to the articulator by a face bow. A diagnostic wax-up is performed on the study cast, and a vacuum form is made, followed by the diagnostic wax-up cast. The vacuum form can be used to check the vertical dimensions and the position of the definitive prosthesis. The sites of the implant fixtures are transferred by silicon impression and fixture analogues. The previous vacuum form is inserted on the transferred cast to determine the position of the inner coping. The inner coping is fabricated and confirmed for a passive intraoral fit (Fig. 35-5, A). After tightening the inner coping with screws and blocking the undercut areas around the inner coping, a mast cast is taken using medium body impression material to fabricate the outer coping. Porcelain is fused to the outer coping, and the definitive prosthesis is finished with occlusal adjustments. Temporary cement is used to fill in the inner surface of the outer coping and to cement it to the outer surface of the inner coping (Fig. 35-5, B). The technique improves the shortcomings of fixed, detachable prostheses and provides the satisfactory, normal mastication and deglutition desired by patients.15
Inaccurately Aligned Implants

Inaccurate implant alignment can lead to malocclusion. It is possible to use angulated abutments in the third stage of implant placement to compensate for this malocclusion. To do this, the degree of angulation should be less than 15 degrees (in lingual or buccal directions). If the degree of angulation exceeds this threshold, the fixture should either be removed or replaced following bone grafting of the drill hole. Angulated abutments may, however, have poor aesthetics and eventually fail as a result of long-term unfavorable mechanical loading. When positioning fixtures in native mandibular bone, it is better to use the manufacturer’s guide pins to check proper angulation in relation to the opposite arch before finalizing the drill hole for the fixture. In the fibula-implant construct, however, waxing screws are used instead of guide pins for this conformation stage.
Progressive Implant Malalignment With Mandibular Growth

Dental implant restoration in girls younger than 14 years of age and in boys younger than 16 should be undertaken with caution, because continued horizontal and/or vertical growth of the alveolar bone may lead to improper positioning of implants after growth is complete.14

Implant Failure

Five criteria define the success of dental implants: (1) implants should be immobile, (2) periimplant radiolucency should be absent, (3) annual vertical bone loss should be less than 0.2 mm, (4) patients should be asymptomatic, and (5) an 85% 5-year survival rate should be expected.16

Several factors can lead to implant failure between the first and second stages, including infection, premature or transmucosal loading from inadequate initial stabilization, heavy cigarette smoking, and exposure of the implant during the healing phase. The quality and quantity of bone must be considered. Severe osteoporosis following radiation therapy, bisphosphonate drug use,17 and other unidentified metabolic bone conditions probably affect the ability of bone to bond properly to titanium on a long-term basis. Immediate removal of all mobile implants is important to minimize destruction so that healing and reimplantation can proceed as needed.

Dental radiographic evaluation of the degree of implant osseointegration is not reliable. Periimplant radiolucency is not always present around failing implants. Even if complete periimplant radiolucency is noted, there is probably more bone destruction than is apparent from the radiograph. Clinically, reverse torque testing of an implant at 20 N/cm² is a valid objective test for osseointegration. A well-integrated implant needs more than 45 N/cm² of reverse torque for removal, whereas an integrated implant stabilized bicortically in the mandible requires more than 70 N/cm² for removal. Consequently, the application of 20 N/cm² of force in reverse does not harm a properly integrated implant.18

Management of Failed Implants

When an implant failure is identified, the implant should be removed immediately. Soft tissues should be completely curetted from the socket. Bone grafting or implantation of a larger fixture in the cavity may be possible, but requires at least 1 mm of buccal and lingual cortical bone on either side of the implant.19
Implant Fracture

Two types of periimplant fractures have been identified using scanning electron microscopy. The first is a fatigue fracture, which is a result of multiple incidences of occlusal trauma (overloading or bending) through the body of the implant itself that the implant cannot withstand. The second is a shear fracture, which is a catastrophic result of occlusal overloading; this usually occurs within the abutment screw.20

Repeated loosening of prosthesis components calls for a check of the entire prosthesis for fit and design. In posttreatment instructions to the patient, it is important to include a warning that any looseness of the prosthesis is considered a relative emergency that needs immediate assessment and correction. Bruxism or extremely heavy bites have been noted as causes.

Bone Loss

Most implants exhibit routine bone loss to the first or second thread.17 If bone loss has progressed beyond that level after a short period of time, the fit of the prosthesis must be checked; lateral occlusal forces or parafunctional habits may be implicated.21 Metabolic diseases causing rapid bone loss are uncommon.

Mucosal Irritation and Pyogenic Granulomas

Nonkeratinized, mobile tissue easily causes discomfort and chronic irritation to the extent that normal hygiene procedures cannot be carried out comfortably, and plaque builds up. More serious irritation may occur when pyogenic granulomas form adjacent to the abutments. They have usually been seen in areas with mobile, nonkeratinized tissue around the abutments. Attempts to eradicate these granulomas by surgical excision, electrocautery, or laser removal are usually unsuccessful, particularly if the hygiene problem is not resolved.14

Successful eradication of these granulomas has been accomplished by removing the abutment and allowing the keratinized mucosal tissue graft to heal over the implant for 4 to 6 weeks.21 After the mucosa attains a normal appearance and completely heals over the implant, the abutment is reexposed and installed. The keratinized tissue can be provided to encompass the abutment completely. This process is one of the few ways in which these granulomas have been eradicated.
RESULTS

Reconstruction of a Hemimandibulectomy

This case presents the reconstruction of a hemimandibulectomy and intraoral defect with a fibular osseoseptocutaneous flap and primary placement of osseointegrated implants. A 46-year-old woman with an ameloblastoma extending from the right mandibular body to the left parasymphysis area underwent en bloc resection and reconstruction with a reconstruction plate and iliac bone block graft. Unfortunately, the nonvascularized bone graft became infected and required removal. The presurgical mandibular contour was maintained with a plate-only reconstruction. She presented to our hospital 3 years later (Fig. 35-6, A and B) requesting aesthetic improvement and a functional restoration with a denture. A reconstruction plate was contoured to the mandibular border according to the morphology of the opposite jaw. A vascularized free fibula osseoseptocutaneous flap was harvested and osteotomized once to produce two segments (4 cm and 6 cm). Four endosteal dental implants were inserted at a side table. The implant-fibula construct was transferred to the recipient site, and waxing screws were used to check for a proper interarch relationship. Finally, the fibula was fixed to the reconstruction plate with screws (Fig. 35-6, C and D), and a portion of the fibular osseoseptocutaneous skin paddle (3 by 6 cm) was used to reconstruct the intraoral lining (Fig. 35-6, E).

Six months later, the implants were uncovered and surrounded with a palatal mucosal graft. One month later, the final functional prosthesis was completed. The patient and her family were satisfied with the results (Fig. 35-6, F through H).

Fig. 35-6  A, This patient is shown before reconstruction. B, Panorex radiography reveals the disappearance of a previously grafted nonvascularized iliac bone.
Fig. 35-6, cont’d  C, A waxing screw is connected to the implant-fibula construct. D, The interarch relationships are checked with the waxing screw. E, An intraorally placed skin paddle. F, A prosthesis has been fabricated. G, Panorex radiography of reconstructed mandible. H, The patient 18 months after reconstruction.
One-Stage, Double-Barreled Fibular Osseoseptocutaneous Flap

This case presents a one-stage, double-barreled fibular osseoseptocutaneous flap and immediate dental implants for functional and aesthetic reconstruction of a segmental mandibular defect. A 38-year-old woman presented with a mandibular ameloblastoma extending from the left first molar to the left condyle area (Fig. 35-7, A). A three-dimensional wax model was fabricated to plan the osteotomy sites and contour the reconstruction plate before surgery. The ablative defect extended from the left second premolar area to the left condyle area. The prefabricated reconstruction plate was fixed along the lower border of the native mandible. A left fibular osseoseptocutaneous flap with 22 cm of bone and a 6 by 3.5 cm skin paddle was harvested. Osteotomies were performed on a side table to produce a total of three segments: segment A was 7 cm, segment B was 3 cm, and segment C was 6 cm. The most proximal (in relation to the peroneal vascular pedicle) segment (A) was used to form the upper part of the alveolar ridge of the mandible to serve as the carrier for osseointegrated implants. The second segment (B) was removed subperiosteally and discarded. Segment C was rotated downward and placed along the lower border of the mandible parallel to segment A (Fig. 35-7, B). Two osseointegration teeth were implanted into segment A at a side table, and their proper positions for interarch occlusion relationships with the upper first and second molar teeth were confirmed with waxing screws (Fig. 35-7, C). Miniplates were used for osteosynthesis between segments A and native mandible. Segments A and C were fixed to the reconstruction plate with screws. After confirming adequate peroneal pedicle length to the recipient facial vessel in a smooth nontwisting manner, the skin paddle of the fibular osseoseptocutaneous flap was used to restore the oral lining and to provide soft tissue augmentation. Microsurgical anastomoses were performed. The postoperative course was smooth.

The patient underwent the second stage procedures 6 months later. This included connection of abutments to the implants, and replacement of the skin flap around the abutments with a palatal mucosal graft. An implant–tissue-supported prosthesis was installed 1 month later to conclude rehabilitation. At the 24-month follow-up, she had good facial appearance with functional teeth. Radiographs showed bone healing between the transplanted fibula and the native mandible (Fig. 35-7, D and E).
Fig. 35-7  A, Preoperative radiography of mandible ameloblastoma. B, Two implants were inserted into segment $A$ (upper strut), which forms the alveolar ridge of the new mandible. Segment $B$ (lower strut) has been rotated inferiorly to rest parallel to segment $A$; this forms the inferior portion of the new mandible. C, The interocclusal relationship was checked with waxing screws. D, The patient is shown 24 months after total rehabilitation. E, Panorex radiography after surgery.
Maxillary Reconstruction With an Anterolateral Thigh Free Flap and Vascularized Bone Graft

This case presents maxillary reconstruction with an anterolateral thigh free flap followed by postoperative radiation therapy, with a fibular osseoseptocutaneous free flap and primary osseointegration of dental implants. A 29-year-old woman was treated surgically 1 year previously for an adenoid cystic carcinoma located in the right maxilla. She underwent hemimaxillectomy and an upper neck dissection. The defect was reconstructed with an anterolateral thigh free flap, and the patient received postoperative radiation therapy (Fig. 35-8, A and B). She subsequently requested functional oral reconstruction and treatment for her right facial deformity.

The anterolateral thigh free flap was elevated in the reconstructed maxillary region to provide the space for a new maxillary alveolar ridge (Fig. 35-8, C). The area from the right zygomatic bone to the native left maxillary alveolar ridge was bridged with a free fibular osseoseptocutaneous flap that had been osteotomized once to produce two segments (4 cm and 3 cm). Four dental implants were inserted into the two fibular segments at a side table. Waxing screws were connected to the implant-fibula construct and used to accurately restore the interarch relationships (Fig. 35-8, D and E). Miniplates were used for fixation, and the monitor skin paddle was placed intraorally. Eight months later, the implants were uncovered and surrounded with a palatal mucosal graft. Finally, an implant-supported prosthesis was fabricated and installed (Fig. 35-8, F).

Fig. 35-8  A, A right maxillary defect was reconstructed with an anterolateral thigh flap. B, Panorex radiography was obtained before maxillary bone reconstruction.
Vertical Distraction of a Free Fibular Osseoseptocutaneous Flap

This case presents vertical distraction of a free fibular osseoseptocutaneous flap to correct alveolar ridge height insufficiency, followed by secondary osseointegration of dental implants. This 30-year-old man had multiple facial bone fractures from a fall and underwent open reduction and internal fixation with miniplates at another hospital. A postoperative infection caused loss of the mandibular parasymphysis. Sequestrectomy performed elsewhere resulted in a collapsed dental arch with malocclusion. He presented to us requesting rehabilitation of oral function.
A fibular osseoseptocutaneous free flap was harvested and used to reconstruct the mandibular symphysis area (Fig. 35-9, A and B). Six months later, vertical distraction of the fibula was initiated using an intraoral device (Track 1.0) (Fig. 35-9, C). A distraction rhythm of 1 mm per day for 2 weeks was used. Consolidation was complete after 3 months, and a 13 mm increase in height was obtained (Fig. 35-9, D). One month later, three dental implants were inserted. A vestibuloplasty was incorporated into the second stage of osseointegration (palatal mucosal graft). A good occlusal relationship was achieved (Fig. 35-9, E and F).

Fig. 35-9  A and B, Clinical appearance and Panorex radiograph after mandibular reconstruction with a single-strut fibular osseoseptocutaneous free flap. C, A vertical distraction device was applied after transverse osteotomy of the transferred fibula (neomandible). D, CT imaging shows a cross section of the reconstructed mandible after the completion of vertical distraction (13 mm increase in vertical height). E, The prosthesis is shown 2 years postoperatively. F, Panorex radiography of the mandible after prosthetic appliance restoration.
LONG-TERM RESULTS

From 1993 through 2005, 109 patients with various composite bone segmental mandibular and maxillary defects underwent reconstruction with a fibular osseoseptocutaneous free flap. Eighty-four received primary and 25 received secondary osseointegration teeth implantations. Among the 84 patients with primary osseointegration teeth implantation, 76 had a single-strut fibular osseoseptocutaneous flap (a total of 280 implants were sited in the fibular bone and 17 were sited in the native mandible), and 8 patients had double-barreled fibular osseoseptocutaneous free flap reconstruction (a total of 19 implants were sited in the upper strut of fibulas). Among 25 secondary osseointegration teeth implantation patients, 21 patients underwent single-strut fibular osseoseptocutaneous free flap reconstructions (a total of 78 implants were sited in the fibula bone and 9 implants were sited in the native bone). Vertical distraction of the fibular bone was performed in 4 cases, and a total of 13 implants were installed in new alveolar bone.

Of these 416 implants, 6 implants became loosened, all in the single-strut fibular and secondary implantation group; no implants became loosened in the primary implantation group. We have found that special care needs to be exercised when placing implants in the region of the second premolar. The height of this region and the angulation required to correct any malocclusion between the upper arch and the fibula-implant construct can be difficult to overcome when using the primary osseointegration method. For this reason, early in this series seven primary fixtures placed in single fibular struts could not be fitted with abutments in the third stage.

Bone loss around the implants was less than 1.5 mm after 33.6 months (average) with oral functional loading (Fig. 35-10). Keratinized palatal mucosal grafts around dental implants provided good oral hygiene. The recovery of lower lip sensation after sural nerve grafting of disrupted inferior alveolar nerves required 3 to 18 months. Implant-supported prostheses were found to be better than implant–tissue-supported prostheses in young patients.

Fig. 35-10  A, Panorex radiography obtained at the beginning of occlusal functional loading (in 1996). B, Panorex radiography of the same patient in 2005.
FUTURE DIRECTIONS

Advancement reconstructive surgery combined with oral function rehabilitation improves survival rates and life quality in patients with head and neck tumors. Complete oral rehabilitation can be achieved in a shorter period of time after microsurgical reconstruction with primary insertion of osseointegrated implants in properly selected patients. The fibular osseoseptocutaneous flap is a reliable composite tissue free flap that allows both procedures to be performed in one stage without additional risk of failure.

CRITICAL POINTS

Must Know
- Surgeons must know the anatomy of the fibula.
- Appropriate patient selection is essential for optimal results with primary and secondary osseointegration of dental implants.
- Techniques to achieve accurate interarch and occlusal relationships for dental implants must be applied.
- It is critical to understand and follow the three stages required for osseointegration of dental implants.
- The correct aftercare for osseointegrated dental implants helps ensure long-term success.

Should Know
- Surgeons should know the technique of primary osseointegration of dental implants.
- Knowing the advantages and disadvantages of the various vascularized free osseous flaps for implant osseointegration is essential for appropriate selection.
- Complications associated with osseointegrated dental implants should be properly managed and, ideally, prevented.

Synopsis
- Although microvascular vascularized bone transfer offers the best overall results for reconstructing segmental mandibular defects, total rehabilitation is incomplete without successful dental restoration. Currently, osseointegrated dental implants provide the best outcome in appropriately selected patients.
- This chapter describes the principles of dental rehabilitation using osseointegrated implants in free vascularized osseous flaps, including critical determinants of successful outcome such as proper patient selection criteria, accurate implant placement/angulation, correct implant aftercare, and methods to address complications if they occur.
References


   The segmental mandibulectomy and immediate vascularized fibular flap reconstruction with simultaneous placement of osseointegrated implants represents an ideal treatment method for large ameloblastomas of the mandible.


   Implants inserted in the fibula showed the highest removal torque when compared with those inserted in the iliac crest and scapula. Moreover, the removal torque was related to the thickness of the cortical bone in the implant site.


   This article describes the use of waxing screws to ensure accurate dental implant alignment in free fibular osteoseptocutaneous free flaps (for segmental mandible defect reconstruction) according to occlusal loading forces and vertical implant axis.

   This article describes a useful method for improving the soft tissue environment around implants. Palatal mucosal grafts are used to replace the skin component of osseous flaps and protect the implants, and acrylic stents are used for graft stabilization.


   This article discusses how complications from osseointegrated implants have become more numerous and frequent since its introduction in the early 1980s and the two general categories of complications: those associated with the surgical procedure, such as infection, and those associated with the implants, such as improper implant alignment and implant failure.


   The double-barreled fibular technique has been proposed to match the height of the native mandible. The inferior basal portion of new mandible is easily matched to the contour of the mandibular defect using a three-dimensional stereolithographic model. The upper part of the alveolar ridge (new mandible) is free of direction. For patients with an incorrect jaw interrelationship, such as a crossbite occlusion, it is very difficult to fabricate a prosthesis. This problem can only be treated with simultaneous dental implantation using waxing screws (as a guide) to connect the implant-fibula construct.


Deformities in the head and neck region can have a profound effect on the function, aesthetics, and psyche of an individual. Considerable time, effort, and ingenuity have been invested in developing meaningful reconstructive solutions to a wide variety of craniofacial defects. Autogenous reconstruction remains the benchmark, but, in certain cases, autogenous reconstruction may be contraindicated, technically impossible, or have the potential to only partially solve the reconstructive problem.

Historically, head and neck reconstruction using prosthetics has offered limited benefit. The retention of facial prostheses has been largely unsuccessful because of the need to use adhesives or crude mechanical means to maintain them. Patients often
lack confidence in positioning a prosthesis and in its ability to stay in place. The length of time and the circumstances in which a prosthesis is worn are limited because of associated pain or discomfort. Adhesives have several drawbacks caused by their adverse effects on the durability and longevity of a prosthesis. The adhesives used have been obtained from industry and were not developed for the unique, sensitive human biologic environment. They may have adverse effects on underlying skin, which is often compromised by radiation therapy, trauma, or thermal injury. With the success of osseointegration and its ability to solve the problem of prosthetic retention, a new treatment modality became available. Prosthetic longevity is increased without the need for adhesives. The use of osseointegration biotechnology in facial prosthetic restoration has been hailed as the most significant advancement in the field of facial prosthetics in the past 25 years. It is estimated that before 2007 more than 90,000 implants had been installed extraorally in more than 45,000 patients.

Criteria for successful osseointegrated retained facial prosthetics are the following:

- Aesthetic acceptability
- Functional performance
- Biocompatibility
- Desired retention

Craniofacial osseointegrated reconstruction gives reconstructive head and neck surgeons a viable treatment option for many challenging head and neck defects. It can provide some patients with a meaningful and enhanced quality of life when other treatment options may not be successful. Unfortunately, competing specialties or providers have presented autologous techniques and craniofacial osseointegration as being unrelated technologies. This problem is further compounded by each group wishing to provide their specific care type for the same patient.

Osseointegrated and autogenous techniques should not be viewed as competing technologies, but as complementary reconstructive procedures that optimize the opportunity for success in the management of patients with major head and neck deformities. Why these technologies are not viewed this way is unclear. In some cases, it may result from a lack of understanding of osseointegration and its benefits. Osseointegration may be viewed only as a salvage procedure when all else has failed and the patient and surgeon are desperate. It is often not viewed as “real” surgery, but only as “throwing a few screws in the bone.” Those in doubt cannot understand how patients would be satisfied with a prosthesis, “a foreign object that never becomes part of their body image.” However, to any surgeon with experience in osseointegration, these lines of thinking are seriously flawed. This intervention requires long-term support by the caregiver and financial provider for implant site maintenance and future prosthetic construction. It is analogous to the time and financial commitment required for an organ transplantation program.
HISTORY OF CRANIOFACIAL OSSEOINTEGRATION

Historically, implants in bone were largely unsuccessful and had a poor reputation for long-term success. In the 1950s, Professor Brånemark from Göteborg, Sweden, discovered that titanium behaved somewhat differently from other metals when in contact with bone. He coined the term osseointegration in 1977,\textsuperscript{10} which is defined as a direct contact—structural and functional—between ordered living bone and the surface of a load-bearing implant. Osseointegration is a dynamic process that involves micromodeling at periosteal and endosteal surfaces, and remodelling at the bone-implant interface.\textsuperscript{7,8} This principle of osseointegration ultimately led to the development of successful dental implants. The principle of osseointegration is now well understood, and outcomes using this treatment intraorally in edentulous patients have been scientifically established in replication studies.\textsuperscript{11} Albrektsson et al\textsuperscript{12} further postulated that a skin-penetrating implant may be possible. This ultimately led to the first clinical trial of skin-penetrating osseointegrated implants in 1977. The first implants were placed in the mastoid region to support a bone-anchored hearing aid or auricular prosthesis in 1979\textsuperscript{13} (Fig. 36-1). Subsequently, numerous reports have confirmed the efficacy and predictability of craniofacial osseointegration.\textsuperscript{14,15}

![Fig. 36-1](image)

**Fig. 36-1** Historical development of osseointegration biotechnology. Since Brånemark, osseointegrated implants have been subjected to more than 30 years of scientific scrutiny. Craniofacial applications were introduced more recently—the first patient was treated in 1977.

ADVANTAGES OF CRANIOFACIAL OSSEOINTEGRATION

Craniofacial osseointegration has many advantages (Box 36-1).\textsuperscript{16} The surgical procedures are generally short with minimal morbidity and are usually performed on an outpatient basis. There is a short learning curve and results are predictable. Patients usually have minimal postoperative discomfort. The examination of the tumor resection site is easy and allows early diagnosis of any tumor recurrence. Craniofacial osseointegration can successfully salvage a failed autogenous reconstruction and often offers superior aesthetics. Compared with adhesive-retained facial prosthetics, osseointegration offers predictable prosthetic retention, increased prosthetic durability
and life span, enhanced prosthetic aesthetics, ease of displacement, no underlying skin
damage, successful incorporation of the prosthesis into the body image, and a more
satisfied patient. Osseointegration can be considered for diabetics and smokers.

Box 36-1  Advantages of Craniofacial Osseointegration

- The procedures are short.
- Morbidity is minimal.
- Postoperative pain is minimal.
- Procedures can be performed on an outpatient basis.
- The learning curve is short.
- The tumor resection site can be examined.
- Autogenous failures can be salvaged.
- The approach can be used in compromised tissues.
- Excellent prosthetic aesthetics are obtained.

Disadvantages of craniofacial osseointegration include the need for a larger multidiscipli-
ary team with skills that are often not freely available. Patients also require reg-
ular maintenance visits and a new prosthesis every 2 to 5 years (Box 36-2).16 Lifetime
ongoing costs can be an issue with some insurance companies.

Box 36-2  Disadvantages of Craniofacial Osseointegration

- A multidisciplinary team is needed.
- Patients must be reliable and committed.
- The expense of prosthetic remakes and maintenance visits is ongoing.
- The tissue used is not autologous.

Craniofacial osseointegration can be particularly beneficial for the reconstruction of
selected defects of the ear, orbit, or nose, and combined midfacial defects.

Ear Reconstruction

Autogenous reconstruction of auricular defects improved greatly in the latter half
of the twentieth century because of the work of pioneers such as Tanzer,17 Brent,18-21
Fukuda and Yamada,22 Cronin,23 Bauer,24 Yanai et al,25 Isshiki et al,26 and Nagata.27-32
However, the appropriate treatment selection for major ear defects is still controversial (Box 36-3). Not all reconstructive attempts are successful. Certain auricular defects have limited autogenous options, particularly after removal of the ear for cancer, with radiation therapy postoperatively. We believe that these reconstructive techniques are complementary and must be presented to the patient in this manner.

Definite indications for osseointegrated auricular prosthetic reconstruction include (1) major cancer resection, (2) radiation therapy to the proposed site of auricular reconstruction, (3) severely compromised local tissue, (4) patient preference (Fig. 36-2), and (5) as a salvage procedure for failed autogenous reconstruction. Relative indications include (1) microtia, (2) the absence of the lower half of the ear, and (3) the presence of calcified costal cartilage.

**Box 36-3  Indications for Osseointegrated Ear Reconstruction**

<table>
<thead>
<tr>
<th>Definitive</th>
<th>Relative</th>
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<tbody>
<tr>
<td>• Major cancer resection</td>
<td>• Microtia (most controversial)</td>
</tr>
<tr>
<td>• Radiation therapy</td>
<td>• Absence of lower half of the ear</td>
</tr>
<tr>
<td>• Severely compromised tissue</td>
<td>• Calcified costal cartilage</td>
</tr>
<tr>
<td>• Patient preference</td>
<td></td>
</tr>
<tr>
<td>• Failed autogenous reconstruction</td>
<td></td>
</tr>
<tr>
<td>• Potential craniofacial anomaly</td>
<td></td>
</tr>
<tr>
<td>• Poor operative risk</td>
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</table>

Fig. 36-2  This patient had a successful outcome with an auricular prosthesis after ear avulsion.
The current availability of these various techniques has led to differing approaches in different countries. Microtia is probably the most controversial indication for osseointegrated auricular reconstruction. Implants have been placed in children as young as 3 years with encouraging early results, but the follow-up in these situations has been short. Because the use of craniofacial osseointegrated implants requires removal of any local ear remnants and produces scarring in the operative field, future autogenous reconstruction options are very limited. For these reasons, the use of osseointegrated auricular reconstruction in the pediatric age group requires very careful consideration by the clinician and family. A publication by Zeitoun et al\textsuperscript{33} outlines the difficulties encountered using osseointegration in the pediatric population and the increased need for psychological support in many of these patients. Our approach is to offer autogenous ear reconstruction to pediatric patients with microtia. Despite the potential for difficult treatment selection decisions, we rarely find this to be the case. Patients usually decide easily and quickly which treatment approach they prefer after the possibilities are discussed. It is rare for a patient to change his or her mind following further discussion.

The use of an adhesive-retained auricular prosthesis is very limited and almost relegated to historical significance only. It certainly cannot be considered a test for the appropriateness of an osseointegrated prosthesis. It offers none of the major advantages of implant-retained prostheses such as ease of placement, predictable retention, improved aesthetics, increased life span of the prosthesis, and no ongoing insult to the skin.

**OSSEOINTEGRATED NASAL RECONSTRUCTION**

Indications for osseointegrated nasal reconstruction include (1) failed autogenous reconstruction, (2) significant scarring in potential autogenous donor sites (Fig. 36-3),\textsuperscript{8} (3) treatment after autologous reconstruction, and (4) patient preference (Box 36-4). Because of the need for a multistaged autogenous reconstruction with associated donor sites and greater variability in the ultimate result, many patients opt for placement of implants and a nasal prosthesis. Less surgery is involved, there is less morbidity, other donor sites are not needed, and the area of resection can easily be observed to detect early tumor recurrence.\textsuperscript{8}
Patients who have lost their orbit and orbital contents have very poor autogenous reconstructive options (Box 36-5). Although autogenous coverage may be necessary to cover important neurologic structures, in many cases it is provided only to fill the residual orbital cavity. However, this approach does not create an aesthetic result. In this situation, osseointegrated orbital reconstruction clearly has advantages over autogenous reconstruction. The aesthetic results are far superior and allow examination for early tumor recurrence (Fig. 36-4). This approach could also be considered for patients with severe enophthalmos and significantly compromised vision. Less frequently, it can be considered for patients with an ocular prosthesis and significant eyelid distortion resulting from trauma or radiation therapy that is not amenable to autogenous correction. The hope for the future is to create an orbital prosthesis that can mimic movement of the lid and globe of the opposite, normal eye.

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**Box 36-4  Indications for Osseointegrated Nasal Reconstruction**

- Failed autogenous reconstruction
- Scarring at autogenous donor sites
- Reconstruction following autogenous reconstruction because of tumor recurrence
- Patient preference
- Medical contraindication to multistaged autogenous reconstruction

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**OSSEointegRATED ORBITAL RECONSTRUCTION**

Patients who have lost their orbit and orbital contents have very poor autogenous reconstructive options (Box 36-5). Although autogenous coverage may be necessary to cover important neurologic structures, in many cases it is provided only to fill the residual orbital cavity. However, this approach does not create an aesthetic result. In this situation, osseointegrated orbital reconstruction clearly has advantages over autogenous reconstruction. The aesthetic results are far superior and allow examination for early tumor recurrence (Fig. 36-4). This approach could also be considered for patients with severe enophthalmos and significantly compromised vision. Less frequently, it can be considered for patients with an ocular prosthesis and significant eyelid distortion resulting from trauma or radiation therapy that is not amenable to autogenous correction. The hope for the future is to create an orbital prosthesis that can mimic movement of the lid and globe of the opposite, normal eye.
Box 36-5  Indications for Osseointegrated Orbital Reconstruction

- Loss of orbit and orbital contents
- Severe enophthalmos with compromised vision
- Difficulty with an ocular prosthesis and significant eyelid distortion that is caused by trauma or radiation therapy and is not amenable to autogenous correction

Fig. 36-4  This patient had an orbital exenteration for a malignancy and underwent reconstruction with an implant-retained orbital prosthesis.
**MIDFACIAL RECONSTRUCTION**

Patients with complex facial defects that include the orbit, nose, and maxilla have poor autogenous options. Craniofacial osseointegration offers significant advantages. It allows the examination of the defect after tumor removal and provides a very acceptable aesthetic result. As an example, the patient shown in Fig. 36-5 underwent surgical removal and reconstruction with a temporoparietal fascial flap and skin graft. Craniofacial osseointegration allowed early detection of a recurrence on the posterior orbital wall. The patient was able to resume wearing his prosthesis only 12 days after surgery to resect the recurrence.

![Fig. 36-5](image)

This patient had an extensive basal cell carcinoma invading his orbit, nasal region, and maxilla. After surgical extirpation, implants were placed and a nasoorbital prosthesis was constructed. Autogenous options were poor.

Extraoral osseointegration combined with intraoral osseointegration may also result in significantly improved functional results compared with conventional prosthetic or autogenous techniques.

**REQUIREMENTS FOR OSSEOINTEGRATION**

**Choice of Implant Material**

Many materials have been considered for osseointegration. The choice of metal is important; its particular characteristics of mechanical strength, machinability, elasticity, and chemical reactivity must be considered.\(^{8,34}\) Titanium is currently the material
of choice, although other metals, including vanadium, tantalum, and aluminum hydroxide, and ceramics such as hydroxyapatite are known to integrate with bone to a certain degree. Titanium is relatively light but stiffer than bone. Its springiness allows it to flex with the bone. The most important factor is the ability of the titanium oxide layer on the implant surface to react with adjacent bone (its biocompatibility). The key to success is what happens at this implant-tissue interface. The most successful form of titanium is commercially pure titanium, which is 99.75% pure. The most commonly used titanium alloy contains 90% titanium, 6% aluminum, and 4% vanadium, and it exhibits less satisfactory characteristics of osseointegration than the pure form.

**Implant-Tissue Interface**

Except for mechanical forces, all interactions between the implant and host occur from physiochemical forces less than 1 mm from the surface. When the titanium implant is exposed to oxygen and contacts the host, a layer of titanium oxide is rapidly formed, which acts as a protective barrier and prevents direct contact between the metal and its environment. The titanium oxide layer continues to grow with time and creates a dynamic interface. The oxidized layer is the bioactive component of the implant. The microsurface characteristics of the implant itself, including roughness, porosity, and thread design, all influence its potential for successful osseointegration. A surface roughness of 100 μm or greater is advantageous. An implant with a very smooth surface will result in poor integration, but with minor bone resorption. A very rough surface facilitates rapid integration, but secondary inflammation and resorption occur, which can jeopardize subsequent integration.

The macrostructure of the implant has importance for integration. Rounding the outer edges and spaces of a threaded implant relieves stress concentration. A screw-shaped implant often shows good primary stability, whereas a cone-shaped implant might be lost because of initial micromovements that result in poor stability.

**Bone Bed**

The bone bed into which the implant is installed is important. A child's bone is relatively soft and immature compared with that of an adult. An older patient with osteoporosis will integrate an implant to a lesser degree, and implant failure rates are higher in this patient population. Patients with irradiated skin or burns have an altered bone texture that reduces the capacity to integrate implants.

**Bone Preparation**

Proper preparation of the bone is crucial for success. Meticulous, gentle surgical technique is vital for osseointegration. Bone preparation must result in new bone healing around the implant, with no interposed fibrous tissue formation and minimal
bone necrosis. With proper healing, bone is ultimately in intimate contact with the titanium oxide layer. Sharp drill bits, copious saline irrigation, and slower drilling speeds are required for success. Studies have shown that temperatures of 89°C occur with high-speed drilling, despite cooling. Bone exposed to temperatures greater than 47°C for 1 minute showed decreased new bone formation. Exposure to 44°C showed no negative effect. The fixture should only be handled by titanium instruments and never touched by the gloved hand. The surgical field should be protected from fibers, powder, and other substances that might hinder osseointegration.

A layer of ground substance consisting of proteoglycans and glycosaminoglycans forms at the junction of the titanium oxide and bone. The thickness of this layer is inversely related to the strength of bone integration with the implant. Titanium has the thinnest ground substance layer—approximately 200 Å. Traumatic surgery and an implant bed of low-healing potential are the primary factors that limit successful osseointegration. Implant mobility, overloading, and poor implant biocompatibility are secondary factors in osseointegration failure. With successful osseointegration, the weakest portion of the osseointegrated bone-implant complex is the bone. After successful osseointegration, attempting to remove an implant will cause failure within the surrounding bone, not at the implant-bone interface.

**Implant Load**

The load of the implant should preferably be in the longitudinal direction. Thus it is important to avoid rotational or cantilever forces once the implant has integrated. If forces are distributed in the longitudinal direction, even very high loads can be withstood by the implant for many years of functionality.

**TREATMENT PLANNING**

Providing craniofacial osseointegration care requires a larger multidisciplinary team than that needed for autologous reconstruction. The core team should include appropriate surgical experts, including plastic surgeons, otolaryngologists, and oral surgeons, as well as a prosthetist, dental technologist, anaplastologist, and appropriate nursing and dental assistants. Careful preoperative assessment and planning are crucial for the ultimate success of this clinical endeavor. By consulting with a full spectrum of team members, a patient can make a truly informed decision. The treatment planning process starts with a multidisciplinary consultation. Team members formulate a unique approach for each patient.

The preoperative workup includes charting, standardized preoperative photographs, a psychological profile, radiologic examinations (including CT scanning with three-dimensional images and implant site planning), impressions of the defect and the corresponding normal side, construction of surgical planning templates, and appropriate medical modeling. Preoperative assessment allows an evaluation of bony sites
for implant placement, the presence of surrounding vital structures, the general quality of the bone, and overlying soft tissues (Fig. 36-6).

Patients should have no systemic or local factors that could significantly influence bone-remodeling capacity. Age is not considered a contraindication. Patients as young as 3 years and those in their eighties have been successfully treated. There should be no psychiatric or substance abuse conditions. Relative contraindications include smoking, radiation therapy, and chemotherapy. The literature on smoking and implant survival discusses dental implants and not craniofacial osseointegrated implants. Patients with a history of radiation therapy may benefit from hyperbaric oxygen treatment before and after implant placement to optimize the chance for successful osseointegration. Patients must have a certain level of cognitive, visual, and dexterous ability to maintain osseointegrated implants. They must also have reasonable geographic accessibility to an osseointegration unit.

The ultimate decision in multidisciplinary treatment planning involves choosing the ideal modality for each patient, rather than the clinician’s preference. With proper preoperative education, patients are able to help select the most appropriate treatment choice. Once the preoperative workup and informed consent have been obtained, treatment can begin.

In autologous reconstruction, the surgeon provides the final result. With osseointegration, the surgeon sets the stage for the final prosthetic result, which is provided by the prosthodontist or anaplastologist. This makes preoperative planning and proper implant placement even more vital to ultimate treatment success. Good communication between the surgeon and prosthodontist or anaplastologist preoperatively, and often intraoperatively, is critical. Implants placed in the wrong position will compromise the final aesthetic and functional result or make further implant placement necessary.
**SURGICAL TECHNIQUE**

The surgical approach developed by Brånemark is a meticulous, five-step technique that may be performed in one or two stages, depending on the clinical situation. Although titanium is used by many specialties in many clinical situations, its application for osseointegration should not be confused with other uses of titanium. Osseointegration biotechnology is very specific in terms of osseointegration fixture production and preparation, surgical technique, and the final, expected surgical result. Other implant systems, including Conexcao, Otorix, Straumann, and ITI, are available but are principally based on the original implant (that is, they use titanium).7

Surgery can be performed in one or two stages.1,8 The one-stage procedure is usually reserved for adult patients with good bone quality and quantity. The surgery can be performed in most instances using either general anesthesia or sedation and local anesthesia.

A treatment template is used to choose the site for implant placement. Appropriate positioning is crucial to the ultimate success of the prosthesis. Advanced digital technologies can be useful for this aspect of treatment planning. Adobe Photoshop and FreeForm have been used successfully for this purpose (Fig. 36-7).

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**Fig. 36-7** Advanced digital technologies such as FreeForm can be useful for prosthetic construction. **A**, Patient with a left ear deformity. **B**, A laser surface scan of the contralateral side. **C**, A laser surface scan of the deformity side with a reversed image of the normal ear over the deformed ear. **D**, The reversed normal ear is superimposed over the affected ear for comparison. **E**, The prosthetic ear model that needs to be created to achieve a symmetrical reconstruction.
For ear reconstruction, implants need to be placed under the future site of the antihelical fold of the ear prosthesis. This area has maximum depth to hide the protrusion of the fixture abutment within the prosthesis.

For orbital reconstruction, the implants need to be placed well within the orbital rim rather than anteriorly, where it is technically easier to place them. Consideration must be given to the space requirements of the orbital prosthesis in all three dimensions. Within the orbit, the implants should not align to a central converging point, because this may make prosthetic procedures very difficult.

For nasal reconstruction, better success is obtained by placing implants into the floor of the nose rather than into the glabellar region. If there are concerns about the underlying bone quality or quantity, a Simplant study is performed. This software, in combination with a CT scan, allows assessment of the bone and simulation of implant placement. Appropriate templates can then be constructed and used for the implant surgery (Fig. 36-8).

Fig. 36-8 Medical modelling technology is used to help with the construction of appropriate cartilage graft and implant placement. A, A model of asymmetrical zygoma with an overlying model of the implant needed to restore symmetry. B, Cartilage graft (left) carved to match the medical model (right). C, Template in place to demonstrate the appropriate position for orbital implant placement.
The area is infiltrated with 1% lidocaine (Xylocaine) and 1:100,000 epinephrine, and a skin flap is elevated. The periosteum is exposed, and either a periosteal flap is elevated or a circular opening is made in the periosteum. A surgical locating template is invaluable in difficult cases to optimize positioning of the implant, minimize the extent of surgical dissection, decrease the number of pilot drill holes needed to find adequate bone, and decrease the length of the procedure. Because it is important to confirm the availability of bone, a guide drill is used. A fresh 3 mm drill bit is used, and if bone is still present at the base of the drill hole, a 4 mm guide drill is used. This drilling is carried out at a speed of 2000 rpm with copious irrigation using saline solution. The drill is used to widen the opening to allow more accurate visual assessment of the bone and depth of the opening. The base of the guide hole is checked to ensure that underlying vital structures have not been penetrated. In the second step, the guide hole is widened with a countersink. A fresh countersink drill and copious saline solution irrigation are used. This also prepares a flat countersink area on the bony surface for seating of the implant flange. In the orbit, flangeless fixtures are often placed, because cleaning and debris accumulation around the implant flange can be problematic in the orbital region. The third step involves tapping the bone hole. It is performed at a drill speed of 15 to 20 rpm and 30 to 40 newton-centimeters of torque. All drills, taps, and countersinks are discarded after each procedure. All of these precautions are taken to minimize bone necrosis. Bone necrosis leads to the development of fibrous tissue, compromising the tissue-implant interface and preventing osseointegration.

The titanium implant is inserted in the fourth step. It is provided in a titanium cylinder within a sterile glass container. When the implant is exposed, a titanium oxide layer immediately begins to develop. There should be no contact between the titanium surface of the implant and any other surface that is not titanium. Craniofacial implants are 3.75 mm in diameter and are available in 3 mm, 4 mm, and 5.5 mm lengths (Fig. 36-9).
A 4 mm implant is preferable if bony conditions allow. In the fifth step, a cover screw or space screw is placed in the implant. This prevents soft tissue ingrowth into the central portion of the implant, where the abutment will ultimately fit. A space screw fits in the center of the implant and does not increase the profile of the implant during the healing phase. It is used if implants are placed under an old skin graft or thin skin flap, usually in the orbit. The surgical incisions are then closed if a two-stage procedure is planned. If a one-stage procedure is performed, the outer layer of the flap is elevated as an attached split-thickness graft, and underlying soft tissues are discarded. The edges around the outside of the flap site are aggressively thinned, and the graft is replaced to take on the underlying periosteum. It is important that hair follicles and any muscles are removed. The most common causes of soft tissue problems are movement around the abutment and remaining hair follicles.

In nonirradiated tissues, the implants are usually left for approximately 3 months, at which time phase two surgery can begin. In the midface, or in patients with a history of radiation therapy, this time period is usually extended to 6 to 9 months. Usually, two implants are required for auricular reconstruction and at least three implants for orbital reconstruction. Extra implants are often placed in the orbital region as sleepers, because the long-term success rates in this region are not as high. If an implant fails, then one of the extra ones can be exteriorized, and the patient can continue to wear his or her prosthesis in an uninterrupted manner.

Phase two surgery, when necessary, involves exposing the implant, radical thinning of the overlying and surrounding tissue, creating a hairless and nonmobile zone of 1 cm around each abutment, and connecting an abutment to the underlying fixture. Improper soft tissue surgery is the most common cause of ongoing tissue reaction around the abutment. Other surgical considerations include the removal of any residual soft tissue elements sufficient to produce a flat tissue surface for an ear prosthesis.

More recently, there has been success in the mastoid region with one-stage placement of implants under optimal local conditions.\textsuperscript{46,47} Accepted clinical criteria for a one-stage procedure in the mastoid region of older children (10 years or older) or adults include:\textsuperscript{8}

- No history of irradiation
- A cortical layer of bone greater than 3 mm thick
- An uncomplicated surgery

Provided that these conditions are met, the technique for phase two surgery is essentially the same as that used for phase one, but both phases are conducted at the same operation. After one-stage surgery, the implant must be protected and not loaded for at least 3 months.
PROSTHETIC CONSTRUCTION

Construction of the prosthesis generally begins 4 to 6 weeks after phase two surgery, when local tissues have healed sufficiently to be a stable base for overlying prosthetic construction. The details of prosthetic construction have been well described elsewhere.\(^3^8,4^8\) In general, a bar superstructure is designed for each patient and connected to the abutments. The prosthesis is first sculpted in wax and oriented to an acrylic resin substructure. When the wax prosthesis is anatomically acceptable, a mold is constructed and the final prosthesis is made from silicone elastomer.

The uses of advanced digital technologies have been helpful in prosthetic construction. Data from the normal side can be captured from a moulage or laser surface scanning. With CAD design software, the image is manipulated and the basic form of the prosthesis is easily constructed. This efficiency optimizes the time that the anaplastologist spends with the patient. A challenge for both the anaplastologist and the prosthodontist is to color match the prosthesis based on the patient’s normal pigments and extrinsic influences such as the time of the year and the patient’s occupation. One of the newer solutions includes the use of spectrophotometry computer technology to color match the prosthesis to the patient.\(^5^9\) Patients may have summer and winter prostheses to adjust for subtle pigmentary changes. Many small details and techniques are used to add realism to the prosthesis. Clips on the undersurface of the prosthesis securely attach the prosthesis to the bar and are most commonly used for ears. A magnetic retention system is more commonly used for orbital prostheses. Usually, two prostheses are made simultaneously to prevent a crisis situation if something happens to one prosthesis (Fig. 36-10).

Fig. 36-10  A, Clips on the underside of the prosthesis ensure secure attachment to the implant-retained bar superstructure. B, The top prosthesis has a lighter “winter” color, and the bottom one has a darker “summer” color.
MAINTENANCE
The long-term success of osseointegration requires an effective, ongoing maintenance regimen, analogous to the follow-up schedule established for an organ transplantation program. Strong patient commitment is required for success. In particular, conscientious care of the periabutment area is crucial. This includes gentle cleaning on a daily basis and the diligent application of appropriately prescribed topical agents (Fig. 36-11). These include mineral oil for general lubrication of the skin, an antibiotic ointment, or a topical steroid. Our patients are given a lifetime maintenance schedule to underline the importance of their commitment. The maintenance visits are important to assess the periabutment region, measure soft tissue height, check for tissue reaction, and monitor the mechanical integrity of the implant-abutment assembly. The life of a prosthesis varies from 2 to 5 years, depending on extrinsic factors such as general care and exposure to sunlight or cigarette smoke. New prostheses are constructed as needed.

ANCILLARY AUTOGENOUS PROCEDURES
Craniofacial osseointegration and autogenous reconstruction are usually not presented at the same time and by the same person. The proponents of craniofacial osseointegration are often at odds with the advocates of autogenous reconstruction. As a result, patient treatment is typically not optimal. Patients are not given the full spectrum of treatment options, and treatment selection is based on a surgeon’s prejudice or preference and established referral patterns. We believe that the treatment of a craniofacial defect is often best managed using a combination of osseointegration and autogenous procedures to optimize the final results. The goals of the ancillary procedures may include decreasing the size of the facial prosthesis, placing prosthetic margins at the junctions of the aesthetic units, decreasing the size of the
maxillary obturator, improving facial contour, improving symmetry, and bringing viable bone for implant placement into a region compromised by surgery or radiation (Fig. 36-12; see also Fig. 36-8).

**OUTCOMES**

To evaluate the success of craniofacial osseointegration, several parameters need to be studied. From a patient’s perspective, craniofacial osseointegration is successful if the prosthesis can be used on a regular basis and has a positive effect on quality of life. Outcome assessments must also include individual implant success rates and local skin responses.

**Individual Implant Success Rates**

Jacobsson et al. proposed the following criteria as requirements for a successful craniofacial osseointegrated implant:

- The unattached implant should be immobile when tested clinically.
- Soft tissue reactions around skin-penetrating abutments should be type 0 (reaction free) or type 1 (slight redness), not requiring treatment in more than 95% of observations.
• Individual implant performance should be characterized by the absence of persistent and/or irreversible signs and symptoms such as pain, infection, neuropathy, and paresthesia.
• A success rate of 95% in the mastoid process and 90% in the orbital region in nonirradiated bone tissue at the end of a 5-year observation period should be a minimum criterion for success.

Many studies in the literature have documented implant success rates. A 1992 study\(^\text{14}\) showed a success rate of 95% in the mastoid and 72% in the orbital region. It was noted that failures in the mastoid occurred within 6 months of insertion, whereas failures in the orbital region tended to occur much later. Further evaluation revealed that the success rate in nonirradiated orbits within this group was 92.1%, whereas that of the irradiated group was 62.7%. Subsequently, Granström\(^\text{41}\) showed that hyperbaric oxygen therapy before and after implant placement significantly improved the success rate of craniofacial osseointegrated implants in irradiated bone. In 1994, Granström et al\(^\text{42}\) found that after hyperbaric oxygen therapy, no implant loss occurred during a 5-year follow-up period in 48 implants placed in irradiated orbital, nasal, and temporal regions.

**Skin Response**

The problems that commonly recur are related to the skin response around the percutaneous abutments. Although these conditions do not usually threaten the long-term success of an implant, they require considerable time on the part of the clinician and patient to resolve. Occasionally, further surgery may be indicated. Tjellström\(^\text{13}\) reported that 70% of the skin reactions occurred in 15% of his patients. He also reported that 90% of his patients had no skin reactions (Fig. 36-13). Adolescence was a contributing factor to adverse skin reactions because of behavior problems and poor compliance with local hygiene.

*Fig. 36-13*  The upper abutment of this implant shows no soft tissue reaction, but the lower abutment shows some hypertrophy.
Prosthetic Success

Data related to patients’ perceptions of treatment are insufficient. In a study from 1990, only 2 of 94 patients were not wearing their prosthesis at the time of assessment. Tolman and Taylor evaluated patients with non-implant-retained prostheses, and only 50% considered their prosthesis stable. After these patients had craniofacial implant prosthetic reconstruction, 93% rated their implant-retained prosthesis as stable. Of 30 patients, 19 wore the prosthesis more than 12 hours per day, 3 wore the prosthesis 8 to 12 hours per day, 3 wore the prosthesis 4 to 8 hours per day, and 5 wore the prosthesis less than 4 hours per day. Twenty-four of the 30 patients viewed the prosthesis as an extension of themselves and part of their body image.

CONCLUSION

Craniofacial osseointegration has an important role in the treatment of major head and neck defects. It offers treatment options in many situations where previously only poor options were available. Patient satisfaction is very high. These patients become strong advocates for this treatment modality. We must consider this biotechnology carefully and encourage its development to better serve our patients.

CRITICAL POINTS

Must Know

• Prosthetic reconstruction should be considered an adjunctive treatment rather than a replacement for other forms of reconstruction.
• Detailed multidisciplinary planning is very important.

Should Know

• The success of osseointegrated implants is high.
• Previous radiation therapy is not necessarily a contraindication for prosthetic reconstruction.
• Patient satisfaction is extremely high.

Synopsis

• Prosthetic reconstruction should be considered whenever complex defects are encountered. The aesthetic results are frequently superior to what can be achieved with tissue alone.
• The lack of need for such things as tissue glues has made prosthetics much more acceptable to patients.
References


   This study evaluates mechanical behavior of retention systems that have been used in craniofacial osseointegration. Retention systems used in craniofacial osseointegration offer more predictable retention than facial prosthetic adhesives. Mechanical retention systems are best suited to situations in which tensile and shear forces will operate. Magnet systems are best used when only tensile forces are anticipated or when horizontal forces on the implants are to be avoided.


   Plastic surgeons have been skeptical of osseointegration biotechnology and the role of prosthetic reconstruction in the head and neck region. This article provides an overview of craniofacial osseointegration and the possibilities it offers reconstructive surgeons for treating this challenging patient population.


   From 1982 through 1993, 55 patients with major ear deformities underwent reconstruction with autogenous tissue. The main indications for autogenous reconstruction included classical microtia, relatively normal lower one third of the ear, patient preference, and less compliant patients. The main indications for osseointegrated alloplastic reconstruction were major cancer ex- tirpation, poor local tissue, absence of the lower half of the ear, salvage following unsuccessful autogenous reconstruction, and poor operative risk. Because of their success, osseointegrated auricular reconstructions should be added to reconstructive surgeons’ armamentarium.
PART SIX

REFINEMENTS AND COMPLICATIONS
CHAPTER 37

Cosmetic Considerations and Secondary Refinements in Flap Reconstruction

Seng-Feng Jeng, Sing-Wing Poon, Fu-Chan Wei

HIGHLIGHTS

• Three important tenets of reconstructive microsurgery in the head and neck area are to restore function, achieve symmetry, and optimize the color match.
• Further advancements in technique and vascular anatomy knowledge, careful donor site selection, and meticulous wound closure may improve quality of life for patients who undergo reconstructive head and neck surgery.
• The three most commonly used workhorse flaps for head and neck surgery are currently the ALT flap, the radial forearm flap, and the fibular osseocutaneous flap.
• Optimal results in complex reconstructive surgery can rarely be accomplished with a single procedure. Secondary procedures include scar revision, staged excision, liposuction, fat grafting, tissue expansion, local or regional flaps, and, in some cases, another free flap transfer.
• Microsurgeons can and should reconstruct aesthetically to optimize the final appearance of the defect and donor site, with appreciation of each patient’s aesthetic expectations for further cosmetic improvement after free flap transfer.
Immediate reconstruction of head and neck defects was first advocated by Edgerton in 1951. For this purpose, several local and regional flaps were developed. Of these, the deltopectoral flap, pectoralis major myocutaneous flap, and latissimus dorsi myocutaneous flap were most commonly used. However, these regional flaps may require multiple surgical procedures and may not contain the necessary tissue components. A significant revolution in head and neck reconstruction occurred with the advent of free tissue transfers. In 1959, Seidenberg et al. were the first to report the use of a segment of jejunum as a free flap for restoring upper esophageal defects. In 1976, free skin flaps were used for head and neck defects. The fibular osseocutaneous flap was first used by Hidalgo for mandibular defects. With further advancements in instrumentation, techniques, and knowledge of vascular anatomy, free tissue transfer has become safe and effective, with a success rate routinely above 95% at many centers. The main goals of microvascular reconstruction using these flaps are coverage of the defect and restoration of function. However, little attention has been given to the refinements and quality of the aesthetic appearance of the recipient and donor sites, and only a few authors have discussed this topic.

When a surgeon plans the reconstruction of a head and neck defect, the wound and the reconstructive requirements are evaluated. However, the psychological problems that patients may develop after tumor ablation often are greater and more serious than the functional deficit. Throughout our experience in reconstructive microsurgery, our approach has evolved to improve the quality of both the functional repair and the aesthetic appearance. By practicing refinements in flap selection, design, tailoring, and application, the aesthetic result can be improved and donor site morbidity decreased.

Aesthetic Considerations at Recipient Sites

Regardless of the extent of the defect, careful preoperative evaluation is essential for head and neck reconstruction. Surgeons must assess the skin, fat, muscle, bone, and mucosa. Replacing like with like tissue, which generally means using local or regional tissue, can provide the best match aesthetically and functionally. In patients who undergo composite resection involving bone, it becomes necessary to consider the bony requirement when planning the reconstruction. Without adequate restoration of skeletal support, soft tissue reconstruction will be inadequate. In addition to bone, the anatomic location, total area, and thickness or volume of the defect must be evaluated.

As with all reconstructive and aesthetic surgeries, small details can make significant differences in the overall aesthetic outcome. For instance, it is helpful to extend a defect involving only a portion of cheek, nose, chin, or forehead to encompass the entire aesthetic unit. Although the defect will certainly be enlarged, suture lines...
will fall in inconspicuous areas. In patients with defects requiring two-dimensional coverage, such as a scalp defect, the skin surface area of the flaps is the most important priority. For three-dimensional reconstruction of a mandibular defect, bone support, flap volume, and consistency are the important considerations.\textsuperscript{15} Extensive composite defects are usually the result of surgical excision of T3 and T4 tumors. Although the options for free flap selection have increased tremendously, it is recognized that a single free flap may not be able to provide optimal reconstruction because of inadequate tissue components, dimensions, and volume. Some defects may require two free flaps simultaneously.\textsuperscript{16,17} During flap inset, we intentionally include more tissue and avoid excessive tailoring of the external skin coverage flap. Although it often has a bulky appearance immediately after the reconstruction, it shrinks by the time radiation therapy begins. This bulky flap allows later revision for better function and appearance.

Adequate tumor control and defect coverage are no longer sufficient to meet patients’ expected quality of life. The three important tenets in the practice of free flap reconstructive microsurgery in the head and neck area are to restore function, achieve symmetry, and optimize the color match.

**Immediate Soft Tissue Augmentation**

For defects that result from a benign tumor or malignancy and require no further radiation therapy, a single-staged microsurgical procedure can restore a devastating defect with relatively good form and function. To achieve better symmetry, proper tissue volume needs to be transferred. For soft tissue deficits, a surgeon can deepithelialize part of the skin flap to provide additional tissue volume\textsuperscript{18} (Fig. 37-1).

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**Fig. 37-1**  
A and B, A 38-year-old man underwent composite hemiglossectomy and segmental mandibulectomy. The defect was immediately reconstructed with a free fibular osseoseptocutaneous flap. A portion of the skin paddle was deepithelialized for soft tissue augmentation (blue lines). The blue arrows are the perforators.
Immediate Thinning of Soft Tissue

A bulky appearance is still one of the most common concerns of patients after free flap transfer. The excess bulkiness of soft tissue flaps may be aggravated by the trapdoor effect. Soft tissue redundancy may not be noticeable at the time of harvest. However, over time, after the flap softens and gravity exerts its effect, the trapdoor phenomenon becomes obvious. For this reason, routine harvest of an excessive amount of soft tissue should be avoided in patients who do not need further oncologic treatments.12

Meanwhile, when covering a defect that requires a thin flap, such as in scalp reconstruction, we recommend immediate in situ thinning to minimize flap bulkiness. This can be accomplished with microdissection around the cutaneous perforator to remove excess subcutaneous tissue, as described by Kimura and Satoh19 (Fig. 37-2). The concept of an ultrathin flap, described by Hyakusoku and Gao,20 is an advancement in which the subdermal vascular network is transferred in the free tissue transfer. Measuring the defect accurately and transferring those dimensions exactly to the planned flap are important in primary thinning procedures.
Occasionally, more complex reconstructions need to be offered to patients, such as those who undergo composite resection of oromandibular tumors, because lip defects usually represent the most challenging aspect of reconstruction. The soft tissue component of the free flap may be needed to reconstruct the lip by incorporating it into the residual sphincter, which is adynamic and insensate. If the total lip defect is less than one third of the oral circumference, tissue from the residual lips remains the best option for lip reconstruction. After a meticulous repair of the orbicularis oris muscle and mucosa, advancement of the residual lip flap with intact sensory and motor innervation can restore oral competence and improve a patient’s appearance.21-23 After completing the deep reconstruction, skin coverage is achieved in an orientation that ensures the most ideal contour. Furthermore, skin texture and color match are also important considerations, particularly when the recipient site is in an exposed part of the body.

**Aesthetic Considerations for Donor Sites**

Ideal flaps for head and neck reconstruction need to fulfill the following criteria: versatility in design, adequate tissue volume, good texture, potential for sensory reinnervation, a large and long pedicle with rather consistent anatomy, easy and safe flap dissection, the possibility of a two-team approach, and minimal donor site morbidity.24 Disa et al reviewed 728 flaps used in head and neck reconstruction and recommended the radial forearm flap, fibular osseocutaneous flap, rectus abdominis myocutaneous flap, and the jejunal flap as ideal workhorse flaps for most defects. Jones et al used these and added the latissimus dorsi flap, scapular flap, and iliac crest flap, resulting in their seven most commonly used flaps in 305 free flaps for head reconstruction.
and neck reconstruction. Gurtner and Evans also advocated the jejunal, radial forearm, fibular, rectus abdominis, and latissimus dorsi as flap choices for head and neck reconstruction. With the growing understanding of the advantages of many different flaps in recent years, the selection of workhorse flaps for head and neck defects has been simplified.

Currently, the three most commonly used flaps are the ALT flap, the radial forearm flap, and the fibular osseoseptocutaneous flap. Since 1996, the ALT flap has become the most frequently used flap for soft tissue reconstruction at our institution.

**ALT Flap**

The popularity of the ALT flap is growing because of its versatility in tissue components, inclusion flap design, and the hidden donor site with negligible morbidity. In adult patients, direct closure of wounds up to 8 to 10 cm in width is always possible. However, the resultant scar is usually stretched and wide in appearance. We perform direct closure only if the width of the ALT flap is less than 16% of the thigh circumference at the midpoint of the thigh (Fig. 37-3).

**Fig. 37-3** A, An intraoperative measurement of maximum skin paddle width and midthigh diameter. If the ratio of these two measurements is less than 16%, tension-free primary closure of the donor site can be performed. B, Primary closure of the ALT donor site.
If the width of the ALT flap is greater than 16% of the thigh circumference, the donor site can be closed using either a tissue expander or the remaining island flap from the distal portion of the ALT, which is based on an independent perforator, in a V-Y advancement fashion (Fig. 37-4).

**Fig. 37-4** A distal fasciocutaneous island flap is used to achieve primary closure of the ALT donor site. **A**, The distal portion of the ALT flap is based on an independent perforator. **B**, The proximal portion of the ALT flap supplied by the lateral circumflex femoral vessel is elevated for free flap transfer; the distal portion of the flap is mobilized and advanced to assist with closure. **C**, Tension-free closure. **D**, The donor site is shown 6 months postoperatively.

**Radial Forearm Flap**

Since the introduction of the radial forearm flap by Yang et al in 1981, it has become the most frequently used free flap in head and neck reconstruction. It provides a reliable skin paddle with a long and large vascular pedicle. It also provides rather good color characteristics for external head and neck reconstruction. The major disadvantage of this flap is that in all but the smallest defects (approximately 3 to 4 cm wide), the donor site must be skin grafted, a necessity that many find aesthetically unacceptable. Donor site morbidity of the radial forearm flap is well documented, with
partial loss of split-thickness grafts occurring in 16% to 35% of cases.\textsuperscript{36-38} In the distal one third of the forearm, the radial artery is enclosed by two layers of the deep fascia that join into one at about 1 to 3 mm radial and ulnar to the flexor carpi radialis and brachioradialis tendons, respectively. With suprafascial flap elevation, the preserved fascia improves the take of a full-thickness skin graft and may contribute to an improved appearance.\textsuperscript{39} The intact conjoin of the two layers of the deep fascia also prevents tenting and adhesions of underlying flexor tendons (Fig. 37-5). Several techniques have been described to facilitate primary closure of small to medium-sized donor site defects. Elliot et al.\textsuperscript{40} used the ulnar artery–based V-Y transposition flap to close small radial forearm donor site defects. The authors developed a bilobed flap based on a fasciocutaneous vessel of the ulnar artery. The bilobed flap is designed along the ulnar artery, adjacent to the radial flap donor site. The pivot point is located approximately 8 to 10 cm proximal to the pisiform bone. There are one to two perforators with their venae comitantes coming from the ulnar vessels around the pivot point. The bilobed flap includes a large lobe and a small lobe. By rotating the flap 90 degrees, the large lobe is used for repair of the radial forearm donor defect, and the small lobe is used for closure of the large-lobe defect.\textsuperscript{41} It allows closure of forearm flap donor sites measuring up to 8 by 8 cm to improve function through possible earlier movement as well as appearance (Fig. 37-6).

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image.png}
\caption{The appearance of a forearm donor site after suprafascial dissection of a forearm flap. The two \textit{yellow arrows} indicate the intact conjoins, which are the deep fascias holding down the brachioradialis and the flexor carpi radialis tendons. Preservation of the conjoins can prevent tenting of these tendons, and facilitate skin graft take. The \textit{blue arrow} is a branch of the antebrachial cutaneous nerve that has been preserved.}
\end{figure}
Fibular Osseoseptocutaneous Flap

Since the early 1980s, the free fibular osseoseptocutaneous flap has been shown to be the best choice for reconstructing mandibular defects. The vascular pedicle consists of the peroneal vessels, which have consistent anatomy, with sufficient size and length. The superior quality of the fibula is a result of the tricortical bone, which tolerates multiple osteotomies. This property allows precise reconstruction of the mandibular arch. The fibula also provides adequate bone width and length and can support osseointegrated implants safely throughout its length.8,27,42

The skin paddle, nourished by the septocutaneous vessel, is reliable and can be designed according to individual needs. One or two septocutaneous vessels arising from the pedicle provide adequate blood supply to the overlying skin in an area about 20 to 25 cm long and 10 to 14 cm wide. The septocutaneous vessels are usually centered at the junction of the middle and distal third of the fibula, and the skin island should be designed accordingly. Skin defects up to 4 cm in width can usually be closed directly to get the best cosmetic results.43 However, direct closure should be avoided if there is a concern about the tightness of the wound, and a skin graft should be used instead. Partial loss of skin grafts occurs in up to 16% of patients because of the absence of deep fascia during flap harvest.

Fig. 37-6  A, A bilobed flap is designed for closure of the donor site of a radial forearm flap. B, The vessels (arrow) coming from the ulnar vessels 8 to 10 cm proximal to the pisiform bone, are the pivot point of the bilobed flap. C, Forearm donor site morbidity is minimized and a better cosmetic result is achieved.

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Since the early 1980s, the free fibular osseoseptocutaneous flap has been shown to be the best choice for reconstructing mandibular defects. The vascular pedicle consists of the peroneal vessels, which have consistent anatomy, with sufficient size and length. The superior quality of the fibula is a result of the tricortical bone, which tolerates multiple osteotomies. This property allows precise reconstruction of the mandibular arch. The fibula also provides adequate bone width and length and can support osseointegrated implants safely throughout its length.8,27,42

The skin paddle, nourished by the septocutaneous vessel, is reliable and can be designed according to individual needs. One or two septocutaneous vessels arising from the pedicle provide adequate blood supply to the overlying skin in an area about 20 to 25 cm long and 10 to 14 cm wide. The septocutaneous vessels are usually centered at the junction of the middle and distal third of the fibula, and the skin island should be designed accordingly. Skin defects up to 4 cm in width can usually be closed directly to get the best cosmetic results.43 However, direct closure should be avoided if there is a concern about the tightness of the wound, and a skin graft should be used instead. Partial loss of skin grafts occurs in up to 16% of patients because of the absence of deep fascia during flap harvest.
To ensure a complete take of the skin graft, the deep fascia over the peroneus longus tendon should be preserved if possible. After the skin is incised, a suprafascial dissection is performed. The skin flap is elevated from the medial and lateral margins toward the posterior crural septum, between the peroneus and soleus muscles. Several stay sutures are placed at the margin of the posterior crural septum to avoid detachment of the deep fascia from the underlying muscles and tendons. The incision is carried down to the deep fascia. We preserve a 1 cm diameter tube of deep fascia around the vessel. The fibular osseoseptocutaneous flap is freed from the surrounding tissue. During wound closure, the flexor hallucis longus muscle is reattached to the interosseous membrane and posterior tibial muscle to preserve great toe flexion postoperatively. The deep fascia of the lateral compartment can then be closed directly to facilitate gliding of the underlying tendons, and the skin graft can be applied for wound closure (Fig. 37-7). After suprafascial flap elevation, the donor site morbidity is low, and the preserved fascia improves the take of the skin graft, which also maintains the range of motion and the strength of the ankle.

Fig. 37-7  A, Suprafascial dissection of the skin paddle of a free fibular flap. The septocutaneous vessels were preserved. A free fibular flap was harvested, sparing the deep fascia. B and C, Direct closure of the deep fascia and a split-thickness skin graft restore the native contour of the donor leg.
SECONDARY COSMETIC REFINEMENTS

Patients who undergo secondary cosmetic refinements often have high expectations and demands, and should be considered as aesthetic surgical patients. It is often not possible to achieve a satisfactory cosmetic appearance with free tissue transfer in single-stage procedures, and further refinement procedures may be necessary (Fig. 37-8).

However, it is unnecessary to perform further procedures if a patient requires adjuvant radiation therapy. The amount of tissue damage from radiation depends on the dose, the patient’s host response, and the skill of the radiation therapist. Heavy doses of postoperative radiation can severely affect the aesthetic quality of the result. Usually, bulky flaps shrink after extensive radiation therapy.
Volume Excess Correction

A debulking procedure should be performed at least 6 months after radiation therapy is complete. Many debulking procedures, such as staged excision of excessive fat and redundant skin, can result in good contour (Fig. 37-9). In patients with no skin redundancy, defatting can be performed safely using suction lipectomy. This technique avoids the repetitive procedure of elevating the flap and defatting the underlying tissues (Fig. 37-10).

Fig. 37-9  A, This 60-year-old man with right buccal carcinoma underwent resection with neck dissection resulting in a through-and-through defect. The defect was covered with a free ALT flap. This 1-year postoperative picture shows a trapdoor deformity. The patient also had oral incompetence. B, The deformity was corrected with a staged excision of the bulky flap. The vermilion border was also re-created by scoring the skin paddle.

Fig. 37-10  This 53-year-old man underwent composite resection of a T4 buccal carcinoma. The defect was reconstructed by using a free fibular and a free ALT flap. A, Postoperatively, the patient was concerned with the bulkiness of the skin paddle. B, Suction lipectomy was performed to correct the bulkiness.
Volume Deficiency Correction

Patients with a depression deformity after radiation therapy often find such contour deformities aesthetically unacceptable and seek surgical restoration of their pre-morbid cosmetics. Ideally, facial soft tissue voids should be reconstructed with filler materials that are biologically inert, predictably durable, inexpensive, readily available, and suitable for single-stage implantation. Soft tissue fillers such as bovine collagen, hyaluronic acid, and cross-linked hyaluronan polymers provide only limited and short-term volume correction.44,45 The use of autologous materials to correct facial soft tissue defects has been a common practice. However, autologous fat has an unpredictable success rate—an absorption rate of 66% has been reported.46 Optimal long-term results remain elusive. Recently, fat suspension injections obtained using vacuum-assisted devices, and harvest and delivery techniques performed with a cannula, have become the mostly widely accepted grafting methods. Several elaborate techniques have been introduced to improve injected fat survival. These include atraumatic fat harvesting techniques, fat washing to eliminate inflammatory mediators, centrifugation, and incubating fat grafts with different bioactive agents. Because of the inevitable absorption of implanted fat grafts, many authors have recommended initial overcorrection to compensate for anticipated graft shrinkage.47 However, we still consider fat grafts as a reliable and effective source of autogenous implant material for augmentation of facial contour defects when applied appropriately in selected patients (Fig. 37-11).

Fig. 37-11  This 35-year-old man underwent resection of a T4 buccal carcinoma and concurrent reconstruction with a free fibular and a free ALT flap. The left cheek depression (A) was corrected with an injection of 20 cc of autogenous fat (B). C, The result is satisfactory 1 year postoperatively.
Patients with contour deformities resulting from adjuvant radiation therapy often are not amenable to correction with fat grafts or local flaps. Distant flaps using free tissue transfers are indicated. The timing of microsurgical intervention to correct these contour problems is straightforward. Free flap transfer should only proceed after a patient is disease free for 2 years, and the stability of the deformities should be considered. The vessels in the previously dissected neck are often unavailable. Therefore ipsilateral superficial temporal vessels are usually chosen to serve as recipient vessels. They are dissected in the subcutaneous plane through a preauricular face-lift incision. This dissection extends beyond the boundaries of the region requiring tissue augmentation. The skin flap is deepithelialized if the skin portion is not needed. The flap is placed with the dermis facing upward and secured to the periosteum as needed. Secondary refinement surgery is expected and needs to be discussed with patients preoperatively. Revisions using ancillary aesthetic techniques to optimize the final result are performed 6 months after the free flap transfer (Fig. 37-12).

Fig. 37-12  A and B, This 57-year-old-man underwent excision of a T4 buccal cancer and free fibular flap reconstruction following radiation therapy. A contour deformity remained over the reconstructed left mandible. C and D, The contracture was released, and a free trapezius perforator flap was used to restore the optimal contour.
Color Mismatch Correction

There are limitations in the reconstruction of major head and neck defects. Color mismatch is one of the most challenging problems. Color mismatch may be handled by excising the unmatched skin and covering the defect with a full-thickness skin graft from the head and neck region. Aesthetic results are optimized when the reconstruction conforms to the facial aesthetic subunits. However, the results are often unsatisfactory. Tissue expansion can supply sufficient amounts of pliable skin for coverage, but it requires staged operations that are time consuming and are not cost effective.

For patients who present with through-and-through defects of the lower face, the portion of the folded flap used for external cheek reconstruction may have an obvious color mismatch. This can be resolved by serial excision of the external skin paddle and local cheek skin advancement in selected patients under local anesthesia. The conversion of an irregular skin patch to a linear scar can significantly improve the aesthetic outcome (Fig. 37-13).

Fig. 37-13  A, This 67-year-old man presented after resection of a T3 lesion that resulted in a through-and-through buccal defect. A folded free ALT perforator flap was used to cover the defect. B, The color mismatch of the flap was excised in stages.
Aesthetic considerations favor the use of local or regional flaps for head and neck defects. Various options, such as a supraclavicular flap, platysma myocutaneous flap, submental artery perforator flap, and facial artery musculomucosal flap, have been shown to provide a good color match for the face (Fig. 37-14).

**Fig. 37-14** A, A 42-year-old man underwent resection of a lower lip carcinoma. The defect was reconstructed using a composite radial forearm–palmaris longus tendon flap. B and C, The color mismatch was corrected with a nasolabial fasciocutaneous island flap.

**CONCLUSION**

Patients with facial deformities after head and neck surgery often struggle with their self-image and encounter difficulty in social acceptance. They may also have significant functional defects that affect the quality of their daily living. The goal of reconstructive surgery in the head and neck area is not merely to provide tissue to cover a wound, but also to restore form and function. Millard stated, “Reconstruction must be aesthetic, with the ultimate goal not just the average normal but rather, if possible, the ideal beautiful normal to reach.” Therefore these patients should be viewed as aesthetic surgical patients.
To achieve an aesthetically pleasing outcome from reconstruction, we should follow the principle of replacing like tissue with like tissue. Careful donor site selection and meticulous wound closure pertain to all parts of the overall reconstructive strategy. We should realize that complex reconstructive surgery can only rarely be accomplished with a single procedure; secondary procedures are often required for optimal results. The key to further cosmetic improvement after free flap reconstruction is to appreciate each patient’s aesthetic expectation.

**Critical Points**

**Must Know**

- The three tenets of head and neck reconstruction are to restore function, achieve symmetry, and optimize the color match.
- Like tissue should be replaced with like tissue.
- Reconstruction is performed with consideration of aesthetic units.
- Reconstruction of the head and neck requires that surgeons focus on the volume and surface area requirements.
- Skeletal reconstruction is the foundation for soft tissue reconstruction.

**Should Know**

- The impact of the aesthetic result of reconstruction is often as important as the functional outcome of reconstruction.
- Multistaged reconstruction is often required to achieve the desired aesthetic outcome.
- The effects of radiation therapy are important to consider when determining the amount of soft tissue required to cover a defect.
- The skin flap is deepithelialized as needed to provide volume augmentation.
- Primary closure of donor sites can be optimized by using techniques such as the perforator-based V-Y advancement flap with ALT flaps and the ulnar artery perforator–based bilobed flap with the radial forearm flap.

**Synopsis**

- When performing reconstructions in the head and neck, the surgeon must be particularly aware of the aesthetics of the reconstruction.
- Issues of color match, bulk, and general appearance can be as important as the functional outcome in this most visible part of the anatomy.
- Aesthetic considerations should also be emphasized at the donor site.
- This elevated level of standard is not only frequently requested by patients, but should be actively pursued by reconstructive surgeons.
The author provides guidelines to improve the aesthetic outcome of mandibular reconstruction based on the experiences of 50 consecutive cases. Mandibular templates are constructed based on preoperative lateral cephalograms and transverse plane CT scans. The bones are shaped while still attached by the pedicles, with the surgical specimen serving as a reference to determine overall bone graft length. Miniplates alone provide fixation, and intermaxillary fixation is used only to prevent errors in total bone graft length.


Composite mandibular resection for T3-4 tumors often results in defects that require two-flap coverage. In this article, the authors adopt the ALT flap for external skin coverage to address the shortcomings of the previously used radial forearm free flap and the rectus abdominis myocutaneous free flap.


21. Jeng SF, Kuo YR, Wei FC, et al. Total lower lip reconstruction with a composite radial forearm-palmaris longus tendon flap: a clinical series. Plast Reconstr Surg 113:19-23, 2004. Several techniques are described in the literature for static suspension of the reconstructed lip to the oral commissure. However, drooling often persists. The authors describe a technique of tendon passage and fixation to the orbicularis oris muscle around the philtral columns to mimic the function of the horizontal fibers of the orbicularis oris and restore complete circumference of the oral sphincter. This technique allows a dynamic reconstruction of the lower lip with a functioning sphincter to prevent drooling, particularly during speaking and eating.


24. Lutz BS, Wei FC. Microsurgical workhorse flaps in head and neck reconstruction. Clin Plast Surg 32:421-430, 2005. The authors propose that the ALT flap, the radial forearm flap, and the fibular osteoseptocutaneous flap are the three main workhorse flaps for head and neck reconstructions. Anatomy, elevation technique, and donor site management are discussed. The authors believe that by concentrating on these three selected flaps, reconstructive surgeons can produce more consistent surgical results with few postoperative complications.


28. Wei FC, Jain V, Celik N, et al. Have we found an ideal soft-tissue flap: an experience with 672 anterolateral thigh flaps. Plast Reconstr Surg 109:2219-2226, 2002. Through this series of 672 consecutive cases, the authors elucidate the numerous advantages of the ALT flap, which can be harvested as a large, thin flap conveniently and without repositioning patients. It also has a reliable primary pedicle position and results in an inconspicuous donor site and low morbidity. Consequently, this flap is becoming many surgeons’ first choice for reconstruction of the head and neck, extremities, and trunk.


This article presents a prospective study of 50 patients who underwent radial forearm free flap surgery with superficial dissection. All had good skin graft take and motor function recovery. Dysesthesia was usually mild and improved as time passed. Accidental injury or unnecessary division of superficial radial nerve branches can be avoided. The aesthetic outcome was rated as good or fair in 98% of the cases.

This article presents a prospective study of 50 patients who underwent radial forearm free flap surgery with superficial dissection. All had good skin graft take and motor function recovery. Dysesthesia was usually mild and improved as time passed. Accidental injury or unnecessary division of superficial radial nerve branches can be avoided. The aesthetic outcome was rated as good or fair in 98% of the cases.
Numerous reconstruction techniques have been devised to deal with the complexity of head and neck defects. These include the use of flaps with multiple skin paddles and multicomponent, so-called chimera flaps. Nevertheless, multiple free flaps may be required for extensive defects of the head and neck. These defects may include skin/soft tissue, oral lining, and/or bone. Composite defects involve all of these components. Our main goals in head and neck reconstruction are to achieve primary wound healing, seal contaminated areas from sterile areas, and restore form and function. Our reconstructions are performed in a manner that ensures wound healing, because many of these patients require adjuvant treatment in the form of chemotherapy, radiation therapy, or both. The reconstruction must facilitate and not hinder adjuvant treatment. A reconstruction that requires a prolonged period of healing with extensive dressing changes may delay the initiation of adjuvant therapy. If adjuvant therapy is not begun at the optimal time, the outcome may be affected, and this is therefore unacceptable.
A variety of flaps ranging from simple pedicled regional flaps to multiple free flaps may be used to perform primary functional and cosmetic reconstruction for any size of postoncologic defect. Although there is still a role for pedicled regional flaps in the reconstruction of head and neck defects, free flaps are now more commonly used because they allow one-stage reconstruction with comparatively lower complication rates, better overall results, and shorter hospitalization periods.\textsuperscript{11-13} Several situations might require the use of multiple free flaps. Some patients receive multiple flaps in a series of operations\textsuperscript{10,14,15} because of previous free flap loss, recurrent disease, or the secondary effects of treatment.\textsuperscript{10,16} However, in some patients, and in certain circumstances, more than one flap may be required synchronously to reconstruct a large, complex defect.\textsuperscript{10,17} Multiple synchronous free flaps are most commonly used in the reconstruction of composite defects of the mandible.\textsuperscript{10} Multiple flaps may also be indicated for compound defects with an insufficient amount of available skin. In this case, one flap may be used for intraoral lining or, if a difficult insetting is anticipated, one may be needed because of the extent of the defect or its three dimensionality. Multiple flaps may also be used for large cutaneous defects such as those that require total scalp resurfacing.\textsuperscript{18}

The reconstruction of head and neck cancer is inherently complex as a result of flap failures, radiation therapy, or other reconstructive complications, as well as local tumor recurrence and second primary tumors.\textsuperscript{19,20} As a result, we are often faced with the challenge of a second major reconstruction in a patient who has undergone previous surgery in addition to chemotherapy and/or radiation therapy. This combination of circumstances significantly increases the complexity of secondary reconstructions under suboptimal circumstances. Not surprisingly, it has been shown that the risk of failure increases with the number of reconstructions, though the risk of failure is not apparently increased in patients undergoing synchronous, multiple free flap reconstruction.\textsuperscript{10} Fig. 38-1 is an algorithm for multiple flaps in different situations.

![Fig. 38-1](image_url)  The most common reasons for multiple flap reconstructions in the head and neck.
CONSIDERATIONS IN MULTIPLE FREE FLAP SURGERY

When planning multiple free flap surgery for the reconstruction of a head and neck defect, the following must be considered:
- The available recipient vessels and which to use
- Arteriovenous (AV) loops
- Vein grafts
- Pedicle reuse
- Cephalic vein transposition
- Pedicled flap

Synchronous Flaps

The flap choices are based on their availability and the requirements of the reconstruction (characteristics of the defect). One of the choices that must be determined is whether the flaps will be connected in series or in parallel (Fig. 38-2). The advantage of flaps connected in series is that only one set of donor vessels is needed, which can be a very important issue in head and neck reconstruction, especially if a patient has had previous surgery and multiple donor vessels are not available. The decision may also be based on the geometry of the reconstruction. It may not be possible to run the flaps in parallel because of the relative positions of the two pedicles, or because of the unique circumstances within a given defect.

Fig. 38-2  A and B, A radial forearm flap and lateral arm flap were anastomosed together on the back table to prepare for reconstruction of a complex pharyngeal defect involving the soft palate and posterior pharyngeal wall. C, Two separate anastomoses (arrows) were performed in a patient undergoing mandibular reconstruction with a free fibular osseous flap and a radial forearm flap. Two separate flaps were chosen in this case, because the patient had particularly heavy lower legs, which precluded use of a fibular skin paddle.
The advantage of parallel anastomoses is that the risk of losing both flaps is, at least theoretically, reduced, because each flap has its own blood supply. If the flaps are connected in series and the anastomosis thromboses, then both flaps are at high risk for being lost. The logistics of the anastomoses need to be worked out for each patient.

### Sequential Flaps

A second reconstruction may be required for several reasons: failure of the original reconstruction, a complication, or recurrent disease (see Fig. 38-1). Reconstructions in these circumstances pose specific problems, as seen with the patient in Fig. 38-3. This individual presented with a T4 squamous cell carcinoma of the mandible requiring a composite resection and reconstruction. Reconstruction was performed with a radial forearm flap and a mandibular reconstruction plate. Although one may argue that this was not the best choice for reconstruction, specific circumstances beyond the scope of this discussion led us to that decision. However, 2 years later, the patient presented with plate exposure (Fig. 38-3, A). He clearly required further reconstruction, but now the situation was more difficult for two reasons: (1) he had undergone radiation therapy to the ipsilateral neck, making the vessels hard, unyielding, and extremely difficult to dissect, and (2) he required bone and skin cover, necessitating a composite flap. The decisions that needed to be made in this case are typical of the problems that a second reconstruction presents. The questions are:

- What is the best flap to use?
- Which vessels are available?
- Will a vein graft be required?

In this patient’s case, we were able to reuse the vessels from the old radial forearm flap (Fig. 38-3, B), thus avoiding the need to dissect vessels in the irradiated area of the neck. We also used a vein graft to access the contralateral vessels. Had the radial artery not been available, one option would have been to avoid the irradiated, ipsilateral neck and look for appropriate vessels on the contralateral side, which had not undergone previous surgery or radiation therapy. However, in this case, our pedicle would not have reached easily and we would have had to use a vein graft.

![Fig. 38-3  A, This patient had an exposed mandibular reconstruction plate. He underwent a composite mandibular resection that was reconstructed with a radial forearm flap and mandibular reconstruction plate.](image-url)
In such situations, the use of an AV loop is a very good way to ensure adequate pedicle length. The loop is used to create a fistula between an artery and vein. This is usually done at the beginning of surgery by harvesting an appropriate vein and completing the fistula before the flap harvest. Therefore blood can flow through the fistula for an hour or more while the flap is being harvested, and during that time any problems with the anastomoses will be evident. Once the flap is ready, the loop is divided to provide an arterial end and a venous end to which the flap can be connected (Fig. 38-4). Alternatively, a flap can be chosen with a pedicle of sufficient length to reach the contralateral neck.
Sometimes the issue with secondary reconstructions is not a lack of arterial inflow but of venous outflow. There are several ways to approach this problem. The cephalic vein can be very useful in these situations and can be flipped up into the neck to provide venous outflow.\(^2\) It easily extends to the angle of the mandible (Fig. 38-5). Another option is to use a flap with a venous pedicle that does not require anastomosis so that only an arterial anastomosis is needed. The radial forearm flap can be used in this way (Fig. 38-6).

Fig. 38-5  **A,** The cephalic vein has been dissected from the upper arm in this patient. **B,** The vein is tunneled into the neck where it easily reaches the angle of the mandible.

Fig. 38-6  This radial forearm flap was prepared for a patient undergoing his third floor-of-mouth reconstruction for a new primary tumor. He had already undergone two previous free flap procedures and had received radiation to his neck after each. The radial artery was divided at its origin, but the vein was dissected all the way up the arm so that it could be pedicled into the neck. This helped to avoid venous anastomosis, because there were no available vessels in the neck.
Surgery remains the fundamental treatment modality for primary and recurrent head and neck tumors. The importance of clear resection margins has led to a more aggressive surgical approach. Advances in reconstructive options, including the use of more than one free flap or the use of chimeric flaps, have made this aggressive approach more feasible. Improvements in surgical technique, radiation therapy, and chemotherapy have provided patients longer intervals of disease-free survival so that it is no longer uncommon for these patients to subsequently present with tumor recurrence or a second primary tumor. Resection of these tumors may result in defects that require another free flap. Secondary and tertiary free flaps may also be required for primary flap failure or long-term complications of the initial free flap such as osteoradionecrosis, mandibular plate exposure, or scar contracture (see Fig. 38-1).

**CONCLUSION**

Successful reconstruction is related to the number of free flap operations rather than the number of synchronous free flaps, and this success rate diminishes with increasing numbers of nonsynchronous flaps. It is intuitive to assume that tertiary flaps are more likely to fail than secondary flaps, and we have found this to be true. With each free flap reconstruction, increased scarring from both the initial surgery and the use of radiation therapy hampers success. The risks of failure are also increased by the lack of recipient vessels. Each free flap reconstruction and neck dissection requires the sacrifice of some neck vessels, thus limiting options for a recipient vessel. Patients with multiple failures may also have an underlying comorbidity, which makes successful free flap reconstruction difficult even in optimal settings. Comorbidity may also restrict flap choices. For example, the patient in Fig. 38-3 had severe peripheral vascular disease severe enough to preclude use of the fibular osseocutaneous flap, which would have been a good choice for either his initial or second reconstruction. Therefore the iliac crest was chosen. Flap selection is also more difficult with each subsequent operation, because the number of available donor sites is decreased. This is not usually a major factor but may nevertheless be an issue. In head and neck reconstruction, multiple flaps may be required for extensive defects that include skin/soft tissue, oral lining, and/or bone.
CRITICAL POINTS

Must Know
- Reconstructing large and complex defects with single flaps may lead to sub-optimal results.
- A clear plan for vascular access to donor vessels needs to be developed.
- A backup plan in these types of reconstruction is vital.

Should Know
- The risk of flap failure is greater with sequential flaps.
- The risk increases as the number of sequential flaps increases.
- The risk is not increased with the use of synchronous flaps.

Synopsis
- It is now common in head and neck reconstruction to use multiple flaps, which may be used synchronously to reconstruct complex, three-dimensional defects.
- Frequently, they are used sequentially either as part of a staged reconstruction or to treat disease recurrence or complications.
- The use of multiple flaps demands detailed planning and meticulous execution.

References
   Osteoradionecrosis of the mandible is a serious complication of radiation therapy for head and neck cancer. The free scapular osteocutaneous flap provides a well-vascularized segment of the bone as well as multiple, large skin paddles, each with an abundant and reliable blood supply. In addition, well-vascularized fascia and overlying subcutaneous tissue can be used to fill dead spaces and cover the bony segment and fixation plates. This reduces postoperative infection and promotes primary wound healing. This flap has proved useful for reconstruction of mandibular osteoradionecrosis, particularly when there is a large soft tissue defect.

The authors introduce three types of free combined tissue transfers for cosmetic and functional restoration of massively large facial defects. For complex craniofacial defects, they find concept of combined chimeric tissue transfers to be the most suitable. The ideal pedicle vessels for combined flaps are those in the lateral circumflex femoral system. This system is far from the head and neck region, allowing flap elevation simultaneously with tumor resection.


Microsurgery has improved the success rate for reconstruction of composite defects in the head and neck. The restoration of mandibular continuity alone is not adequate for reconstruction. The replacement of the oral lining with thin tissue is necessary to improve tongue mobility and to prepare for later dental restoration. Combining free flaps can take advantage of the strengths of the individual donor sites and eliminate some of the problems with current osseocutaneous flaps. This approach allows surgeons to customize the defect by improving both the functional and aesthetic aspects of reconstruction, and is useful if vascular access is limited, such as after head and neck surgery and radiation therapy.


Ablative surgery in the head and neck often results in defects that require free flap reconstruction. With improved ablation/reconstructive and adjuvant techniques, improved survival has led to an increase in the number of patients undergoing multiple free flap reconstruction. The authors retrospectively analyze a single institution’s 10-year experience in free flap reconstruction for malignant tumors of the head and neck. More than one free flap may be required for reconstruction of head and neck defects, although success decreases as the number of reconstructive procedures increases.


The use of microvascular free tissue transfer has been established as a routine reconstructive option in many clinical cases. Although still technically challenging, the reported success rates of free flap surgery in many centers worldwide have consistently been more than 95%, and when performed by experienced surgeons, the success rate is comparable or even superior to other reconstructive options such as skin grafts, local flaps, and regional flaps. Since first introduced in the 1960s, the
technique and experience of using free flaps for reconstruction have been refined to such a degree that microsurgical transfer has become the first choice of reconstruction in many instances. This has fundamentally changed the structure of the reconstructive ladder, and the traditional concept of “climbing up” the reconstructive ladder is no longer followed rigidly.

When used appropriately, free flaps can provide versatile reconstruction with like-for-like tissues even in extensive composite tissue defects resulting from trauma, chronic wounds, or ablative surgery. The constantly evolving nature of microsurgery has allowed the development of increasingly sophisticated techniques with better functional and aesthetic results for recipient and donor sites. With the recent development and refinement of the free-style free flap concept, any part of the body can now be a potential donor site, provided a Doppler signal arising from a sizable perforator can be detected. This technique vastly expands the repertoire of available flaps.

Despite continual refinement in microsurgical techniques, improvements in technology, and the accumulation of experience, a small percentage of free tissue transfers fail in most centers. Unlike other, less technically demanding reconstructive options, failure in microsurgery represents a potentially devastating situation for patients and surgeons. For patients, mental and physical suffering and the hospital stay are prolonged, further surgery is uncertain, and costs spiral. For surgeons, failure represents a challenging situation in which there is an ongoing defect to be filled but fewer donor sites, especially if composite tissues are needed for functional reconstruction. In addition, the choice of recipient vessels may be limited if conditions for reanastomosis in the vicinity of the same vessels are suboptimal. The original defect has frequently been made larger because of necessary debridement, sometimes with critically exposed structures needing prompt coverage, especially in the head and neck area. The patient may not be able to tolerate another long period of anesthesia because of comorbid conditions.

There are surprisingly few articles in the literature related to the management of flap failure. This may be explained by the low failure rate in most centers, which means it is hard to accumulate experience in its management. Management of the failed flap is a contentious issue with regard to the timing, choice of flap, and method of reconstruction for the residual defect. Nakatsuka et al performed only 23 second free flaps out of their series of 2372 free tissue transfers over a 20-year period. Fearon et al reported a series of 7 cases of flap failure, and Oliva et al performed 18 second free tissue transfers in 54 patients with initial flap failures. In our institution, we encountered a total of 101 failures out of 3361 free flaps over an 8-year period. Of these failures, only 34 underwent a second free flap transfer. Similarly, Amin et al reported a small series of 28 second free flaps. According to these reviews, flap failures occur sporadically and in widely different situations. Without a large number of cases, which is only seen in major specialized units over a long period of time, it is difficult to draw any valid conclusion that is supported by statistically significant data.
Yet, the management of failed flaps should be an integral part of overall preoperative planning and surgical training. Surgeons should inform patients of the possibility of flap failure while obtaining informed consent for free flap surgery. However, it is unlikely that a comprehensive and detailed plan for secondary reconstruction, should the first flap fail, is explained to patients. It is important that surgeons have a secondary reconstructive plan and include this in preoperative planning and counseling.

DEFINITIONS

Flap failure results from a wide spectrum of problems and is not only caused by inadequate perfusion and necrosis. It is helpful to establish certain definitions to help plan approaches. A failing flap is a flap that is potentially salvageable, provided prompt action is taken to reverse the cause or causes of failure. In contrast, a failed flap is an irreversible situation in which part or all of the flap has undergone necrosis and requires further management such as wound care, debridement, or further reconstruction.

The management of flap failure requires a thorough understanding of free flap surgery and the causes of flap failure, including the possible patient factors and the technical risk factors for surgery. A comprehensive philosophy of care is needed that involves the prevention of failure and recognition and prompt salvage of a failing flap. Box 39-1 lists possible patient, surgeon, and technical factors that may contribute to higher risks of flap failure, although some studies have shown no statistically significant differences between certain risk factors.11-13 Certain conditions, such as diabetes, do not necessarily increase failure rates. Interestingly, although tobacco has long been deemed a risk factor for free flap surgery, the studies reviewed here show that smoking is not associated with a higher flap failure rate.

### Box 39-1  Risk Factors Associated With Flap Failure

- Previous reconstruction or previously failed reconstruction
- Obese patients
- Prothrombotic disorders
- Atherosclerotic disease
- Local infection or inflammatory process
- Vein graft or AV loop formation
- Composite flap with an osseous component
- Previous radiation therapy

AV, Arteriovenous.
In addition, certain risk factors may apply only to free flap reconstruction of a particular region, such as head and neck reconstruction or breast reconstruction. This may explain the discrepancies in findings among various studies regarding the risk factors for free flap surgery. When considering patients for microsurgical reconstruction who have these risk factors, it is recommended that extra attention be paid during preoperative planning, surgery, and postoperative monitoring. It is far better to prevent than to manage flap failure. Knowledge of the causes of flap failure could help prevent a second failure and optimize the conditions for further reconstruction.

**MANAGEMENT OF A FAILING FLAP**

**Timing**

The timing of the presentation of vascular compromise demonstrates the need for intensive flap monitoring postoperatively. In our series of 1142 free flaps, reexploration was performed in 113 patients (9.9%). Of these, 51.3% presented signs of vascular compromise within the first 4 hours after surgery; 82.3% displayed signs within the first 24 hours; and 95.6% of patients with compromised flaps presented with signs within the first 72 hours. Moreover, flaps showing very early signs of circulatory compromise on admission to the microsurgical ICU had a significantly lower salvage rate. Based on these data, it can be concluded that close postoperative monitoring of flaps is quintessential in the prompt and accurate diagnosis of failing flaps (Table 39-1).

<table>
<thead>
<tr>
<th>Table 39-1</th>
<th>Salvage Outcome Related to Signs of Circulatory Compromise*</th>
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<tbody>
<tr>
<td>First Record of the Flap After Admission to ICU</td>
<td>No. of Flaps (N = 113)</td>
</tr>
<tr>
<td>Abnormal signs (+)</td>
<td>22</td>
</tr>
<tr>
<td>Abnormal signs (−)</td>
<td>91</td>
</tr>
</tbody>
</table>

*p = 0.01.

Once a compromised vascular supply has been detected, prompt action should be taken to salvage the flap before the no-reflow phenomenon sets in. Early exploration has a higher success rate in flap salvage than late exploration. In our published series of 672 free anterolateral thigh flaps, the success rate was 96.58%. This included the successful salvage of 19 flaps out of 34 that were reexplored.
success rates after salvage of a compromised flap are approximately 28% to 87.5%.\textsuperscript{1,4,14,20,21} Alternatively, the negative reexploration rate is reported to be 14% to 27%.\textsuperscript{16} Reconstructive surgeons need to be well versed not only in flap monitoring, but also in the immediate actions that are essential for successful flap salvage.

Conservative Management

Postoperatively, patients should be cared for by experienced personnel in a warm and quiet environment where they are well hydrated and as comfortable and pain free as possible. A patient’s temperature, pulse, blood pressure, and urine output should reflect the adequacy of these environmental measures. These measures must be constantly maintained when managing patients with failing flaps. After a general assessment of the patient is made, attention is given to the flap. For an excessively tight flap inset, simple actions such as releasing sutures at the bedside can produce significant improvement. The need for surgical exploration can then be determined.

The use of a medicinal leech, \textit{Hirudo medicinalis}, dates back to ancient Egypt in the fourteenth to fifteenth century BC. It has proved effective in relieving venous congestion in compromised free flaps. \textit{H. medicinalis} secretes hirudin, a potent anticoagulant; hyaluronidase, which allows the spread of the hirudin locally around the wound; and antihistamine, which leads to vasodilation and prolongation of bleeding from the bite of the leech. This bloodletting relieves venous congestion in free flaps. \textit{Aeromonas hydrophila} infection is a known complication of medicinal leech therapy.\textsuperscript{22} Adequate prophylactic antibiotic coverage should be administered. In a series of 74 patients, Smoot et al\textsuperscript{23} and Soucacos et al\textsuperscript{24} applied medicinal leeches and salvaged free skin flaps in 17 of 20 patients who presented with venous insufficiency of a free skin flap for upper and lower extremity coverage.

Anecdotal results have been reported regarding the role of hyperbaric oxygen (HBO) therapy in salvaging failing flaps. This may be useful for patients who are not suitable for surgical exploration and in institutions where the facility of HBO is readily available. So far, studies related to the effects of HBO on free flaps are mainly on experimental rat models.\textsuperscript{25-31} It has been shown that perioperative treatment with HBO can improve free flap survival and increase secondary critical ischemia time.

Surgical Management

Once the decision to reexplore is made, the rationale, risks, benefits, and alternatives of the procedure must be clearly communicated with the patient and his or her family. During reexploration, the pedicle and the anastomotic sites should first be identified with great care, particularly in an infected wound in which purulent material and fibrinous exudate tightly adhere to the pedicle. The use of a microscope may be
warranted at times for safe dissection. The anastomoses need not be opened if they appear patent. Often, the simple evacuation of a hematoma surrounding the vascular pedicle may relieve venous congestion. If the patency is uncertain, the anastomoses are opened for examination. When intravascular thrombus is encountered, thrombectomy is performed. Intravenous heparin is started, provided there is no systemic contraindication to anticoagulation therapy. Thrombectomy can be performed by gently milking the vessels if only a small, soft clot is identified. A 2 Fr Fogarty catheter can be used if a more extensive clot is encountered. These patients are placed on a maintenance dose of intravenous heparin.¹⁶

When thrombolysis is performed, the thrombolytic solution can be introduced through the original arterial anastomosis or through a side branch of the artery. Clamps are placed in the artery proximal to the injection and in the draining vein to allow the thrombolytics to remain in the flap for 20 minutes. Free drainage of the venous effluent is required to prevent systemic circulation of the thrombolytics.¹⁶

Numerous protocols have been proposed regarding the use of anticoagulant or antithrombotic solutions during the perioperative or postoperative period.²²,²³,³² Currently, there is no conclusive evidence to show that one agent is superior to another. Similarly, the systemic or localized administration of thrombolytics such as urokinase to salvage failing flaps has shown mixed results. The role of anticoagulants or antithrombotics in free flap salvage remains unclear, and their administration depends on the operating surgeon’s preference.

**Vein Grafts**

The cause of vascular compromise of flap circulation usually becomes apparent during surgical exploration. If the arterial anastomosis is thrombosed, the anastomosis and the unhealthy segment should be excised and revised. The proximal arterial inflow should be checked. If the thrombus is not organized and has extended proximally, it can be removed by passing a Fogarty catheter in a retrograde fashion. If a long segment must be excised, a vein graft may be required to bridge the gap. Alternatively, a new recipient artery can be sought. A similar approach is used for venous thrombosis.

Regardless of the presence of any obvious thrombus along the vascular pedicle, signs of external compression must be explored. First, the whole pedicle to the flap should be inspected under microscope. It must be ensured that the pedicle is not twisted or kinked and that the tunnel through which the pedicle passes is of adequate size. Inadvertent injury to the pedicle or its side branches must be excluded. On rare occasions, a hemoclip may be compressing or partially occluding the vessel.⁵ Although an excessively long arterial pedicle seldom causes problems, the venous equivalent is highly susceptible to kinking and, as a result, venous outflow can be obstructed. Once identified, the causes of circulatory compromise must be rectified accordingly (Table 39-2).
Chapter 39  

Management of Flap Failure

If all causes of external compression or pedicle kinking are excluded, and the flap is still pale, we believe that the anastomosis should be excised and the procedure repeated. A soft thrombus is often not detected from outside the vessels, but can then be removed. A thrombolytic solution such as urokinase can be used to perfuse the flap. In short, prompt surgical exploration is the key step to successful free flap salvage. Table 39-3 summarizes the possible findings in a vascular compromised flap and their respective corrective measures. An algorithm for the management of microvascular thrombosis suggested by Bui et al\(^\text{16}\) is useful and shown in Fig. 39-1.

### Table 39-2  Surgical Measures for Compromised Flaps

<table>
<thead>
<tr>
<th>Problems</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient tunnel</td>
<td>Widen tunnel</td>
</tr>
<tr>
<td>Kinking/twisting of the pedicle inset</td>
<td>Unkink the pedicle ± stabilize the sutures ± reinset the flap</td>
</tr>
<tr>
<td>Excessively long pedicle</td>
<td>Shorten the pedicle + reanastomose</td>
</tr>
<tr>
<td>Injury to the pedicle or side branches</td>
<td>Excise the injured segment ± vein graft</td>
</tr>
<tr>
<td>Poor arterial inflow</td>
<td>Release the surrounding connective tissues/use alternative recipient vessels</td>
</tr>
<tr>
<td>Poor venous backflow</td>
<td>Release the surrounding connective tissues/use alternative recipient vessels</td>
</tr>
<tr>
<td>Soft thrombus</td>
<td>Reanastomose</td>
</tr>
<tr>
<td>Organized thrombus</td>
<td>Thrombectomy with a Fogarty catheter; excise the affected segment, reanastomose ± vein graft</td>
</tr>
<tr>
<td>Thrombus extends into the flap/ perforators</td>
<td>Discard flap</td>
</tr>
<tr>
<td>No flow</td>
<td>Perfuse the flap with thrombolytics/discard flap</td>
</tr>
<tr>
<td>No identifiable cause</td>
<td>Take down the anastomosis, inspect the lumen, and reanastomose</td>
</tr>
</tbody>
</table>

If all causes of external compression or pedicle kinking are excluded, and the flap is still pale, we believe that the anastomosis should be excised and the procedure repeated. A soft thrombus is often not detected from outside the vessels, but can then be removed. A thrombolytic solution such as urokinase can be used to perfuse the flap. In short, prompt surgical exploration is the key step to successful free flap salvage. Table 39-3 summarizes the possible findings in a vascular compromised flap and their respective corrective measures. An algorithm for the management of microvascular thrombosis suggested by Bui et al\(^\text{16}\) is useful and shown in Fig. 39-1.

### Table 39-3  Conservative Measures for Compromised Flaps

<table>
<thead>
<tr>
<th>Problems</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold patient</td>
<td>Keep warm</td>
</tr>
<tr>
<td>Arterial insufficiency</td>
<td>Maximize cardiac output, local vasodilator</td>
</tr>
<tr>
<td>Venous congestion</td>
<td>Release the inset sutures, pin prick, leeching</td>
</tr>
<tr>
<td>Struggling flap, or patient not fit to return to operating room</td>
<td>Hyperbaric oxygen therapy</td>
</tr>
</tbody>
</table>
Salvage reconstruction after flap failure is challenging. The most suitable flap was already used in the first reconstruction, and the available recipient vessels for microvascular free tissue transfer are limited. Furthermore, the risk of infection and delayed wound healing may be higher. Patients who undergo repeated operations may have a poor general condition that does not permit further surgery involving lengthy operating time.

Oliva et al\textsuperscript{3} stated in 1993 that once the initial free flap was deemed nonviable, three issues must be clarified: (1) the reason or reasons that the transplant failed, (2) the original indication for transplantation, and (3) the status of the resultant wound. Once these issues are carefully considered, the surgeon and patient must decide on the next course of action regarding reconstruction.

The following decisions must be made:

- The need for reconstruction. Is the flap failure partial or total? Partial flap failure is defined as flap loss resulting from necrosis that is not simply classified as wound dehiscence. Can the area be treated by conservative means alone? Or does it require a secondary skin graft or another locoregional or distant flap?
- The timing of reconstruction. Are critical structures exposed? Prompt secondary reconstructions are especially pertinent in the head and neck region, because major vessels or neurologic structures may be exposed with a resultant increased morbidity or mortality.
- If reconstruction is needed, is there a need for a second free flap? Or can it be done with a regional flap or local flap instead? The main considerations for a free flap are function and adequate coverage of vital structures.
• If a second free flap is needed, what are the suitable donor sites? Do the same kinds of tissue or tissues need to be used, or should the reconstructive goal be downgraded by using a simpler free flap?
• If a second free flap is needed, what are the suitable recipient vessels? Is a vein graft needed?
• Based on the answers to the last two questions, a decision may be made to change plans and pursue other options.

Simply from the number of questions to consider, it is easy to see that management of a failed flap is an extremely dynamic and fluid situation that depends on many factors that vary from patient to patient and from site to site. The rest of this chapter focuses on drawing out a few principles that may be useful in most situations.

### Need for Further Reconstruction

Reconstructive surgeons must understand that failed flaps do not always necessitate further reconstruction. That is why the initial indication for free flap surgery must be reevaluated. When managing flap failure in breast reconstruction, it is reasonable to have no further reconstruction, provided the patient is satisfied with the cosmesis. If the original indication is purely for cosmesis, further reconstruction is optional. Similarly, in lower limb free flap reconstruction, partial flap failure can often be managed conservatively, provided that metal constructs or vital structures are not exposed. Therefore an accurate reassessment of the resultant defect after adequate debridement is of paramount importance. A long healing time with conservative management of flap failure is acceptable in lower limb trauma reconstruction, whereas timely wound healing is an important factor in head and neck oncologic reconstruction in which adjunct radiation therapy is often indicated. In these circumstances, a second regional or free flap reconstruction is likely to expedite complete wound healing, provided the cause of the initial flap failure is identified and corrected.

### Timing of Reconstruction

The issue of immediate or delayed second free tissue transfers after initial flap failure has been the subject of ongoing debate.\(^5,9\) When is the optimal time to embark on the second free flap? How long should the wait be? In the series reported by Fearon et al,\(^9\) three of the seven patients had 2-week intervals between the initial and second free flaps, and the rest of the patients had intervals ranging from 5 weeks to 21 months. In the series reported by Wei et al,\(^7\) the mean delay between initial failures and subsequent second free flaps was 12 days (range 2 to 60 days) in the head and neck region and 18 days (range 2 to 56 days) in the extremities. Oliva et al\(^3\) reported that initially the mean delay for a second transplant was 248 days (first seven cases) after the initial surgery. This has been gradually shortened to 7.2 days and, in several cases, immediate second flaps were performed at exploration when the first flap was deemed unsalvageable.
The timing of reconstruction is different if critical structures are exposed. An exposed skull base defect may lead to patient death because of meningitis and abscess formation. Similarly, exposure of the major vessels in the neck to air and saliva after unsuccessful oromandibular reconstruction may eventually cause rupture and life-threatening bleeding. Generally, if the cause of initial failures has been determined and the wound has been bed debrided adequately, an early second free flap is preferable to a delayed second attempt. Specific patient factors and logistics have to be considered for each case.

### Need for a Second Free Flap

As mentioned previously, reconstructive goals may have to be downgraded for patients with previous flap failure. In certain patients, the goal may have been set unrealistically high for the first reconstruction. Reconstructive surgeons must consider all surgical or nonsurgical options apart from free flaps.

In 2001, Wei et al. reported the largest series to date, with 3361 head and neck and extremity reconstructions; complete and partial flap failures occurred in 101 cases. Reoperative free flaps were performed in 34% of cases. Treatment options differed largely, depending on the anatomic location of the reconstruction and extent of flap failure. Most of the failures in the head and neck were treated with second free flaps (40%), and most of those in the extremities were treated conservatively (37% conservatively and 29% second free flap). The authors concluded that a second free flap is the ideal choice of reconstruction for flap failure in the head and neck region and for failed vascularized bone flaps for long bone reconstruction and functional muscle transfer; failed free flaps in the extremities can be treated with regional flaps or conservative treatment (Figs. 39-2 and 39-3). Similar findings were reported by Culliford et al. In their series of 50 free flap failures in the lower extremities, only 16% of the patients had second free flaps, and most of the patients (66%) were treated with regional flaps, skin grafts, or conservative management.

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**Fig. 39-2**  
A reoperative free flap is indicated in situations in which the failure exposes major neck vessels, delays wound healing and subsequently life-saving radiation therapy, or creates a potentially limb-threatening scenario. Severe local infection is a relative contraindication, particularly for osseocutaneous flaps. However, the deterioration of a patient’s medical status is a contraindication to a reoperative free flap. Patients need to be informed that second free flap surgery poses higher rates of flap failure (9% to 11%) and complications.

Although many studies have shown that age alone does not affect the outcomes of microvascular surgery, patient-related factors or comorbidity, such as cardiopulmonary and vascular status, have an important impact on free flap complications. Limitations of the surgeon should also be considered. It is an important attribute of surgeons to realize the limits of their capabilities and choose a simpler but safer reconstructive option. The goals and indications of the first reconstruction have to be reexamined after the first flap failure. The indications for the first free flap surgery can be cosmetic, functional, or life saving. Downgrading the reconstruction yields suboptimal results in some cases but can be life threatening in others. For example,
downgrading the reconstruction in patients with composite segmental bony and soft tissue defects in the lower limb can result in amputation; the same downgrading in patients with exposed major neck vessels can result in torrential bleeding or death (Box 39-2).

**Box 39-2  Indications and Contraindications for Second Free Flaps**

**Indications**
- Timely wound healing for life-saving radiation therapy is required
- Exposed major vessels or vital structures
- Exposed instrumentation
- Better cosmetic and functional results still expected and cannot be achieved by alternative reconstructive methods such as toe transfer or functioning muscle transfer
- Limb-threatening wound in extremity

**Contraindications**
- Deteriorating general conditions
- Severe local infection

**Choice of Donor Sites**

According to Kroll et al., some flaps have higher failure and complication rates than others. In this series, the thrombosis rate for the combined rectus abdominis–based flap group was much lower than for all other type of flaps (0.9% versus 6.6%). However, there are marked differences in series reported by others. This could be explained by the various proficiencies and experiences with flaps that have been accumulated by different surgeons. However, it is generally agreed that a composite flap with an osseous component poses additional difficulties during flap elevation and inset and thus has a higher failure rate. When reviewing the options for a second free flap, a safer option should be considered. This should be a flap that surgeons are familiar with, preferably a fascial, cutaneous, or fasciocutaneous flap.

Additional factors to consider are the pedicle length and diameter of the vessels. In head and neck cases without adequate recipient vessels, the contralateral set of vessels can be used. Therefore flaps with long pedicles are preferred. This avoids the use of a vein graft or the formation of a vascular loop, which carries a higher incidence of flap failure and vascular complications.

The second free flap should be designed carefully. Wound debridement after the initial flap failure can result in a larger defect; therefore a larger design of the second free flap may be required. The second flap should also have good vascularity and a
longer pedicle. Donor site morbidities are important factors in usual free flap surgery; however, they take a lower priority in the flap selection process for second free flap reconstruction. In short, when choosing the donor tissue for a second free flap, the first priority is to avoid another failed flap by using flaps that are familiar to the surgeons, without an osseous component and preferably with a consistent and long vascular pedicle. If all of these criteria are fulfilled, in most instances, the ideal second free flap is the contralateral side of the original donor tissues. This has been the first choice of second free flap in our experience.

As mentioned previously, sometimes the initial reconstructive goal needs to be downgraded to avoid a second flap failure. As an example, after a failed mandibular reconstruction, the surgeon might use a large, single free flap (anterolateral thigh flap) instead of double free flaps (anterolateral thigh and fibular flaps), or a fasciocutaneous flap (anterolateral thigh flap with reconstruction plate) instead of an osseocutaneous (fibular) flap (Fig. 39-4). In other circumstances, downgrading a reconstructive goal means using a locoregional flap instead of a free flap. Conservative treatment should also be considered as a reconstructive option. Although conservative treatment is a valid option in extremities with no exposed vessels, joints, or instrumentation, it is usually not suitable for most head and neck defects (Box 39-3).

Fig. 39-4  A, Advanced lower gum and lip cancer. B, The composite mandibular defect after radical excision and reconstruction plate fixation. C, The appearance after double flap reconstruction showing the mandible and intraoral defect reconstructed with a fibular osseoseptocutaneous flap. The lip and cheek and chin were reconstructed with an anterolateral thigh flap.

Continued
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Fig. 39-4, cont’d  D, Failure of the fibular osseoseptocutaneous flap. E, The necrotic fibular osseoseptocutaneous flap was removed and replaced with an anterolateral thigh myocutaneous flap. F and G, The appearance after the completion of postoperative radiation therapy.

Box 39-3  Flap Choices for Second Free Flap

• Contralateral side of initial donor site usually the first choice
• Flaps that the surgeons are familiar with and are relatively easy to perform
• Flaps with long and sizeable pedicles that are more likely to match the recipient vessels
• Flaps without an osseous component
• Downgrade reconstructive goals appropriately to avoid second flap failure

Choice of Recipient Vessels
Choosing appropriate recipient vessels can be the most significant factor relating to flap failures. This is particularly important in patients who had previous free flap transfer in the same area or those who require double flap reconstruction. In selecting recipient vessels for the second free flap, it is preferable that the original recipi-
ent vessels not be used because of the possible presence of vasculitis. The anasto-
mosis should be performed away from the problematic site.  

The choice of recipient vessels is more important in lower limb reconstruction than
in head and neck reconstruction for several reasons. First, in patients with atheroscle-
rotic disease, the lower limb vessels are usually affected to a larger extent. Second,
more vessels are available in the head and neck region as potential recipient vessels.
In our experience, the four most commonly used recipient arteries are the superior
thyroid, facial, superficial temporal, and transverse cervical arteries. For flaps with
long pedicles such as anterolateral thigh flaps, the contralateral vessels can also be
used without the need for vein grafts or vessel loop formation.

Choosing the right recipient vessels requires even more consideration in cases with
previous free flap surgery or failed free flaps, or if the commonly used vessels have
been removed or damaged during ablative oncologic excision. Increased free flap
failure rates are associated with the use of vein grafts or the formation of an arterio-
venous loop.  

Additional consideration must be given to the choice of recipient vessels in the vicin-
ity of areas that have been irradiated or have had localized infection. Even if vessels
are available, a surgeon must anticipate a more difficult dissection of these vessels.
Yazar et al  reported a series of 131 double free flaps in 130 patients and showed that
careful consideration of the recipient vessel choice could minimize the need for a
vein graft and that vessels in the vicinity of the previously irradiated or operated
neck can be used safely. Nahabedian et al  had similar findings in their series of head
and neck free flap reconstructions. The flap failure rate in this series was not related
to the choice of recipient vessels or previous irradiation.

It may seem contradictory to state that the choice of recipient vessel is of utmost
importance and that several series reported similar thrombosis or failure rates using
different vessels. However, that is exactly the point we try to emphasize: If the vari-
ous factors mentioned previously have been considered carefully, the choice of recip-
ient vessels should not affect the success of the second free flap reconstruction.

CONCLUSION
There should not be a standardized protocol for the management of failed flaps. In-
stead, management should be tailored to the surgeon’s experience, the clinical set-
ning, the defect, and expected functional outcomes. As with the initial reconstruc-
tion, the patient’s general conditions have to be taken into account. A more simple
salvage reconstruction generally produces less optimal outcomes, but it may be indi-
cated in select patients for whom a quick recovery is more important. This is espe-
cially true in oncologic patients who require postoperative adjuvant radiation therapy.
In our experience, a second free tissue transfer is, in general, a relatively more reliable and more effective choice of reconstruction in patients with flap failure. The indication of a second free flap is clearer in head and neck reconstruction. Conservative treatment remains a simple and valid alternative option for the management of flap failures in the extremities.

Although a common algorithm for the management of microvascular thrombosis during reexploration has been suggested (see Fig. 39-1) and is applicable to most free flap reconstructions, we believe that different algorithms are required for head and neck, breast, and extremity reconstructions.

**Critical Points**

**Must Know**
- Initial indications and aims of reconstruction must be carefully reviewed before any secondary reconstruction.
- A thorough root cause analysis of the failure of the initial flap must be performed.
- The extent of the secondary defect after flap failure is often greater than the original defect.
- Deteriorating medical condition and severe local infection are contraindications for second free flap.

**Should Know**
- Downgrading the initial reconstructive goal to minimize further complications is a viable option after flap failure.
- Be familiar with the choices of secondary local flaps, free flaps, and the anatomy of secondary recipient vessels, and be able to determine the best choices available.
- An early second free flap is preferable to a late second attempt, provided the initial cause of failure is determined and a clean wound bed is available.

**Synopsis**
- The successful salvage of failing flaps requires a timely diagnosis, an accurate determination of the cause of the vascular compromise, and prompt corrective action.
- The management of failed flaps requires an objective evaluation of the extent of the original reconstruction, a thorough root cause analysis of the failure, and a comprehensive review of local and free tissue availability. Through this evaluation, the best secondary reconstructive options can be presented to patients.
References


   This paper reports a series of 54 failed microvascular transplantations over 20 years. Eighteen of these cases underwent a second transplantation with a success rate of 89%. According to the authors, three important issues must be clarified: (1) the reason or reasons that the transplant failed, (2) the original indication for transplantation, and (3) the status of the resultant wound. Indications for second free flaps are also discussed.


   This is the largest study to date discussing the outcomes and management of failed free flaps. From 1990 to 1997, 3361 head and neck and extremity free flap reconstructions were performed; 101 flap failures were encountered. Thirty-four second free flaps were performed with a success rate of 91%. Regional flaps or conservative treatment for failed head and neck free flaps are associated with high complication rates, and second free flaps should be the treatment of choice.

   This is the earliest study on the management of free flap failures. From 1982 to 1986, seven patients underwent second free flaps. One patient had failure of a second free flap. It was concluded that second free flaps are technically more demanding and have a higher failure rate. However, if the reason for the initial failure is identified and corrected, a second free flap should be considered.

   In this retrospective study, 194 head and neck free flap reconstructions were performed from 1989 to 1999, with an overall success rate of 85%. Diabetes and salvage free flap surgery were identified as predictors for complications, and interposition vein grafts and salvage free flap surgery were shown to be associated with higher flap failure rates. As a result, their strategy of flap selection and preoperative evaluation of patients was changed. An additional 105 free flap head and neck reconstructions were performed from 2000 to 2005, with an improved success rate of 94.3%.

A series of 990 consecutive free flaps was reviewed to determine the timing, incidence, and causes of pedicle thrombosis. Eighty percent of the thromboses happened within the first 2 postoperative days. Venous thrombosis was more common than arterial thrombosis and had a later presentation.


This retrospective review describes a series of 1193 free flaps performed from 1991 to 2002. The reexploration rate was 6%. The most common causes for reexploration were pedicle thrombosis and hematoma. Venous thrombosis was more common than arterial thrombosis and had a higher salvage rate. Salvaged free flaps were reexplored more quickly than failed flaps. An algorithm for the management of microvascular thrombosis was suggested.


Osteoradionecrosis
Following Radiation Therapy

Christopher Loiselle, Gabrielle M. Kane,
Peter C. Neligan

HIGHLIGHTS

• Osteoradionecrosis is a necrotic wound in irradiated bone that persists for 3 to 6 months without healing, with no evidence of tumor recurrence.
• Radiation-induced fibrosis is currently believed to be the primary cause of osteoradionecrosis.
• The buccal cortex of the premolar, molar, and retromolar areas of the mandible are more vulnerable to osteoradionecrosis.
• Factors that increase the probability of osteoradionecrosis include the radiation dose, tumor site, stage, and the patient’s baseline health characteristics.
• Radiation oncologists and dentists should coordinate efforts to minimize extractions after radiation therapy.

ANATOMY AND PATHOPHYSIOLOGY

Key Points

• Fibroblast dysregulation, destruction of osteoblasts, and the susceptibility of irradiated tissue to late inflammatory reactivation after minimal injury are major factors in osteoradionecrosis pathophysiology.
• Osteoradionecrosis is most likely to occur in the mandible secondary to tumor proximity and vulnerability of the mandibular vascular supply to radiation.
Lyons and Ghazali\(^1\) eloquently explain the historical development of theories on the pathophysiology of osteoradionecrosis (ORN). From the 1930s through the 1970s, infection was considered to play a pivotal role, leading to widespread use of antibiotic agents.\(^2,3\) After closely studying osteonecrotic lesions in the 1980s, Marx\(^4\) identified clear distinctions between the bacterial profiles of ORN and osteomyelitis and set forth the 3H, or hypoxic-hypocellular-hypovascular, theory, in which infection was relegated to a secondary process. This identification of relatively hypoxic and hypovascular tissue was the basis for trials of hyperbaric oxygen therapy (HBOT).

Current theories identify radiation-induced fibrosis as the inciting process underlying ORN.\(^5,6\) This contemporary understanding identifies abnormal fibroblast activity as leading to a paucicellular environment with a disorganized extracellular matrix. Histologically, there is a remarkable scarcity of osteoblasts and deficiency of osteoid production at bone margins.\(^7\) These tissues remain relatively fragile and susceptible to late inflammatory reactivation with minimal injury.

Most authors attribute the greater incidence of ORN in the mandible compared with that in the maxilla to the blood supply and tumor location. Tumors of the oral cavity are often close to the mandible and its critical arteries, which are jeopardized by fibrosis caused by high-dose radiation therapy. Bras et al\(^8\) described mandibular ORN resulting from radiation-induced obliteration of the inferior alveolar artery, with insufficient revascularization by facial artery branches. They identified the buccal cortex of the premolar, molar, and retromolar regions of the mandible as particularly vulnerable.

**Timing, Incidence, and Risk Factors**

**Key Points**
- The period of highest risk for ORN is the first 1 to 3 years after radiation therapy.
- Modern radiation techniques such as intensity-modulated radiation therapy (IMRT) have dramatically reduced the incidence of ORN to less than 2%.
- The incidence depends on the radiation dose and is very low with doses less than 60 Gy.
- Other risk factors for ORN include the oncologic stage, tumor site, and the patient's dental health.

ORN typically manifests within the first few years following radiation therapy—most cases in the first year and more than 90% within 3 years.\(^9,10\) However, the risk of ORN remains for life. Berger and Symington\(^11\) reported two cases of ORN 38 years and 45 years after treatment with external beam radiation therapy and a radium implant, respectively.
As a result of dramatic improvements in radiation therapy targeting and dosimetry, the incidence of ORN has declined in recent years in patients with head and neck cancer. Before 1968, the incidence was 11.8%; from 1968 to 1992, the incidence dropped to 5.4%. Since 1997, pooled studies have shown an incidence of approximately 3%.

In the past 5 to 10 years, the frequency of ORN has further declined with the advent of IMRT, which became commercially available in the late 1990s and has been rapidly adopted into widespread use in radiation centers across North America and Europe. IMRT is a radiation planning and delivery technique in which photon beam arrangements are custom tailored according to three-dimensional imaging to deliver high-dose radiation to tumor volumes while sparing critical structures of normal anatomy.

Using IMRT and a standardized pretherapy prophylactic dental evaluation, Ben-David et al reported no cases of ORN at a median follow-up of 34 months (95% confidence interval, 0% to 2%) among 176 patients with head and neck cancer treated at the University of Michigan. In Germany, Studer et al confirmed the prevention of ORN with IMRT, reporting only one case of ORN among more than 200 patients treated from 2002 to 2007.

Potential risk factors for ORN include the radiation dose, oncologic site and staging, and a patient’s baseline health characteristics. The radiation dose is a critical factor. ORN is exceptionally rare at less than 50 Gy—most cases occur at doses greater than 60 Gy. Patients undergoing repeat radiation therapy following tumor recurrence in the head and neck are at exceptionally high risk for ORN.

The tumor extent and location are used to determine whether the dose exposure of the mandible is less than 60 Gy. The target dose to control gross disease is 66 to 70 Gy. Patients with primary tumor sites in the oral cavity are at higher risk for ORN than patients with primary tumors in the oropharynx or hypopharynx. In a published series from the University of Florida, ORN occurred most often in patients with oral cavity cancers. Patients with laryngeal or hypopharyngeal cancers in which only the angle or ramus of the mandible were within the radiation delivery field had a very low likelihood of developing ORN, necessitating surgical or HBOT. The risk of ORN increases at all sites with concurrent chemotherapy.

Patients with poor dental health who require dental extractions are at higher risk for ORN. Extractions before, during, or after radiation therapy compound the risk of developing ORN. Dental extractions after high-dose radiation therapy in the contemporary setting are associated with an ORN risk in the range of 3% to 6%.
PREVENTION

Key Points

- A dental evaluation and extraction of nonrestorable teeth are critical before initiating radiation therapy.
- Dental extractions should be minimized after radiation therapy.
- The benefit of prophylactic HBOT before dental extractions from the irradiated mandible is questionable.

Collaboration between an experienced dentist and radiation oncologist is vitally important early in the care of patients with head and neck cancer. Nonrestorable teeth should be removed using a minimally traumatic technique before radiation therapy and chemotherapy. Dental extractions should be minimized after radiation therapy. Though some have advocated the prophylactic extraction of all teeth in the radiation field (including healthy teeth), that practice is generally considered excessive and offers no proven benefit. Custom fluoride trays are fashioned by the dentist for ongoing daily use of topical sodium fluoride gel. The generally accepted interval between dental extraction and the initiation of radiation therapy is 10 to 14 days.

Some investigators have advocated the use of prophylactic HBOT for postradiation extractions. In 1985 Marx et al conducted a randomized trial of extractions from irradiated mandibles, treating prophylactically with either HBOT or antibiotic agents. They reported two cases of ORN in 37 patients (5.4%), compared with 11 cases (29.9%) in the antibiotic group. This trial set the stage for the extensive use of prophylactic HBOT for postradiation dental extractions. However, Marx’s trial is criticized for an uncharacteristically high rate of ORN in the antibiotic group. According to Wahl, pooled studies of dental extractions from irradiated bone show a 3.1% to 3.5% incidence of ORN, compared with a slightly higher rate of 4% among patients treated prophylactically with HBOT, calling into question the benefit of HBOT. In addition, HBOT is costly, time consuming, and has risks. Further study of prophylactic HBOT before extractions is needed.

CLINICAL PRESENTATION

Key Points

- Patients presenting with ORN have necrotic wounds in irradiated bone that persist for 3 to 6 months, with no evidence of tumor recurrence.
- The most common site for ORN in the head and neck is the mandible, followed by the maxilla.
Following radiation therapy for head and neck cancer, ORN is an infrequent yet well-known potential complication. The most common site is the mandible, followed by the maxilla. Patients typically present with bone breakdown and bone exposure through overlying skin or mucosa (Fig. 40-1). The ORN spectrum ranges from small, asymptomatic lesions that may heal with conservative management to severe, painful areas of necrosis that impede jaw function and require reconstructive surgery.24

![Image](image-url)

**Fig. 40-1** This patient developed ORN of the left mandible after a composite resection and reconstruction with a fibular free flap. The instrumentation has become exposed, with a chronically draining wound.

The criteria used to diagnose ORN vary among authors; however, it is generally described as a necrotic wound in irradiated bone that persists for 3 to 6 months, without evidence of tumor recurrence.25 Multiple classification schemes for ORN are published, grading lesions based on the extent of cortical and/or medullary bone involvement, the degree of soft tissue ulceration, and the presence or absence of pathologic fracture.1,25 A contemporary and highly detailed categorization method is the “late effects on normal tissue (LENT) and subjective, objective, management, and analytic (SOMA)” grading system used by the Radiation Therapy Oncology Group.9

**DIAGNOSIS**

**Key Points**
- The diagnosis of ORN is based on the clinical finding of persistent, exposed bone in the setting of prior radiation therapy.
- A thorough evaluation for cancer recurrence is critical.
- CT and MRI are useful to evaluate for fracture and lesion magnitude but are not specific in differentiating tumor recurrence from ORN.
The diagnosis of ORN is primarily based on the clinical finding of exposed bone in the setting of prior radiation therapy. Tumor recurrence should be excluded and the patient evaluated for fractures. CT demonstrates cortical breakdown and soft tissue edema. MRI additionally shows marrow signal disruption. The lesion may be enhanced to some degree with the administration of intravenous contrast agents. CT and MRI are useful to evaluate for fractures and lesion magnitude but are not specific in differentiating tumor recurrence from ORN. Positron emission tomography (PET) has not been shown to specifically delineate between ORN and tumor recurrence.

**TREATMENT**

**Key Points**
- Conservative treatment may be reasonable for early, asymptomatic lesions.
- The role of HBOT is controversial.
- Radical resection and reconstruction with free tissue transfer is generally required for established ORN.

The goal of management for established craniomaxillofacial ORN is twofold: treatment of the symptoms and restoration of form and function. Although ORN is not necessarily related to tumor recurrence, it is important to rule out tumor recurrence when making the diagnosis and decision to treat. Numerous strategies are available to treat ORN. Small, asymptomatic lesions may be observed until spontaneous healing occurs. It is recommended not to wait too long for this to occur before initiating treatment. Medical therapies with pentoxifylline and vitamin E and bisphosphonate clodronate have reportedly been helpful.

HBOT has been used frequently to treat ORN; however, the practice is not supported by randomized clinical trials. In a prospective randomized trial, Annane et al. reported a detrimental effect of HBOT. (This trial was terminated early because of the unexpectedly worse outcomes in the HBOT group.) Trials in patients with advanced ORN have demonstrated little benefit of HBOT. Further, among patients undergoing resection and free flap reconstruction, HBOT was associated with increased complications. Despite these results, HBOT continues to be used and may have a place in the setting of surgical debridement for small lesions. Surgeons in particular tend to associate ORN with the double insult of surgery and radiation. This is not necessarily the case. We have already stated that the breakdown of tissues can ensue with or without trauma. This supports the hypocellular-hypovascular-hypoxic theory of Marx.
Radical resection followed by free flap reconstruction has been recommended as the reconstructive method of choice in the surgical management of mandibular ORN (Fig. 40-2). The main advantage of free tissue transfer is the ability to import non-irradiated, well-vascularized tissue to an irradiated and diseased area. Furthermore, radical resection provides tissue that can be examined carefully to rule out tumor recurrence. The surgical management of these patients is particularly challenging. Several factors contribute to this complexity. All of the patients have undergone radiation therapy with its attendant wound-healing problems, and some have had previous surgery, resulting in obliterated tissue planes. Friedlander et al concluded that patients with radiation doses sufficient to cause ORN of the mandible are at higher risk of developing carotid artery atherosclerotic lesions than age-matched, nonirradiated controls. In addition, because some of the patients have had previous free flap reconstruction, the choice of recipient vessels may be limited. Meticulous and careful dissection and the use of alternative vessels for anastomoses can overcome some of these difficulties. These include vessels from the opposite side of the neck, the external carotid artery for arterial anastomosis, and the cephalic turnover vein for venous anastomosis if no native neck veins are suitable.

Fig. 40-2  A, A CT scan showing ORN of the left mandible with erosion. B, The necrotic mandible is exposed. C, The resected, necrotic mandible. D, Reconstruction with a fibular osseocutaneous flap.
CRITICAL POINTS

Must Know
- Major factors in ORN pathophysiology are fibroblast dysregulation, destruction of osteoblasts, and susceptibility of irradiated tissue to late inflammatory reactivation following minimal injury.
- Most ORN incidences occur during the first 3 years after radiation therapy.
- It is strongly recommended that nonrestorable teeth be removed 10 to 15 days before the initiation of radiation therapy.
- ORN classification schemes are based on the extent of cortical and/or medullary bone involvement, the degree of soft tissue ulceration, and the presence or absence of pathologic fracture.

Should Know
- The occurrence of ORN has decreased dramatically to less than 2% among head and neck cancer patients in recent years because of enhancements in radiation therapy targeting and dosimetry and the widespread use of IMRT.
- Multiple classification schemes for ORN are available.

Synopsis
- ORN is a persistent, necrotic wound in irradiated bone that does not heal within 3 to 6 months and shows no evidence of tumor recurrence.
- Although its occurrence has declined in recent years, it is critical that reconstructive surgeons consider risk factors and are thoroughly aware of current trends in prevention, diagnosis, and options for treatment.

References
   *The historically accepted sequence in the pathogenesis of ORN of the jaws was radiation, trauma, and infection. The author challenges this sequence and offers a new one that more accurately describes the biochemical and cellular pathology. The sequence is as follows: radiation, hypoxic-hypocellular-hypovascular tissue, tissue breakdown, and a chronic, nonhealing wound.*

To review and discuss the management of jawbone ORN based on levels of evidence, the authors searched Medline/PUBMED and Cochrane to identify all studies on the management of jawbone ORN, published in English, French, and German from January 1975 through October 2007. A total of 73 articles and 45 citations were evaluated, most providing observational evidence. They conclude that most of the reports on the treatment of jawbone ORN offer weak evidence. Current information seems insufficient for establishing definite treatment guidelines; thus well-designed studies with long-term clinical data are encouraged.


In a 6-year period, the authors treated 21 patients with ORN using wide resection and free flap reconstruction. The median interval between radiation therapy and ORN was 4 years. The median radiation dose was 6000 cGy. The affected areas included all parts of the craniofacial skeleton. Flaps used for reconstruction included the free fibular flaps, iliac crest flaps, scapular flaps, and rectus abdominis flaps. All patients achieved relief from their presenting symptoms and primary bone or wound healing. The authors conclude that conservative measures such as limited debridement and HBO therapy may be effective in preventing the progression of ORN. However, they fail to eradicate established ORN, which requires radical surgical resection followed by functional reconstruction with well-vascularized tissue.


The authors used panoramic radiography, which previously proved useful in identifying carotid artery atherosclerosis in nonirradiated individuals, to assess the carotid vasculature of 61 patients treated for ORN. All patients received radiation therapy (40 to 72 Gy to the area of the carotid bifurcation) 36 months or more previously and were assessed for the presence of carotid artery atherosclerotic lesions. The lesions seen in the test and control populations had a similar morphologic appearance and were radiographically located within the soft tissues of the neck 1.5 to 4 cm inferoposterior to the angle of the mandible. The authors conclude that patients with radiation doses sufficient to cause ORN of the mandible are at significantly higher risk of developing carotid artery atherosclerotic lesions than age-matched, nonirradiated control patients.
Signal 1: MHC/peptide recognition by TCR

Signal 2: Costimulatory signal

Signal 3: Soluble mediators (e.g. IL-2)

Selective depleting agent: T10B9mAb
Nonselective depleting agents: OKT3, ATG

Nonselective depleting agents:
- Anti-CTLA4 mAb
- Abatacept
- Belatacept

IL-2 binding inhibitors:
- Anti-CD25 mAb
- Daclizumab
- Basiliximab

IL-2 signaling inhibitors:
- Rapamycin (sirolimus)

DNA synthesis inhibitors:
- Mycophenolate mofetil
- Azathioprine

Calcineurin inhibitors:
- Cyclosporine
- Tacrolimus

Calcineurin

NFAT

Calcineurin inhibitors:
- Cyclosporine
- Tacrolimus

Calcineurin

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Prefabricated and Prelaminated Flaps

Brian M. Parrett, Julian J. Pribaz

HIGHLIGHTS

- Flap prefabrication is the implantation of a vascular pedicle into a new territory followed by transfer of the flap neovascularized by this pedicle.
- Prefabrication is used for cervicofacial reconstruction to make thin, specialized flaps from nontraditional donor sites, with texture and color similar to those of the recipient site.
- Flap prelamination is the implantation of tissues or other devices into an axial flap before transfer.
- Prelamination can provide missing layers for the reconstruction of complex central facial defects.
- Prefabrication and prelamination can be performed distal to or near the recipient site.
- Both procedures require two stages.
- Prelamination and prefabrication are complex procedures reserved for specialized cases in which simpler, conventional flaps are unavailable or undesirable.

Refinements in flap design have improved the functional and aesthetic outcomes of head and neck reconstruction. The emphasis has shifted from simply obtaining flap survival and wound coverage to better flap selection and more elegant reconstructions. Flap prefabrication and prelamination are techniques that make possible the transfer of thinner flaps, flaps that match recipient site color and texture, composite flaps for complex three-dimensional reconstructions, and specialized flaps...
such as hair-bearing flaps. It is important to distinguish these two techniques, because these terms have been used indiscriminately in the literature to describe all possible flap modifications.

The term prefabrication was introduced by Shen in 1982 and describes the implantation of a vascular pedicle into a new territory, followed by a period of maturation and neovascularization, and the subsequent transfer of tissue based on its implanted pedicle. Prefabrication allows any defined tissue volume to be transferred to any specified recipient site, greatly expanding the armamentarium of reconstructive options.

The term flap prelamination, coined by Pribaz and Fine in 1994, describes a process in which tissues or other devices are implanted into a vascular territory before it is transferred; the blood supply is not manipulated. The goal in prelamination is to transform a native axial flap into a multilayered flap by adding the appropriate support and lining structures needed for composite reconstruction. Prelamination of local flaps was described in the early 1900s, usually for nasal reconstruction using cartilage grafts under a forehead flap. Sir Harold Gillies used prelamination techniques for nasal and facial reconstruction and described the “up and down” forehead flap implanted with chondrocutaneous grafts before rotation.

Flap prefabrication and prelamination are complex procedures that are reserved for cases in which conventional, simpler flaps will not achieve the desired goal or are unavailable.

**Flap Prefabrication**

**Indications**

In head and neck reconstruction, it is desirable to use flaps that are thin with a good color match or specialized flaps such as hair-bearing flaps. Although there may be suitable tissues with these special characteristics, they may not have a reliable axial blood supply; flap prefabrication provides this by implanting an axial blood supply into the desired donor tissue, rendering it transferable once neovascularization has occurred. Prefabricated flaps allow the transfer of moderate-sized units of thin tissue from unconventional sites, which is useful in patients with limited donor sites. The largest group of patients who benefit from these flaps comprises severely burned patients with significant facial disfigurement or diffuse neck contractures that require release and coverage. However, this technique can be expanded to any patients for whom conventional solutions are not available. Seemingly endless options are available for prefabrication, from osseous flap prefabrication to jejunal prefabrication with the latissimus muscle on the thoracodorsal pedicle.
Operative Technique

Stage 1: Implantation of the Vascular Pedicle

The defect, requirements for reconstruction, and available donor sites are defined. A plan and timeline for reconstruction are formed. The prefabrication process takes at least 8 weeks and involves two stages. A vascular pedicle (which includes at least the artery and its venae comitantes surrounded by adventitial tissue and possibly fascia or a cuff of muscle) is dissected out, transferred to a new area of tissue, and implanted. The distal end is ligated, and no vascular anastomoses are performed (Fig. 41-1). Vascular connections occur spontaneously between the implanted pedicle and surrounding tissue, creating a new vascular territory. We often wrap Gore-Tex tubing or silicone sheeting around the pedicle to facilitate later flap harvest and pedicle dissection.

Fig. 41-1  Technique of flap prefabrication. A, A deep vascular pedicle is dissected out with a cuff of fascia or muscle around it. The distal end and branches are ligated. B, The vascular pedicle is placed between the underside of the skin flap to be prefabricated and a tissue expander. Gore-Tex tubing is placed around the proximal pedicle to facilitate later flap harvest. C, Tissue expansion begins 1 week later. D, After at least 8 weeks, the prefabricated flap is raised off the tissue expander (the capsule is included within the flap) and transferred to the recipient site.

Tissue expansion is often used in conjunction with prefabrication. Tissue expansion has been shown to stimulate angiogenesis and neovascularization. In addition, it helps to thin the flap and allows the recruitment of nearby tissue for primary closure of the future donor site. The implanted pedicle is placed directly underneath the skin and on top of the expander. Expansion begins 1 week postoperatively and lasts until the flap is transferred. A handheld Doppler unit may be used to ensure patency of the pedicle at the time the expander is filled. If a signal disappears, removing fluid from the expander restores flow.
Stage 2: Flap Transfer

After maturation, the neovascularized tissue is harvested and transferred based on the implanted pedicle. Transfer is performed after at least 8 weeks of maturation. The flap is transferred as a local or free flap. The donor site, especially if tissue expansion has been used, can usually be closed primarily.

The flap size can be rather large. Although animal studies demonstrate that a long flap with a 6:1 ratio (the flap length versus the pedicle length within the flap) can be successfully transferred, in clinical cases, a more conservative 2:1 ratio is most commonly used.\textsuperscript{11,12} Flap delay may also be used to enhance neovascularization and increase the size of the transferred flap. Delay is accomplished by progressively raising the flap tissue off its nonaxial blood supply, rendering it entirely dependent on the implanted pedicle.\textsuperscript{12} Tissue expansion is another way to increase the size of the flap that can be transferred.

Prefabrication at a Distant Site

Flaps may be prefabricated at a distant site in cases where no local tissue is available, with the aim of creating a thin flap for head and neck reconstruction by transferring the pedicle superficially (Table 41-1).

<table>
<thead>
<tr>
<th>Anatomic Location</th>
<th>Vascular Pedicle</th>
<th>Technical Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distal Site</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial thigh</td>
<td>Descending branch of the lateral femoral circumflex vessels</td>
<td>The greater saphenous vein is incorporated for drainage.</td>
</tr>
<tr>
<td>Lateral thigh</td>
<td>Descending branch of the lateral femoral circumflex vessels</td>
<td>The tissue expander is placed below the pedicle to thin the flap and increase the flap size.</td>
</tr>
<tr>
<td>Inner upper arm</td>
<td>Thoracodorsal vessels to the latissimus and serratus muscles</td>
<td></td>
</tr>
<tr>
<td><strong>Near Recipient Site</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper cervical</td>
<td>Superficial temporal vessels</td>
<td>The temporoparietal fascia is included in the pedicle.</td>
</tr>
<tr>
<td>Retroauricular or mastoid region</td>
<td>Superficial temporal vessels</td>
<td>The temporoparietal fascia is included in the pedicle.</td>
</tr>
<tr>
<td>Supraclavicular</td>
<td>Thoracoacromial vessels</td>
<td>The pedicle is transferred over the clavicle and above a tissue expander.</td>
</tr>
</tbody>
</table>
After the maturation period, the flap is transferred as a free flap (Fig. 41-2). This has been useful in neck resurfacing after burn scar excision using prefabricated thigh flaps; the descending branch of the lateral femoral circumflex vascular pedicle is transferred from deep to the vastus lateralis muscle to the subcutaneous plane to make a thin, supple flap.

**Fig. 41-2**  
A, This 32-year-old woman had diffuse neck burn contractures. B, A prefabricated lower abdominal flap with two pedicles was designed. C, The inferior epigastric pedicles (with Gore-Tex at the bases) were ligated distally and transferred superficially over tissue expanders. D, The lower abdominal skin was expanded, thinning the flap for future neck resurfacing. E, After 10 weeks of maturation, the prefabricated flap, with an inferior epigastric pedicle, was transferred to the neck after the burn scar was excised. Two venous and arterial anastomoses were performed. F, The patient is shown 3 years postoperatively.
Prefabrication Near the Recipient Site

Prefabrication can be performed locally in patients who have undamaged areas adjacent to the face, such as the neck area. Using regions near the recipient site provides a flap with an excellent color and texture match and is our preferred technique. Common local donor sites are the anterior and posterior neck, supraclavicular region, postauricular area, and the scalp (see Table 41-1). Tissue expansion allows the transfer of greater amounts and thinner tissue. Another benefit of prefabrication near the recipient site is the possibility of using multiple, sequential prefabricated flaps for complex reconstructions of multiple facial subunits, transferred sequentially by the same vascular pedicle; we refer to this process as the “vascular crane” principle.13

No microsurgery is involved in these cases when a local pedicle is used. During the first stage, a local vascular pedicle is rerouted into a new area, and this neovascularized tissue is transferred locally into the defect in the second stage. Most commonly, the superficial temporal vascular pedicle is dissected, ligated distally, and transferred into the upper neck, usually above a tissue expander. This allows prefabrication of the neck for later transfer to the face. This is especially useful for cheek or lower jaw reconstruction, providing a good color and texture match.

Occasionally, the native pedicles are too short to reach the area to be vascularized. In these cases, a vascular pedicle can be transferred as a mini–free flap from a distant area to the neck or another chosen area (Fig. 41-3).

Fig. 41-3  A, This 28-year-old woman had skin necrosis after embolization of a facial arteriovenous malformation. B, The affected area was originally reconstructed with serial tissue expanders to repair the skin and a radial forearm flap to provide intraoral lining; however, the patient still had significant lip deformities and oral incompetence.
C, For an optimal color and texture match, an upper cervical prefabricated flap was designed. D, To provide an axial blood supply to this flap, the descending branches of the lateral femoral circumflex artery and vein were anastomosed to the external jugular vein and a branch of the external carotid artery. The distal ligated end of the pedicle was placed subcutaneously below the new flap design. E, After 9 weeks, the lower lip defect was prepared, a turnover flap raised, and a facial artery musculomucosal flap raised for the upper lip. F, The prefabricated flap was locally transposed into the lower lip defect. G, She is shown 1 year postoperatively.
Any long vascular pedicle is suitable, but most commonly the descending branch of the lateral femoral circumflex vascular pedicle or the radial forearm vascular pedicle with surrounding fascia is used. The base of the pedicle is anastomosed and the distal ligated end is tunneled beneath the area to be prefabricated. After at least 8 weeks of maturation, the prefabricated flap is transferred on its implanted pedicle as an island pedicle flap without further microsurgery. It is important to plan ahead and ensure that the vascular pedicle is long enough and appropriately based to allow transfer at the second stage without detaching the anastomosis and requiring further microsurgery.

Complications

After transfer, the prefabricated flap usually has some degree of venous congestion that is transient, but can last as long as 48 hours. Including a native subcutaneous vein in the flap and performing an additional anastomosis or waiting longer before the flap transfer is effective in decreasing congestion. Microangiographic studies show that the extent of arborization and vascular connections increases with time, allowing better perfusion and safer flap transfer. Venous congestion also decreases if the prefabricated flap is delayed by incising around the perimeter of the flap a week before transfer. Occasionally, chemical “leeching” may be used to relieve venous congestion.

It is critical that the prefabricated flap not be folded, because this increases the deleterious effects of venous congestion and likely leads to necrosis of the folded part. Prefabricated flaps cannot tolerate manipulation and folding as well as axial flaps.

FLAP PRELAMINATION

Indications

The goal of prelamination is to compose multilayered composite flaps for the reconstruction of complex, multilayered facial defects. Prelamination is particularly useful for patients with central facial defects, especially of the nose, lips, and palate, with layers of skin, cartilage, and mucosa to be reconstructed. Tissue engineering may allow the incorporation of biomaterials and cultured cells, thus greatly expanding the usefulness and versatility of prelaminated flaps (Table 41-2).
Table 41-2  Prelaminated Flap Options for Specific Defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>Flap Location</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial, full-thickness nose</td>
<td>Forehead</td>
<td>Skin graft for lining and cartilage for support on the underside of the paramedian forehead flap⁸</td>
</tr>
<tr>
<td>Total nose</td>
<td>Forearm</td>
<td>Skin graft for lining and cartilage for support on the underside of the RFF⁶</td>
</tr>
<tr>
<td>Total ear</td>
<td>Forearm</td>
<td>Cartilage framework placed in the RFF¹⁴</td>
</tr>
<tr>
<td>Full-thickness cheek</td>
<td>Forearm</td>
<td>Subfascial skin graft or mucosal graft on the underside of the RFF⁶,¹⁴,¹⁵ Tissue expander + skin graft or mucosal graft on the underside of the submental platysma flap</td>
</tr>
<tr>
<td>Full-thickness lip</td>
<td>Forearm</td>
<td>Subfascial skin grafts underneath the RFF¹⁶ Tissue expander + skin graft on the underside of the submental platysma flap²</td>
</tr>
<tr>
<td>Intraoral</td>
<td>Forearm</td>
<td>Mucosal grafts placed on the underside of the RFF¹⁴,¹⁵</td>
</tr>
<tr>
<td>Maxilla or mandible</td>
<td>Scapula</td>
<td>Osseointegrated implants into the bone¹⁷,¹⁸ Mucosal grafts with a fibula flap for combined osseous and intraoral defects¹⁴</td>
</tr>
<tr>
<td></td>
<td>Fibula</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proximal toe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>phalanx</td>
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</table>

RFF, Radial forearm flap.

Operative Technique
Stage 1: Introduction of Tissue

Prelamination involves a two-stage procedure and begins by defining the defect and the layers that need to be reconstructed. Stage 1 involves introducing the appropriate graft material, which may be as diverse as cartilage, bone, mucosa, nerve, or bio-engineered materials.⁶,¹⁴-¹⁸ Skin or mucosal grafts can provide lining, and costochondral grafts or ear cartilage can provide structural support. Rath¹⁴ described the use of buccal mucosal grafts to line prelaminated flaps for intraoral reconstruction. Because of the limited supply of mucosal donor sites, tissue-engineered mucosa has been used successfully to prelaminate radial forearm flaps for intraoral defects.¹⁵
The forearm provides abundant and thin tissue for nasal, cheek, and upper lip reconstruction. The radial artery territory is the site most commonly used for prelamination (Fig. 41-4), but we have also used the ulnar arterial territory when appropriate, because it is less hairy and the scar is better hidden. These territories have reliable vascularity that facilitates the incorporation of skin, mucosal, and cartilage grafts to construct a complex, three-dimensional flap. Prelamination is used at a distant site, because reconstruction in a remote, unscarred territory allows the best chance for healing and graft incorporation.

**Fig. 41-4**  A, This 34-year-old man had an extensive arteriovenous malformation of the nose and right cheek. B, A prelaminated flap was designed on his right forearm. C, A skin graft was inserted on the underside of the radial forearm flap to provide nasal lining.
Fig. 41-4, cont’d  D, An L-shaped costal cartilage graft was carved to provide nasal support. E, The costal cartilage graft, cartilage graft for the ala, and skin grafts for the vestibular lining were inserted. F, The patient is shown intraoperatively, 5 weeks after prelamination and immediately after resection of the arteriovenous malformation. G, He is shown 3 weeks after the prelaminated flap was transferred. H, An expanded forehead flap was used to resurface the nose, the cheek was advanced, and the nasal flap debulked. I and J, The 2-year postoperative result.
Generally, the fasciocutaneous flap is partially raised, the grafts sutured onto the forearm fascia, and the flap reinset (see Fig. 41-4). With mucosa, the graft is meshed or cut into small pieces, sutured onto the fascia, and a 1 mm Silastic sheet is placed over the grafts to avoid adhesions and promote spreading. A tissue expander can be placed under the lining and allows the grafts to better abut the flap tissue.

Flaps may also be prelaminated in close proximity to the facial defect. Gillies\textsuperscript{8} demonstrated the use of a prelaminated forehead flap for nasal reconstruction. We have used the submental flap, based on the submental branch of the facial artery, as a prelaminated flap for full-thickness lip and cheek reconstruction (Fig. 41-5).

Fig. 41-5  A, This 18-year-old patient had extensive defects of the upper lip, cheek, and nose resulting from a noma infection. B, A tissue expander with a full-thickness skin graft was placed in the submental area, deep to the platysma and anterior belly of the digastric muscle. C, The lateral view at 4 weeks shows expansion of the submental and forehead areas.
Prefabricated and Prelaminated Flaps

Fig. 41-5, cont’d  

D, The design of the right and left prelaminated submental flaps was based on the submental branch of the facial artery and contained innervated platysma muscle.  
E, The tissue expander was removed and the left submental flap raised to show the healed skin graft on its underside.  
F, The submental flaps were transferred to the upper lip bilaterally, a forehead flap was transferred to the nose with local turndown flaps for lining and cartilage grafts for nasal support, and an Abbé flap was transferred for central upper lip reconstruction.  
G and H, The patient is shown 6 weeks postoperatively.
Stage 2: Flap Transfer

After a period of 3 to 4 weeks to allow graft incorporation into the flap, the composite flap is transferred to the face. This can be performed as a free tissue transfer if prelamination occurs distally (see Fig. 41-4) or as a pedicle flap transfer if prelamination occurs in the head and neck (see Fig. 41-5).

Complications

With this two-stage procedure, edema, scarring, and contraction may result at the donor site before transfer and at the recipient site after transfer. This often leads to a suboptimal result initially, and revisions are necessary to achieve an aesthetically pleasing result. However, the prelaminated flap provides an excellent foundation on which refinements can be added. For instance, for complex cheek and nasal reconstruction, prelaminated flaps may need to be debulked and sculptured and nasal anatomic subunits separated to enhance the aesthetic result.

Conclusion

Flap prefabrication and prelamination expand our head and neck reconstruction armamentarium. With flap prefabrication we are no longer restricted to an anatomic vascular territory, making it possible to customize flaps with similar color, texture, and thinness to the area to be reconstructed. Prelamination allows the construction of multilayered flaps to reconstruct complex, multilayered defects. Prefabrication and prelamination are likely the highest rung on the reconstructive ladder, but their complexity is balanced by the endless, sophisticated solutions available for our patients’ reconstructive needs.
CRITICAL POINTS

Must Know

• Prefabrication and prelamination are distinct techniques.
• They are complex procedures reserved for specialized cases.
• It is critical that the prefabricated flap not be folded.
• Prefabricated flaps should not be transferred until at least 8 weeks after first stage, which is pedicle transfer.

Should Know

• Prefabrication and prelamination can be performed distal to or near the recipient site.
• Using a prefabricated flap near the recipient site often results in a better color and texture match.
• Transient venous congestion is common after prefabricated flap transfer.
• The prelamination of multilayered flaps with mucosal, skin, and cartilage grafts is currently possible.
• Prelaminated flaps require future revisions and refinements to achieve an aesthetically appropriate result.

Synopsis

• Prefabrication is the implantation of a vascular pedicle into a new territory, followed by transfer of the flap neovascularized by this pedicle; it is most widely used in cervicofacial burn reconstruction.

• Flap prelamination is the implantation of tissues or other devices into an axial flap before it is transferred and is most often used to reconstruct complex, multilayered, central facial defects.

References

   The authors present the advantages and indications of three clinical flap prefabrication methods: delay or expansion, grafting, and vascular induction by staged transfer. A fourth, still experimental method is based on cell biology advances on the horizon and may have revolutionary future clinical applications.

   Flap prefabrication involves the introduction of a new blood supply by means of a vascular pedicle transfer into a volume of tissue, and flap prelamination refers to a technique in which additional tissue is added to an existing flap (without manipulation of its axial blood supply) to make a multilayered flap that may be used for complex, three-dimensional, multilayered reconstructions. Examples of each are described in this article.

During the past 10 years, 17 flaps were prefabricated and 15 flaps were transferred successfully in 12 patients. Prefabricated flaps allow the transfer of moderate-sized units of thin tissue to recipient sites throughout the body. They have been particularly useful in patients recovering from extensive burn injury who have limited, thin donor sites.


This article is a review of five patients who underwent reconstruction of nasal and paranasal facial defects with prelaminated forearm free flaps. All flaps were successfully transferred to the face, but revisions were needed to separate the subunits and improve appearance. A prelaminated free flap should be considered for patients requiring reconstruction of complex central facial defects.


Different anatomic structures and multiple tissues such as skin, bone, muscle, blood vessels, nerves, and cartilage are transferred during CTA procedures. CTA represents the optimal replacement for defects resulting from trauma, tumor resection, or congenital absence. Each component of CTA carries its own characteristics, expresses different types of antigenicity, and is rejected in different ways, all of which make CTA distinct from solid organ transplants. These allografts are performed primarily to restore anatomic, cosmetic, and functional integrity, whereas solid organ transplants, such as those that replace the heart or liver, are predominantly needed to restore physiologic organ functions that support patient survival. In contrast, composite tissue transplants are performed to improve function and quality of life and do not necessarily affect a patient’s survival. Therefore the benefits of CTA have to be balanced against the morbidity of the surgery and the complications of lifelong immunosuppression.¹
BRIEF HISTORY OF CTA

The concept of CTA dates back to the fourth century AD. The legend of the twin saints-cum-surgeons, Cosmos and Damian, describes the restoration of an extremity by miraculous transplantation from a cadaver donor. This apocryphal legend shows that the desire to perform transplantation from another human dates back more than 1700 years.

Before CTA was tested in humans, many experimental studies were performed by different researchers. Years of basic science have contributed to the progression of transplantation science, and there have been many milestones on the road to successful CTA. A detailed discussion of this history is beyond the scope of this chapter. Here we focus on recent history—specifically, recent clinical history. Ulusal et al introduced the first composite facial and scalp transplantation model in the rat in 2003. This was followed by a hemiface transplantation model, a composite hemiface/calvarium transplantation model, a maxillary allotransplantation model, a composite hemiface/mandible/tongue allotransplantation model, and a composite osseomusculocutaneous hemiface/nose/lower lip model (Figs. 42-1 through 42-3).

Fig. 42-1 Composite tissue allografts in the experimental rat model across the major histocompatibility complex (MHC) barrier between an LBN (RT1n) donor and a Lewis (RT1) recipient. A, A hemiface allograft transplant. B, A full face allograft transplant. Both are shown more than 300 days after the transplant and have good graft acceptance without signs of rejection.
The first attempt at CTA in humans was made by a team led by Dr. Robert Gilbert in Ecuador in 1964. Dr. Gilbert and his team transplanted the hand from a cadaver donor to a patient who had lost his hand in an explosion. Although successful initially, the allograft failed within 2 weeks because of an acute rejection. The immunosuppressive regimen was composed of azathioprine and hydrocortisone at doses used in renal transplantation.

In 1997, Hofmann et al. reported on the allogenic vascularized transplantation of cadaveric knee joints for the treatment of posttraumatic and tumor-ablative defects of
the lower extremities. Birchall \(^8\) reported the first successful vascularized laryngeal transfer, which was performed by Strome and colleagues in 1998. The allograft was composed of larynx, thyroid and parathyroid glands, three laryngeal rings, and 70% of the pharynx. Guimberteau et al\(^9\) reported two cases of vascularized digital flexor tendon apparatus transplantation in 1988 and 1989.

In September 1998, the first successful allotransplantation of a human hand was performed in Lyon, France, and a new era of CTA began.\(^10\) Since then, different clinical applications of CTA have been reported, including abdominal wall, tongue, and pharynx/larynx composite allotransplantation.\(^8,11,12\)

Mackinnon and Hudson\(^13\) reported on a series of seven patients with peripheral nerve allografts in 2001. It is still the largest series of nerve allotransplantation with the longest follow-up. All patients had massive peripheral nerve defects that could not be reconstructed by conventional methods.

Birchall\(^11\) performed the first tongue transplantation in 2003 into a patient with tongue cancer. There were no signs of rejection during 8 months of follow-up. Although the patient was able to swallow his saliva and some fluids, his sense of taste was unlikely to return.

Levi et al\(^12\) reported nine abdominal wall transplantations from cadaveric donors to eight patients in 2003. Either an isolated small bowel or a multivisceral allograft was transplanted with the abdominal wall.

In November 2005, a team of surgeons led by Drs. Jean-Michel Dubernard and Bernard Devauchelle, carried out the first partial face transplant.\(^14\) The transplant included perioral muscles; a portion of the nose, chin, oral, and nasal vestibular mucosa; arteries; veins; and nerves from a cadaver donor to the lower face of a 38-year-old woman. The patient had lost her nose and chin after being bitten by a dog, and as a result she was not able to eat or speak well. This operation was deemed a success with respect to appearance, sensation, and acceptance by the patient’s body. This first case, however, opened medical and ethical debates on facial allotransplantation.\(^15\)

Eight partial face transplantations have been performed worldwide to date. Five months after the case was performed, a second case of partial face transplantation was reported in China. The patient was a 30-year-old man who had been attacked by a bear.\(^16\) In February 2007, in Paris, France, a team led by Dr. Laurent Lantieri performed the third partial face transplant to a 27-year-old man with neurofibromatosis.\(^17\) In November 2008, a team led by Dr. Siemionow performed a subtotal face transplant on a female patient. The transplant included the midface (with bone), nose, upper lip, and lower eyelids. Since then, Dr. Lantieri has performed two further transplants, the most recent of which was a partial face and double hand transplant.\(^18\) In April 2009, Dr. Bohdan Pomahac led a team to perform the second partial face transplant in the United States.\(^19\)
Face transplantation has become the most debatable topic in CTA in recent years. To date, successful full face-scalp allotransplantation has been limited to animal and cadaveric studies. A currently established, full face-scalp allograft cadaver model has been reported by Siemionow et al.\textsuperscript{20,21} In this model, a composite face-scalp flap was based bilaterally on the external carotid arteries, which served as the arterial pedicles, and on the external jugular and facial veins, which served as the venous pedicles. The supraorbital, infraorbital, mental, and great auricular nerves were included in the facial flaps to restore sensation (Fig. 42-4).\textsuperscript{20} Thus far, no case of full face transplant in humans has been reported.

**Fig. 42-4**  Cadaver model of the full face transplant in humans. \textbf{A}, The vascular pedicles are marked for a face-scalp flap. \textbf{B}, The arterial network of the flap is seen after flap elevation. \textbf{C}, The following structures are shown: 1, common carotid artery; 2, external carotid artery; 3, superficial temporal artery; 4, facial artery; 5, lower border of the mandible. \textbf{D}, The total face-scalp flap is harvested. \textbf{E}, A facial flap is harvested without the scalp.
GRAFT ACCEPTANCE AND REJECTION PROCESSES

The major problem in allotransplantation is the immunologic response against the major histocompatibility complex (MHC) molecules between donor and recipient. The antigens encoded in the MHC of the transplant determine its rejection or acceptance. The human leukocyte antigen (HLA) system is the human version of the MHC, and it provokes the activation of T cells following transplantation. It is located on chromosome 6 and includes more than 200 genes. There are two types of MHC molecules: MHC class I antigens are expressed on all nucleated cells, whereas the MHC class II antigens are expressed on B lymphocytes, monocytes and macrophages, dendritic cells, endothelial cells, and activated T cells—and these T cells act as antigen-presenting cells. The strongest immunologic response is provoked by allogenic MHC antigens. The MHC molecules expressed on the transplanted tissues of the donor may be recognized in a direct or indirect pathway. In the direct pathway, recipient T cells recognize allogenic MHC molecules expressed on the donor antigen-presenting cells. In the indirect pathway, peptides shed from the graft are presented by self-MHC on recipient antigen-presenting cells similar to the process of bacterial or viral antigen presentation.

The rejection process in CTA is not uniform and is carried out by different effector mechanisms. Variable degrees of rejection have been reported among different tissue types of the CTA in experimental models. Skin has the highest antigenicity of all tissue types in composite tissue transplants, followed by muscle, bone, nerve, tendon, and vessels. At present, no standardized criteria have been established clinically to characterize the severity or type of rejection of CTA; however, a basic classification system for acute rejection of the skin component of CTA transplants has been recently introduced, based on samples provided by multicenter hand and abdominal wall transplant cases.

No single parameter has been identified as a reliable early clinical sign of reversible rejection, but in many of the studies, early skin changes such as erythema and edema are reversible with adequate adjustments of immunosuppressive protocols. The evaluation of a skin biopsy specimen is essential to confirm rejection in clinical cases of CTA containing a skin component.

Based on knowledge of solid organ allotransplantation and the first clinical cases of CTA, the rejection of composite tissue allografts may present in three forms: hyperacute/accelerated rejection, acute rejection, and chronic rejection.

Hyperacute/Accelerated Rejection

Hyperacute/accelerated rejection occurs rapidly following reperfusion of the graft, within minutes to hours, and is mediated by antibodies present in the recipient’s circulation before the transplant. Immunologic complexes cause most of the damage that occurs during the hyperacute rejection process, which in turn damages the vascular endothelium of capillary vessels and small arterioles and, ultimately, causes
graft dysfunction. Because it is irreversible, this type of rejection must be avoided with a thorough pretreatment screening of each candidate’s serum for preformed antibody profiles and avoidance of the corresponding antigen in donors. From 24 hours to 5 days after transplantation, the accelerated phase of rejection may occur and is associated with vascular thrombosis, leukocyte infiltration, and release of proinflammatory mediators. The humoral-mediated response of accelerated rejection precedes the T-cell–dependent mechanism of acute rejection.22

**Acute Rejection**

Acute rejection occurs within a few days and up to a few months after transplantation. To date, all human CTA recipients have had at least one acute rejection episode. Although antibody-mediated humoral acute rejection is common, acute rejection is most often mediated by T cells, as evidenced by the absence of acute rejection in research animals that are T-cell deficient.30

During acute rejection, leakage and focal necrosis occurs, leading to vascular obstruction. In addition, inflammatory perivascular infiltrates accumulate in the graft. The evaluation of skin biopsy specimens from the first human hand and face recipients confirmed that cellular components in acute human CTA rejection include vasculitis, dermatitis, myositis, and perineural involvement. Most acute rejection episodes occur in the first 3 to 6 months following transplant, and most of these are successfully reversed by adjusting immunosuppressive protocols.28,29

**Chronic Rejection**

Chronic rejection is the third major form of allotransplant rejection and usually manifests months or years after transplantation.22 The frequency of chronic rejection correlates with several alloantigen-dependent and alloantigen-independent risk factors. Alloantigen-dependent factors predisposing to chronic rejection include acute rejection episodes, recipient sensitization, an insufficient number of MHC-matched antigens, and inadequate immunosuppression. Alloantigen-independent factors that may contribute to chronic rejection include tissue injury secondary to brain death of the donor before organ procurement, prolonged ischemia time of the graft before transplantation, differences in donor-recipient age and race, cytomegalovirus (CMV) infection/reactivation, hypertension, hyperlipidemia, and a smoking history in the recipient before transplantation.31

The chronic rejection process is still not fully understood. In one case report of a hand allograft recipient, immunosuppression was not maintained because of noncompliance on the part of the patient, and the allograft was rejected 29 months after transplantation.28 In this case, clinicopathologic and histologic examination revealed features resembling a chronic lichenoid, cutaneous, graft-versus-host disease process. However, this single case is not sufficient to identify the factors and features of chronic rejection in CTA patients.
Based on the well-established criteria of chronic rejection in solid organ transplants, cardinal features of chronic rejection are represented by luminal obliteration, atherosclerosis, and graft fibrosis.\textsuperscript{32}

**DONOR-RECIPIENT MATCHING**

In allograft transplantation, the donor and recipient must be of the same blood group to prevent hyperacute rejection because of the preformed antibodies. Ideally, the recipient and the donor should have the same CMV status, because this virus can be the cause of serious complications in the posttransplant period. It has been shown that the more the donor and recipient differ immunologically, the higher the incidence of rejection in solid organ transplantations. However, it is yet not clear whether the degree of matching has a significant influence on composite allograft survival.

The CTA must be cosmetically matched to the recipient (for example, gender, ethnicity, and age), because most of the reconstructive allografts are visible. The amount of matching required is variable; the matching required for hand transplantation does not have to be as accurate as the match required for face transplantation. This additional nonimmunologic matching is unique for CTA and makes the donor-recipient pairing much more difficult than that of solid organ transplantation.\textsuperscript{33}

**FUNCTIONAL RECOVERY**

Significant functional recovery is indispensable for successful CTA. The regeneration of axonal innervation is needed for functional recovery. Mackinnon and Hudson\textsuperscript{13} performed nerve allotransplants in experimental models and clinically showed that the host’s own axonal regeneration replaced donor axons after the cessation of immunosuppression. Thus only limited immunosuppression may be required for nerve allografting to bridge the interim of host axonal regeneration. This finding suggests that the nerve tissue of the CTA does not need lifelong immunosuppression.\textsuperscript{34}

The return of function is assessed by temperature, pain, and pressure sensation in the palm and fingers, and by electromyographic and clinical evidence of innervation of the intrinsic muscles of the hand. Grip strength at three hand positions, lateral pinch strength, digital motion, wrist stabilization, and range of movement are the other parameters used to estimate functional recovery of hand allografts. The patients from Austria and Louisville have gained great functional improvements since their hand transplantations.\textsuperscript{35,36}

A face that moves and looks like a human face is essential for successful face transplantation. This depends on the healing of the muscular structures and on nerve regeneration along the facial nerve across the graft.\textsuperscript{37} Sensibility and mimic and lip function are evaluated to estimate the functional recovery of the face. In patients with hand and peripheral nerve allografts, nerve regeneration across the graft was
observed to be potentially faster than the known rate of 1 mm per day.\textsuperscript{13,38} This was attributed to the favorable effect of FK-506 (also called tacrolimus [Prograf]) on axonal regeneration, as previously observed in experimental and clinical trials.\textsuperscript{39,40} The nerve regeneration distance is another factor affecting the functional recovery of the allograft. If the facial nerve is dissected closer to its emergence from the stylomastoid foramen to include all branches, nerve regeneration takes a very long time and is unlikely to enable muscular activity within the facial allograft. Therefore it is more suitable to move the neural coaptation level more distally to shorten the nerve regeneration time.\textsuperscript{37}

**CURRENTLY USED IMMUNOSUPPRESSIVE AGENTS**

Most CTA immunosuppressive protocols are based on standard therapy used in patients with kidney transplants. These include a combination of steroids, calcineurin inhibitors (CsA, FK-506), antiproliferative agents (MMF, azathioprine), polyclonal antibodies (ATG or antithymocyte globulin), and monoclonal antibodies (anti-CD25, anti-CD3).

Immunosuppressive drugs that are currently used clinically after transplantation are given for three purposes: induction, maintenance, and treatment of rejection. The aim of induction therapy is to inhibit the immune system and reduce the incidence of acute rejection. Polyclonal antibodies such as ATG, monoclonal antibodies such as anti-CD3 (OKT-3), and antibodies against the IL-2 receptor (daclizumab and basiliximab) are currently used for induction therapy.\textsuperscript{41} Maintenance therapy is used to prevent the immune system’s ability to recognize and reject transplanted tissues. Calcineurin inhibitors such as CsA and tacrolimus, which inhibit activation of T cells by suppressing IL-2 production, are generally used for maintenance therapy. More recently developed drugs, such as MMF and rapamycin, reduce the incidence of acute rejection, extend graft survival, and reduce systemic drug toxicity by specifically targeting T-cell subsets and modulating cytokine expression.\textsuperscript{41}

Corticosteroids are the most commonly used agents in clinical transplantation. Prednisolone is the prototypic agent and is analogous to cortisol (hydrocortisone), the major endogenous corticosteroid. However, its effectiveness or potency is four times that of cortisol. Subcellular hormone receptors that form steroid receptor complexes mediate the action of corticosteroids. By binding to DNA, these complexes affect the expression of the genes that drive protein synthesis and cellular processes. They inhibit the secretion of IL-1, IL-6, interferon-gamma (IFN-gamma), and TNF-alpha from lymphocytes and macrophages. IL-2 production and binding to its receptor is also inhibited. Corticosteroids block the effects of macrophage activation factor and migration inhibition factor and inhibit prostaglandin synthesis. They induce lymphocytopenia, which is greater for T cell populations than for B cell populations. Currently, corticosteroids are used in much reduced dosages in combination with other drugs used for maintenance therapy. Often, short courses of higher dosages are given to treat acute rejection episodes.\textsuperscript{41}
Long-term allograft survival was not established until the discovery of CsA by Borel et al\(^\text{42}\) in the late 1970s during routine screening of fungal extracts. The first use of CsA in CTA was reported in 1982.\(^\text{43}\) It was a more potent and specific immunosuppressant compared with previously used drugs. CsA suppresses the immune response by inhibiting the signal transduction pathways of calcineurin, and it subsequently inhibits the production of proinflammatory cytokine IL-2.\(^\text{44}\)

Tacrolimus was discovered in 1987 as another calcineurin inhibitor and was proven to be successful in solid organ transplants in clinical practice. It has been used successfully for induction therapy in CTA such as with human hand transplants,\(^\text{10}\) abdominal wall transplants,\(^\text{12}\) and most recently with partial face transplantation.\(^\text{14}\) Moreover, it has been shown that tacrolimus accelerates axonal regeneration, which improves the chances of success with functional restoration of hand allograft transplants.\(^\text{45}\)

Mycophenolate mofetil (MMF [Cellcept]) has been used in solid organ transplantation since 1990 for induction therapy and the treatment of acute rejection. The mechanism of action of MMF is through inhibition of de novo purine synthesis and inhibition of both T and B lymphocyte proliferation. It induces apoptosis of activated T lymphocytes and reduces synthesis of antibodies. It is an antimetabolite and has replaced azathioprine. The first study on the use of MMF in CTA research was reported in 1993.\(^\text{46}\)

Rapamycin (also called sirolimus [Rapamune]) received FDA approval in 1999 for the prevention of acute rejection in kidney transplant recipients. Rapamycin interferes with cytokine signaling by binding the IL-2 receptor and therefore blocks T-cell activation and proliferation induced by IL-2. Independent of its inhibition of T-cell activity, Rapamycin acts on B cells by inhibiting cytokine-dependent differentiation into antibody-producing cells, thus decreasing immunoglobulin synthesis. Rapamycin is an attractive agent to include in transplantation protocols, because its unique mechanism of action, lack of end-organ toxicity, and ability to be used synergistically with other immunosuppressants avoids overlapping side effects.\(^\text{47}\) In CTA, Rapamycin has been used in two human hand transplant recipients as maintenance therapy.\(^\text{48}\)

Different antibodies are used for induction therapy to prevent acute rejection and extend graft survival. Currently, polyclonal antibodies such as ALG and ATG are used as induction therapies. To improve inhibition of the immune response, monoclonal
antibodies have been used (anti-CD3, anti-CD25); they are more specific and act against exactly defined antigens. These agents are discussed in Tolerance-Inducing Strategies (see p. 873). Commonly used immunosuppressants and their actions are summarized in Table 42-1.

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LONG-TERM SIDE EFFECTS OF IMMUNOSUPPRESSION

A major problem that restricts the routine use of CTA is the risk of lifelong immunosuppression in patients receiving transplants that do not directly affect their survival. Although the adverse effects of immunosuppressants have been greatly reduced, and the specificity of their actions has been increased, their effects can still be deleterious to the recipient’s health and life. Long-term side effects of immunosuppressants fall into three categories: opportunistic infections (cutaneous, fungal, and tinea infections, and cytomegalovirus and herpes virus infections and reactivation), metabolic disorders (diabetes, Cushing’s syndrome), and malignancies (basal cell and squamous cell carcinomas, Epstein-Barr virus, polyoma virus, and B-cell lymphoproliferative disorders). These side effects are a major limiting factor in CTA, which is performed to correct physical, aesthetic, and functional disabilities.

Most known side effects of immunosuppressants are described. Cyclosporine-A is nephrotoxic and can induce hypertension, hyperglycemia, hyperlipidemia, and gastrointestinal complications. Tacrolimus is neurotoxic and nephrotoxic and can also induce diabetes. MMF may cause gastrointestinal complications and leukopenia. Steroids are associated with delayed wound healing, diabetes, and gastrointestinal complications. Infectious complications are seen in 80% of recipients, and out of all reported infections, 55% are bacterial, 30% are viral, and 15% are fungal. Up to 10% of all transplant recipients develop hepatitis B or C, which can lead to liver failure or hepatocellular carcinoma. Malignancy is the most serious complication of immunosuppressants. Its incidence varies from 4% to 20%, and approximately 80% of these are skin cancers. Posttransplant lymphoproliferative disease is another fatal complication of immunosuppression and is characterized by B-cell proliferation. A high incidence of opportunistic infection and the occurrence of malignancy in the late posttransplant period have been reported with ATGAM, ATG, OKT-3, and Campath-1.

TOLERANCE, CHIMERISM, AND GRAFT-VERSUS-HOST DISEASE

Tolerance is the state of permanent nonreactivity of the recipient’s immune system against donor-specific antigens present on the graft in the absence of ongoing immunosuppression, while the recipient’s ability to respond to other antigens such as viruses and bacteria is maintained, confirming the recipient’s immunocompetence. Recently, a new concept of minimal immunosuppression tolerance known as prope (almost) tolerance was introduced and is defined as donor-specific hyporesponsiveness under a low dose of immunosuppressive therapy that reduces immunosuppression-related side effects but allows normal graft function.
Donor Bone Marrow Transplantation for Chimerism Induction

Transplanted organs and CTAs contain a large number of cells known as passenger leukocytes, which migrate from transplanted tissues to the lymphoid and nonlymphoid organs of recipients. The presence of donor-origin cells within different recipient compartments is known as a chimerism.\textsuperscript{55-57}

Donor hematopoietic cells can develop donor-specific microchimerism and/or macrochimerism, often leading to allograft acceptance. Two types of macrochimerism, induced by donor-origin cells, have been reported: (1) full chimerism occurs when the recipient immune system is destroyed by myeloablation and replaced fully by donor hematopoietic cells (donor cell population is 100%); (2) mixed chimerism occurs after nonmyeloablative host conditioning, when donor and recipient hematopoietic cells coexist within the recipient microenvironment (donor cell population ranges from 1% to 100%). Microchimerism usually occurs spontaneously after organ transplantation; donor-origin cells represent less than 1% of all cells.\textsuperscript{56}

Mixed T-cell chimerism has been obtained in semiallogenic and fully allogenic experimental CTA models of cellular and vascularized bone marrow transplantations.\textsuperscript{58-60} Bone marrow transplantation is thought to have the potential to accelerate immune reconstitution of the recipient and tolerance induction through the process of established chimerism. This mechanism of tolerance induction is currently being studied.\textsuperscript{34,60-63}

Graft-Versus-Host Disease

Composite tissue allografts such as human hands represent vascularized allograft containing functional bone marrow. The transfer of immunocompetent donor cells with the bone marrow and/or lymph nodes of CTA may result in graft-versus-host disease (GVHD). GVHD may develop when the immunocompetent donor cells recognize the recipient antigens as foreign and develop defense mechanisms against the recipient. GVHD was reported in experimental models of solid organ and CTAs, but so far none of the clinical CTA recipients has developed GVHD.\textsuperscript{64,65}

Tolerance-Inducing Strategies

The mechanism of tolerance induction is still being investigated, and current research has focused on three main strategies to induce donor-specific tolerance in the recipient: genetic matching, elimination of immunocompetent T cells, and donor bone marrow transplantation as a strategy for developing mixed chimerism. MHC matching among unrelated individuals would be rare, making this approach unlikely in the clinical setting.\textsuperscript{66}
To promote tolerance in CTA, the elimination of immunocompetent T cells may be accomplished during induction therapy by nonselective or selective T-cell depletion and costimulatory blockade (Fig. 42-5).

**Fig. 42-5** Overview of the interactions between T cells and antigen-presenting cells showing the sites of action of antirejection drugs. T-cell activation is initiated by the first signal, which is delivered through T-cell antigen receptors in association with the MHC antigens expressed on the graft cells. The second signal is accomplished by costimulatory molecules. When both activating signals are completed, T cells secrete IL-2 and generate third signal of activation leading to T-cell differentiation and proliferation. T-cell activation and proliferation may be inhibited by selective and nonselective inhibition of signal 1, costimulatory blockade, inhibition of IL-2 receptor signal transduction and IL-2 production, and blocking DNA synthesis. *MHC*, Major histocompatibility complex.
Nonselective T-Cell Depletion

Many experimental and clinical observations have indicated that the elimination of mature T cells is a critical mechanism of transplantation tolerance. In clinical practice, nonselective immunosuppression using lymphocytotoxic drugs has been used as induction therapy before transplantation. The nonselective depletion of T cells (targeting all T cells, not just alloreactive T cells) is achieved using polyclonal lymphocyte-depleting antibodies such as antilymphocyte globulin (ALG), ATG or monoclonal lymphocyte-depleting antibodies directed against CD3 (muromonab), and the anti-CD52 mAb Campath-H1. Moreover, Campath-1 also depletes B cells and monocytes. These reagents are also used to prevent and treat acute rejection episodes.

Selective T-Cell Depletion

Recently, selective inhibition of alloreactive T cells has been achieved by blocking the alphabeta-TCR receptor on alloreactive T cells in experimental studies and in clinical practice. In clinical practice, T10B9 mAb directed against the human alphabeta-TCR of the T-cell receptor complex was successfully introduced to prevent or reverse acute heart and renal allograft rejection and to treat hematologic malignancies.

Selective depletion of alphabeta–TCR-positive cells, which are predominantly CD4 T cells, promotes allograft acceptance by preserving CD8+/CD3+/alphabeta–TCR populations of T cells. In our experimental limb, larynx, and nerve allograft models, selective targeting of alphabeta–TCR-positive cells in combination with a short course of CsA therapy correlated with tolerance and long-term allograft survival.

Costimulatory Blockade

Costimulatory blockade is another strategy that targets the T-cell requirement for multiple signals before antigen-stimulated proliferation. Full activation of T cells requires at least two synergistic signals. The first signal is delivered through a T-cell antigen receptor in association with the MHC antigens expressed on the graft cells. The second costimulatory signal is not antigen specific and is delivered by binding of the CD28 molecule present on T cells with their ligands B7-1(CD80) and B7-2(CD86), expressed on activated antigen-presenting cells. The costimulatory pathway for T-cell activation may also be accomplished by the CD40 molecule expressed on antigen-presenting cells and the CD40 ligand (CD154) expressed on activated T cells. When both activating signals are completed, T-cells are able to secrete IL-2 and generate a third signal of activation, leading to T-cell differentiation and proliferation and, consequently, graft rejection (see Fig. 42-5).

To block IL-2–supported T-cell proliferation, therapeutic protocols are introduced to inhibit second-signal T-cell activation and proliferation by transient blockade of various costimulation pathways (CD154/CD40 pathway, CD28/B7 pathway) using mAb as a therapeutic strategy to prevent acute and chronic rejection in skin and cardiac allograft models. Costimulatory molecules CD154 and CD40 were blocked by
using anti-CD154 mAb thymic allorestance. In an experimental mouse limb allograft model, the combined regimen based on anti-CD40 ligand mAb, T-cell depletion, and a donor bone marrow transplantation protocol prolonged limb allograft survival, but tolerance was not achieved. The second costimulatory pathway, CD28/B7, may also be inhibited by using mAb CTLA4Ig (abatacept), which binds to the CD80 and CD86 receptors present on antigen-presenting cells.

A recently introduced, second-generation agent, LEA29Y (belatacept), acts as a selective costimulatory blocker. Belatacept had a higher affinity for CD80 and CD86 molecules than CTLA4Ig and was found to be more effective than CTLA4Ig mAb when used in initial preclinical primate studies. Belatacept was used recently in a clinical trial in renal transplantation as a primary maintenance immunosuppressant.

Donor Bone Marrow Transplantation

Successful tolerance-inducing strategies using donor bone marrow cell transplantation have been reported in rodent and large animal models of CTA. In these studies, successful long-term limb allograft acceptance was achieved under different treatment protocols based on T-cell depletion and short-term administration of calcineurin inhibitors, without chronic immunosuppression, and was associated with the presence of stable donor-specific chimerism in the rat model. In a miniature swine model, tolerance developed to the musculoskeletal part of the allograft but not to the skin component; however, prolonged skin allograft survival was reported.

An attractive concept for tolerance induction in CTA may be developed by donor whole bone marrow or selective hematopoietic stem cell transplantation in combination with T-cell depletion and/or costimulation blockade. Human hand transplants represent a vascularized bone marrow transplant model that may facilitate allograft acceptance. However, most composite tissue allografts do not contain a bone marrow component. The load of donor antigens can be increased in recipients by infusing donor bone marrow cells. This protocol was used in the first partial human face transplant recipient, but there is no supporting evidence that donor bone marrow transplantation facilitated allograft acceptance. Further studies are needed to justify supportive therapy with bone marrow cell transplantation during CTA procedures.

CONCLUSION

Despite encouraging clinical outcomes with different CTAs, there is an ongoing ethical debate regarding submitting otherwise healthy patients to lifelong immunosuppression for nonvital organ transplants. Undoubtedly, CTA currently represents the best reconstruction option for patients with massive tissue loss when access to tissues is limited and it is not possible to replace the damaged body parts with parts resembling the recipient’s own tissues or organs.

To facilitate the routine application of CTA in clinical practice, scientific efforts and research continue in an attempt to develop safer strategies for immunosuppression, including tolerance-inducing and minimal immunosuppression protocols.
CRITICAL POINTS

Must Know

- CTA involves transplantation of alloplastic anatomic structures composed of multiple tissues such as skin, bone, muscle, blood vessels, nerves, and cartilages.
- The major problem presented by allotransplantation is immunologic response against the graft. The antigens encoded in the MHC of the transplant determine its rejection or acceptance.
- The process of rejection in CTA is not uniform. Variable degrees of rejection have been reported in different tissue types of the CTA.
- Skin has the highest antigenicity of all the tissue types in composite tissue transplants, followed by muscle, bone, nerve, tendon, and vessels.
- The rejection of composite tissue allotransplants is T-cell mediated; only activated T cells are responsible for rejection. Rejection may present in three forms: hyperacute/accelerated, acute, and chronic.
- Tolerance is the state of permanent nonreactivity of the recipient immune system against donor-specific antigens present on the graft in the absence of ongoing immunosuppression, while the recipient maintains the ability to respond to other antigens such as viruses and bacteria, confirming immunocompetence.

Should Know

- CTA is distinct from solid organ transplantation, because each component in the composite tissue allotransplant carries its own characteristics, expresses different types of antigenicity, and is rejected in different ways.
- The evaluation of skin biopsy specimens is essential to confirm rejection in the clinical practice of CTA containing a skin component.
- Chimerism refers to the coexistence of genetically different donor and recipient cells in the recipient lymphoid and nonlymphoid compartments.

Synopsis

- Composite tissue allotransplantation is the transplantation of anatomic structures that include multiple tissues such as skin, bone, muscle, blood vessels, nerves, and cartilages.
- A major problem restricting routine use of CTA in daily practice is the risk of lifelong immunosuppression in patients receiving transplants that do not directly affect their survival. Over the past 20 years, the quality and specificity of immunosuppressive drugs have greatly improved; however, their side effects are still a major concern.
- Many disfigured patients would benefit from the unlimited sources of CTA; however, before CTA can be routinely performed in reconstructive surgery, new strategies using less toxic immunosuppressive protocols must be developed. Different tolerance-inducing strategies are promising and may alter the risk-benefit ratio in support of the routine use of different CTA models in clinical practice.
References

   This review article traces the origins of CTA and outlines the challenges posed by immunosuppression. This is part one of a three-part comprehensive review and is very complete. The essential consideration in allograft preservation is that success depends on preservation of the specific component tissue in a given graft that is most sensitive to ischemia. In most cases of CTA surveyed in this article, this refers to skeletal muscle or bone marrow.


   On July 19, 2003, a Viennese team of surgeons performed the world’s first tongue transplanta-
tion, grafting a tongue from an ABO-matched heart-beating donor into a 42-year-old man with tongue cancer. The recipient was discharged from the hospital a month later with a tracheostomy for airway support and a gastrostomy for nutrition. The graft showed no signs of rejection after 8 months, and had some useful sensation, enabling the patient to swallow all saliva and some fluids, although there was some muscle wasting.


   Extended soft tissue defects of the face are difficult to reconstruct, and autologous tissue transfers usually lead to poor cosmetic and functional outcomes. The 4-month outcome in this study demonstrates the feasibility of this procedure. The functional result will be assessed in the future, but this graft can already be deemed successful with respect to appearance, sensitivity, and acceptance by patients.


Chapter 42  Composite Tissue Allotransplantation

   Based on anatomic dissections in this cadaver study, the authors have estimated the time and sequence of facial flap harvest and inset to mimic the clinical scenario of the facial transplantation procedure.
   Although transplantation of musculoskeletal allografts in humans is technically feasible, the adverse effects of long-term immunosuppression subject patients to high risks for correcting a non–life-threatening condition. Achieving immunologic tolerance to musculoskeletal allografts, without the need for chronic immunosuppression, could expand the clinical application of limb tissue allografting. This report explores the possible relationship between hematopoietic chimerism and tolerance to musculoskeletal allografts in swine. Induction of tolerance to musculoskeletal allografts can be achieved in MHC-matched swine. Although hematopoietic chimerism is present in the immediate postoperative period, persistent, long-term chimerism does not seem to be necessary for maintenance of such tolerance.


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