Chapter 82: Oromandibular Recdonstruction

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A variety of etiologies for segmental mandibular defects exist, ranging from congenital to acquired. By far, the most common causes are oncologic surgery, severe trauma, and osteoradionecrosis. These defects can also be caused by inflammatory disease such as osteomyelitis or developmental disorders. There is a spectrum of aesthetic deformity and functional disability that varies with the size and location of the segmental defect. Loss of a small segment of the posterior body or ramus seldom leads to a cosmetic or functional disturbance. Event though a shift of the mandible to the affected side occurs, with a resulting malocclusion, the patient is generally able to function adequately. As the defect becomes more extensive to include a significant portion of the body and/or the anterior arch, the resultant deformity can become crippling. Loss of the structural support for the tongue and laryngeal suspension not only will lead to problems of mastication and deglutition, but prolapse of the tongue may also compromise the airway, requiring a permament tracheostomy. It is obvious that these types of defects must be reconstructed if the patient is to be rehabilitated.

Methods of Reconstruction

A multitude of surgical procedures have been advocated for mandibular reconstruction. The most common involves the use of autogenous bone grafting. However, allogenic bone and, to a lesser extent, xenogeneic bone have been used effectively. Prosthetic devices, pedicled bone flaps, and, more recently, free vascularized bone-containing flaps have also been used, each having its indications, limitations, and complications. An overview of each of these techniques is presented.

Bone grafting in mandibular reconstruction

Several types of bone grafts have been used for mandibular reconstruction, including autogenous, homologous, and xenogeneic grafts. They differ in their potential to cause host-graft immunologic response.

Autogenous bone grafts

Autogenous grafts, or autografts, are procured from the same patient, usually from another body site. It is the material of choice for mandibular reconstruction because it provides viable and immunocompatible osteoblastic cells. Autogenous bone graft sources used in mandibular reconstruction incldude the calvarium, rib, ilium, tibia, fibula, scapula, humerus, radius, and metatarsus.

Three forms of autogenous bone grafts can be harvested: cancellous, cortical, and corticocancellous. Which graft is used depends on the type of defect to be reconstructed.

Cancellous bone grafts consist of medullary bone and bone marrow. This type of graft contains the highest percentage of viable transplanted cells. Furthermore, because of the particulate structure and large surface area, it becomes revascularized more rapidly, resulting in a higher percentage of cells surviving the transplantation procedure.

Cortical grafts, on the other hand, are lamellar bone struts. The predominant cell type that is transferred in this type of graft is the osteocyte. Osteocytes rarely survive transplantation because of the relatively long time that is necessary for revascularization of this type of graft to occur.

Corticocancellous grafts consist of a piece of cortical bone with its underlying cancellous portion. The advantage of this type of graft is that it provides not only viable osteoblastic cells, but also the strength necessary to bridge discontinuity defects. A drawback to large corticocancellous bone blocks is the slow revascularization of the cortical portion of the graft, sometimes resulting in decreased survival of the cancellous portion as well.

Homologous bone grafts

Homologous, or allogeneic, grafts are obtained from individuals within the same species. Obviously, these grafts are a potential source of antigens, since they are genetically dissimilar to the host. Their antigenicity is usually reduced by a process such as lyophilization. Unlike autogenous bone, allogeneic grafts do not provide viable cells. They are believed to contain osteoinductive elements that will "turn on" the host's pluripotential cells to differentiate into the osteo-progenitor cells. This type of graft material is often used a bioresorbable crib or an an expander of an autogenouc bone graft when additional bone is difficult to obtain.

The most popular graft used in secondary mandibular reconstruction is an allogeneic crib, usually a freeze-dried iliac bone or mandible, that is hollowed out and filled with autogenous corticocancellous bone chips (Obwegeser and Sailer, 1978). The bone chips provide a sufficient amount of viable material for phase one bone healing while the crib acts as a biodegradable tray that is replaced by host bone.

Xenogeneic bone grafts

Xenogeneic bone grafts are transferred across species. Bovine bone has been used extensively in reconstructive surgery. Because of the high antigenic potential, this type of bone graft material, popular in the 1950s and 1960s, is no longer widely used today.

Graft healing

Bone graft healing is unique, since new bone is formed as opposed to scar, which results from other connective tissue repair. Graft healing is termed *incorporation.* The quality and vascularity of the recipient bed, into which the graft is placed, plays a significant role in successful incorporation. The bed provides the cellular elements that are transformed into osteoblasts mediated by inductive factors contained within the bone graft. The bed also supplies the vessels that provide the nutrients needed to ensure survival of the transplanted osteoblasts contained within the cancellous moiety of the bone graft.

Radiation therapy greatly affects the quality of the soft tissues. Radiation injury usually causes hypocellularity, hypovascularity, and hypoxia of the recipient bed, creating an environment that is inadequate for graft incorporation. Under these circumstances hyperbaric oxygen therapy has been used preoperatively to improve the quality of the recipient bed.

Hyperbaric oxygen creates a marked oxygen tension gradient between the hypoxic radiated bed and the surrounding normal tissues. This leads to neoangiogenesis and invasion of the hypoxic area by blood vessels and fibroblasts, which in turn improves the vascular and cellular components of the site, providing the elements required to support the incorporation of a free bone graft. When hyperbaric oxygen is not available, the quality of the soft tissues can be improved by the transfer of well-vascularized soft tissue using pedicled myocutaneous flaps or, alternatively, the microvascular transfer of bone-containing flaps that have their own blood supply and do not rely on the recipient bed for revascularization.

Two-phase theory of bone graft incorporation

Barth in 1893 and Axhausen in 1907 studied serial histologic specimens to better define the process of graft incorporation. They concluded that the vascularity of the recipient bed was critical in providing vessels that eventually invaded the inert graft and replaced it with living host bone. This concept, initially termed *death and resurrection,* became known as *creeping substitution* and remained unchallenged until the introduction of the two-phase theory of osteogenesis. The first phase consists of new osteoid formation from cells that survive and proliferate following transplantation. This usually begins soon after the transplantation and can last up to 4 weeks. The amount of bone that is formed during this phase is proportional to the number of bone cells that survive the transplantation procedure. It is therefore important to provide the greatest number of cells per given volume to ensure adequate bone formation. Phase one bone determines the volume of the bone graft. The second phase of bone formation contributes very little to the new bone mass. Phase two usually begins approximately 2 weeks after transplantation and lasts for an indefinite period, so long as the bone remodeling process continues. It is marked by a period of intensive angiogenesis and fibrogenesis, followed by host bone formation. Fibroblasts and mesenchymal bone cells are induced by a substance present within bone that promotes their differentiation into osteoblasts that lay down new bone. Urist (1970) proposed that this inductive substance that "turned on" the host mesenchymal cells was a protein aggregate of low molecular weight present in bone matrix. This substance, later termed *bone morphogenic protein (BMP)*, is acid insoluble but can easily be destroyed by heat in excess of 80°, gamma irradiation, and proteolytic enzymes. Other factors responsible for the differentiation of mesenchymal cells into chondrocytes and ultimately bone have also been described. For example, two cartilage-inducing factors (CIF) have been isolated and characterized. However, experimental studies showed that the CIFs alone were insufficient to cause endochondral bone formation when placed in ectopic subcutaneous sites. Endochondral bone formation did occur when the CIFs were mixed with yet another bone protein, termed *osteoinductive factor (OIF).* It then became evident that these two factors must work in tandem to produce heterotopic bone formation. The best source of inductive substances is autogenous bone and demineralized allogeneic bone. The action of BMP was found to be somewhat suppressed in nondecalcified allogeneic struts. Senn (1989) and Narang and Wells (1973) confirmed that demineralized allogeneic grafts outperformed similar nondemineralized grafts in terms of earlier calcification and ultimate incorporation to the host bone.

Donor site selection

In a thorough review of the literature, Ivy (1951) reported that the first attempts at a mandibular reconstruction with autogenous bone were accomplished using long bones, such as the femur and the tibia. Other sites that have been advocated include ribs, cortical strips of iliac bone, and the fourth metatarsal, used in condylar head replacement.

Major advances in grating techniques for mandibular reconstruction followed the first and second world wars, which resulted in significant numbers of patients with traumatic mandibular defects. Lindenman (1917) reported the use of iliac bone grafts in 160 cases with clearly better results than occurred with his previous series where he had used tibial grafts. Waldron and Risdon reported similar results with use of the iliac bone (Risdon, 1922; Waldron and Risdon, 1919). Chubb (1920), Billington and Round (1926), Ivy (1951), and others reported similar findings. By the end of the second world war, it had become apparent that a bone graft with a high percentage of cancellous bone was superior to cortical bone, as demonstrated by the increased rate of healing and the higher resistance to infection (Mowlen, 1963). Presently the iliac bone, rib, and calvarium are the donor sites of choice for free bone grafts to the cranio-maxillofacial region.

Iliac bone. The ilium is an excellent donor site because of the ability to harvest cancellous bone, cortical strips, and corticocancellous blocks that can be ground down using a bone mill to provide corticocancellous bone chips. These can in turn be condensed into bony defects or packed in alloplastic or allogeneic bone cribs. Harvesting bone from the ilium can be perfromed through either an anterior or a posterior approach (Fig. 82-1). The major difference between the two choice is the amount of cancellous bone that can be harvested. When a small amount is needed, a bone trephine can be passed through a small skin incision to harvest cancellous bone from the anterior iliac crest region. With the use of an open technique, approximately 50 cc of cancellous bone can be harvested from the anterior ilium. Both the lateral and medial approaches to the anterior ilium have been described. It is generally believed that the anteromedial approach minimizes postoperative gait disturbance because the attachment of the gluteal muscles is maintained. These muscles are very active in walking, and detaching their bone insertion always lead to a transient gait disturbance secondary to surgical pain and guarding. Marx and Morales (1988) reported that 42% of patients undergoing bone harvest from the anterior ilium via a lateral approach exhibited a gait disturbance on the tenth postoperative day. At 8 weeks 10% of those patients continued to have some gait disturbance. Only 6% of patients who underwent bone harvest from the posterior hip had similar gait problems in the immediate postoperative period. Fortunately, long-term disturbances are relatively rare. A gluteal gait may develop in a small number of patients, usually as a result of weakness of the gluteal musculature or tensor fascia lata. When this occurs, the patient is unable to lock the knee in extension, and a limp results. When a larger amount of cancellous bone is needed, the posterior ilium is the donor site of choice. It usually contains twice as much cancellous bone as the anterior ilium.

Donor site complications are not limited to gait disturbance. Injury to the abdominal contents can be caused by inadvertent perforation of the peritoneal cavity by an instrument. It is for this reason that a medial approach to the ilium is preferred by the majority of surgeons. The peritoneal contents and iliacus muscle are retracted medially and protected by the use of a deaver retractor. Paralytic or mechanical ileus is a more common complication of this type of surgery. A mechanical ileus may result from the lateral approach, probably as a result of hematoma formation when the medial cortex is violated and the iliacus muscle is injured.

Other complications of iliac bone harvesting include sensory disturbances from injury to the lateral femoral cutaneous nerve, or branches of the subcostal and iliohypograstric nerves. The latter run across the iliac crest in the area of the tubercle and can easily be damaged by the surgical procedure. Abdominal hernias, even though rare, have been associated with bicortical block harvest.

Rib. The rib remains a popular source of bone-grating material. It is most often used in conjunction with its costochondral junction for condylar replacement. This is especially useful in the growing patient, where transfer of the growth center may assist in the development of the mandible. Corticocancellous split rib grafts have been used as an autogenous onlay grafting material in craniomaxillofacial osteotomies, and as biodegradable autogenous cribs when used in combination with corticocancellous bone chipts.

The fifth, sixth, or seventh rib is usually harvested (Fig. 82-2). When more than one rib is needed, alternate ribs can safely be harvested without risk of producing a flail chest. Closure of the periosteum following the rib harvest often leads to complete regeneration of the rib within a year. The advantage of this technique is that it allows for a renewable source of grafting material when multiple, staged procedures are planned.

The development of a pneumothorax is perhaps the most serious complication that has been described following rib harvesting. This is especially true when the costochondral junction is also harvested. The periosteum overlying the costochondral junction is preserved on the superior, anterior, and inferior surfaces. Inadvertent tears of the parietal pleura require placement of a chest tube to ensure reexpansion of the affected lung. Atelectasis, congestion, and even pneumonia are some of the other common pulmonary problems associated with hypoventilation secondary to guarding from incisional pain. The use of a long-acting nerve blocks reduces the chances for developing such pulmonary complications.

Alloplastic implants

A variety of alloplastic implants have been used in mandibular reconstruction. The use of prosthetic devices can be divided into three major categories. The first category is composed of implants that are used as temporary spacers when a more definitive bony reconstructive procedure is planned in the future. The second category consists of patients who are not considered good candidates for a more extensive bone-grafting procedure or for whom the nature of the defect does not warrant a more elaborate reconstructive procedure and the implant is used as a permanent gap-bridging appliance. In the third group the implants are used as internal fixation devices for the fixation of a bone graft (Fig. 82-3).

Kirshner wires and Steinman pins are perhaps the simplest forms of implants that have been used as spacers in mandibular reconstruction. They are threaded into the medullary portion of the proximal and distal stumps to maintain their preoperative spacial relationship. Unfortunately, adequate long-term fixation is difficult to achieve, and these implants tend to loosen, causing their displacement, internal or external extrusion, and infection of the overlying soft tissues. Several attempts were made to increase the implant stability by grooving the bone, contouring the appliance, and even adding retention bolts on either end of the appliance, but with similar disappointing results. It is for these reasons that this method of reconstruction is rarely used today.

Metallic and polyurethane-coated Dacron mesh cribs are also used to bridge continuity defects of the mandible. These are preformed devices that are trimmed and contoured in situ to the exact dimensions of the defect and fixed to the remaining mandible using bone screws. While this implant is rigid enough to allow for immediate mandibular function, its long-term retention often leads to complications such as implant fracture. In addition, when these cribs are used in conjunction with a bone graft, there is often resorption of the graft, demonstrated by a radiographic "empty crib" appearance. This complication is most likely due to two phenomena: (1) poor revascularization and incorporation of the graft and (2) the stress-shielding effects of the crib on the graft.

The most popular prosthetic device presently used in mandibular reconstruction is the transosteal bone plate with retention screws. Plating systems have been used routinely in orthopedic surgery for the treatment of long bone injuries. Over the past 20 years, we have witnessed an explosion in the number of plating systems specifically designed for maxillofacial reconstruction. They differ from their orthopedic counterparts in that they take into account the unique biomechanical requirements of the mandible. Mandibular reconstruction plates should posses the following characteristics: they should be constructed from a biocompatible and bioinert material; they should be easy to contour during surgery yet rigid enough to withstand immediate masticatory loading; and they should not interfere with the delivery of radiotherapy.

Stainless steel, Vitallium, and titanium are the most common metals used in the fabrication of mandibular reconstruction plates. Titanium is generally considered to be the most biocopatible of the three. However, the low modulus of elasticity of titanium makes this type of implant more fragile and difficult to contour. This is a critical factor, since one of the most important aspects in the use of these plates is the ease of adaptation. Certain basic principles must be followed to ensure a successful result. The plate must be contoured to fit passively over the outer aspect of the mandible, approximating the posterior and inferior borders in the ramus and body areas, respectively. If the plate is to be used in the symphyseal area, it should be undercontoured to avoid overprojection in the area of the bony pogonion. The contoured plate is then fixed to the underlying bone using a minimum of four pretapped screws in the most proximal and distal holes. Pretapped screws are better suited for use in bone exceeding 4 mm in thickness (Phillips and Rahn, 1989). Tapping the bone leads to a significant reduction in the insertional torque forces when compared with self-tapping screws (Phillips and Rahn, 1989). Following contour and fixation, the plate is removed and the bony resection completed. In cases where the extent of the tumor completely distorts the normal mandibular anatomy or a total disarticulation of the condyle is expected, prebending of the plate before bony resection is an impossible task. Other methods that are employed to maintain mandibular relationships include the use of external pin fixators, maxillo-mandibular fixation, gunnint-type splints, and skeletal fixation. If a prosthetic condyle is to be used, preservation of the temporomandibular joint disk is helpful.

One of the major controversies that have resulted from the use of these implants has been their effect on the delivery of therapeutic radiation to the area. A number of studies have demonstrated that buried metallic bone plates cause a small increase in radiation at the entrance side and a decrease at the exist or deep aspect of the implant (Dutreix and Bernard, 1966; Schwartz et al, 1979; Tacjer et al, 1984). Slight variations were noted when the different metals were studied. The shape and size of the implant was also found to be significant. Current clinical opinion suggests that the use of these plates in a field that will be radiated does not have a serious effect on dosimetry. The radiation oncologist should be aware of the presence of the buried hardware so that it can be accounted for when calculating the dose and planning the portals. Finally, another issue that remains unclear is the necessity for removal of the hardware, when used to fix a bone graft, and the timing of this procedure. In general, removal of a reconstruction plate in the asymptomatic patient should be performed 6 to 8 months following the bone-grafting procedure. This will ensure that enough time has elapsed to allow for complete integration of the bone graft. Perhaps the main reason for hardware removal is the prevention of the long-term effects of stress shielding (Kennady et al, 1989). Other benefits include improvement in lower facial contour and facilitation of preprosthetic surgery, such as vestibular depth extension (vestibuloplasty) procedures.

Primary Versus Secondary Mandibular Reconstruction

There are many issues regarding the timing of mandibular reconstruction, some of which are based on technical considerations, whereas others are philosophical. In the past, delayed reconstruction was considered the standard. Avoiding graft contamination by saliva resulted in a superior success rate with little or no infection or extrusion of the graft. However, a number of successful series of primary mandibular reconstruction using free bone grafts have been reported. Obwegeser and Sailer (1978) reported a 70% success rate in cases where an immediate bone graft was used via a transoral route. Strelzow (1983) also reported good results in his series, with only two failures in his 11 patients.

The major technical considerations are related to the use of vascularized versus nonvascularized bone. The exposure of a nonvascularized bone segment to oral contamination is fraught with a high rate of complications and failures. This fact alone has led the majority of otolaryngologists - head and neck surgeons to adopt a policy of delayed reconstruction. Some clinicians also maintain the philosophy that the recurrence rate of oral cavity cancer is sufficiently high to impose a mandatory disease-free interval before undertaking a complex mandibular reconstruction.

This philosophy has been challenged as newer techniques using vascularized bone have led to higher success rates, approaching 96%, despite exposure to oral microbes and a previously radiated site (Urken, 1991). The predictable nature of this method of reconstruction allow it to be performed in the primary setting. This alternative approach is based on the philosophy that patients should not be forced to live with the aesthetic and functional deficits that follow ablative surgery. Rather, they should be restored to as near normal a life-style as possible for the duration of their life. The goals of primary oromandibular reconstruction are to restore lower facial contour, occlusal relationships, functional lower dentition, and, most important, deglutition and mastication in a safe, rapid fashion. In addition, through primary reconstruction, the surgeon avoids the major problems incurred in the secondary setting related to drift of the remaining mandibular segment, soft tissue contracture, and risk of facial nerve injury when the ramus and condyle are reconstructed in a scarred, previously operated and radiated bed.

In most cases of secondary mandibular reconstruction, the soft tissue coverage has been established and the surgeon is only concerned with restoring the bony mandibular architecture. Alternatively, primary mandibular reconstruction requires that the soft tissue lining be restored at the same time as the bone. The remainder of this chapter addresses the techniques that are available or primary reconstruction.

Techniques of Reconstruction

Classification of oromandibular defects

The recognition that the majority of mandibular discontinuity defects are problems of both the bone and the surrounding soft tissue makes the restoration of such defects more appropriately termed *oromandibular reconstruction.* The establishment of an accepted classification scheme to describe these defects is critical for a variety of reasons. The detailed definition of a patient's defect provides a framework for the surgeon to select the best method for reconstruction. It permits critical evaluation of the functional and aesthetic outcome of the reconstructive procedure so that different methods can be effectively compared. In addition, it allows the surgeon to predict the outcome for an individual patient with a particular defect. Finally, the classification of a defect into its component part forces the surgeon to approach each missing part in a more selective fashion so as to achieve the optimum restoration of form and function.

Bone defects

The mandible can be divided into different parts based on a variety of different schemes. The scheme that we devised is based on functional considerations related to detachment of different muscle groups, and on the degree of difficulty of achieving a successful aesthetic outcome (Table 82-1). The divisions are illustrated in Fig. 82-4. The condyle (C) is an important component that is difficult to reconstruct. The number of options in condylar replacement reflect the fact that no single technique is universally successful. The alternatives for reconstruction of the condyle include vascularized bone, costochondral grafts, and alloplastic condyles. The resection of the ramus of the mandible causes disruption of the masticator muscle sling. The division between defects of the ramus (R) and defects of the body (B) in the classification scheme is somewhat arbitrary. However, a defect of the ramus indicates a near-complete detachment of the muscles of mastication. Body defects (B) extend to the mental foramen. Defects of the symphysis are divided into total (S) and partial (Sh) defects based on the degree of disruption of the suprahyoid and tongue muscle attachments and the difficulty of restoring the contour of the mandibular arch.

Palatal defects are included in the scheme for bone for a very important functional reason. Those defects of the hard and/or soft palate that require placement of an obturator interfere with the sensory feedback from a large mucosal surface. The loss of this sensation imposes a significant deficit in an oral cavity that is already partially anesthetized as a result of an ablative procedure and the introduction of foreign tissue.

Soft tissue defects

The classification of soft tissue defects of the oral cavity is more challenging than that of bone defects because of the intricate three-dimensional geometry and the markedly different qualities of the soft tissue in different regions of the oral cavity. The classification system becomes even more complex when consideration is given to the functional aspects related to the loss of motor activity of the tongue, the soft palate, or the muscles of facial expression.

In 1991 we introduced a detailed system for classifying soft tissue defects (Table 82-2). The oral cavity and oropharynx were divided into different mucosal and myomucosal regions. The soft palate (SP) was divided into hemi (SPh) and total (SPt) defects (Fig. 82-5). The pharynx (PH) was subdivided into lateral (PHl) and posterior (PHp) pharyngeal defects based on the requirements for soft tissue augmentation to restore function and prevent pharyngeal stenosis. Defects of the labial (L) and buccal (B) mucosa were classified according to the need to place a flap or skin graft in order to restore normal sulcular anatomy. The same is true of floor-of-mouth defects (FOM) which are divided into anterior (FOMa) and lateral (FOMl) defects (Fig. 82-6). In addition to restoration of sulcular anatomy, the effect on tongue mobility is assessed to determine the need for additional tissue to prevent ankylosis.

The function of the tongue is the most important determining factor in the overall success of oral rehabilitation. It is particularly difficult to classify tongue defects. However, because of the propensity of neoplasms to involve the lateral border, the tongue was longitudinally divided into quarters in addition to being divided into the mobile tongue (Tm) and the tongue base (Tb) (Fig. 82-7). Total glossectomy defects were designated (TG, and resections that left a non-functional residual tongue were classified as Tmnf Tbnf (Fig. 82-3).

Traumatic defects, as well as ablative defects, may involve the skin of the face and neck as well. These deficits habe been classified according to the scheme outlined in Table 82-4. The division between the mentum (Cm) and the cheek (Cch) is based on a vertical line extending through the lateral oral commissures (Fig. 82-8). Perhaps one of the most challenging aspects of soft tissue reconstruction is the restoration of aesthetically pleasing and functionally competent upper and lower lips. The classification of these defects is provided in Table 82-4 and Fig. 82-8.

Neurologic defects

A critical assessment of functional and aesthetic deficits following ablative oral cavity surgery demands that neurologic defects be included in a classification scheme (Table 82-4). The nerves that are most often involved in an ablative procedure include the lingual (Nl), hypoglossal (Nh), facial (Nf), and inferior alveolar (Nia). When the neurologic problem is bilateral, the subscript B is used. Therefore a bilateral inferior alveolar nerve defect is denoted (Niab) (Table 82-5).

Vascularized bone in mandibular reconstruction

The advantages of using vascularized bone in mandibular reconstruction were outlined through a series of experimental studies performed in an animal model in the early 1970s (McCullough and Fredrickson, 1973). Through the transfer of rib with its blood supply as an onlay graft or to bridge a segmental defect, it was found that vascularized bone resists infection and extrusion, has an osteogenic rate comparable to that of other bone in the skeleton, and heals to the surrounding bone in a fashion similar to fracture-type healing. Additional studies demonstrated that vascularized bone behaved in a comparable fashion whether it was placed in a radiated or nonradiated bed and was superior to non-vascularized bone (Ostrup and Fredrickson, 1975). The ability of vascularized bone to contribute both a blood supply and an osteogenic potential at the graft-mandible interface was particularly appealing.

A flurry of activity in the 1970s and early 1980s centered around the transfer of vascularized bone to the oral cavity through a variety of mechanisms. Staged procedures were devised whereby bone grafts were wrapped in regional cutaneous flaps and subsequently transferred as a composite flap once the bone had become vacularized (Conley, 1971; Snyder et al, 1970). Rib grafts were transferred on the internal mammary pedicle through a median sternotomy approach (Taylor et al, 1975). Finally, as more and more muscle and musculocutaneous pedicle flaps were used for soft tissue reconstruction, associated bone segments were transferred as composite flaps. The pectoralis major flap was used to carry rib and sternum. Rib was also transferred with the latissimus dorsi muscle. The trapezius flap was popularized as composite flap with the scapular spine. The sternocleidomastoid muscle was used to carry a segment of clavicle, and the temporalis was a carrier for the outer table of the calvarium. None of the regional flaps achieved lasting popularity as a composite flap for the following reasons: (1) difficulty in harvesting, (2) tenuous blood supplyu to the bone, (3) poor bone stock, and (4) limited maneuverability of the soft tissue component relative to the bone in order to allow accurate reconstruction of the intricate three-dimensional soft tissue anatomy of the oral cavity.

During the time that much attention was being focused on regional flaps for head and neck reconstruction, slow developments were being made in the microvascular transfer of a variety of vascularized bone flaps. The first reported vascularized bone-containing free flap (VBCFF) was used by McKee in 1970 to reconstruct the mandible (McKee, 1971). It was not until 1978 that the first large series of mandibular reconstruction using VBCFFs was published (Daniel, 1978; McKee, 1978). Eight different donor sites have been reported in the literature for harvesting VBSFFs to be used in oromandibular reconstruction: ilium, scapula, radius, fibula, rib, humerus, metatarsus, and ulna.

Before discussing these donor sites and their relative utility, it is important to separate the bone and soft tissue components of the composite flaps to discuss the ideal qualities of each. The most desirable qualities for bone used in reconstruction of the mandible include the following: (1) it is of adequate length to restore a segmental defect of nearly any length; (2) it has a natural shape or easy contourability to conform to the missing mandible; (3) it is well vascularized; (4) it has a vascular anatomy that is readily preserved while contouring the graft; (5) it is of sufficient height and width for reliable placement of endosteal dental implants for dental rehabilitation; and (6) there are no significant functional or aesthetic deficits at the donor site following harvest. Any composite flap should have a consistent vascular anatomy with a pedicle that is long enough and of sufficient diameter to permit easy revascularization through anastomoses to recipient vessels in the neck. In an effort to shorten the total operative time, it is also beneficial to select a donor site that permits harvest of the flap by a second team of surgeons at the same time that the recipient site is being prepared.

The soft tissue component of the VBCFF is of equal or greater importance than the bone component in achieving the optimum functional result. The management of the tongue following floor-of-mouth resection or partial glossectomy is critical. At the present time there is no way to restore functional tongue musculature following ablation. However, one of the major goals in soft tissue reconstruction is to ensure that the remaining tongue mobility is preserved. This is achieved through the use of a pliable and redundant segment of tissue. A split-thickness skin graft or a thin cutaneous flap is ideal for that purpose. When the resection is limited to the floor of the mouth and the lateral aspect of the tongue, the former technique is quite adequate (Urken et al, 1989b). When a significant portion of the tongue has been removed, a thin, cutaneous flap, such as the radial forearm free flap, can be fashioned to restore the volume, shape, and sensation while preserving overall tongue mobility. Therefore the ideal qualities of the soft tissue component of a VBCFF are as follows: (1) it is abundant; (2) it is well vascularized, (3) it is thin and pliable; (4) it has adequate mobility relative to the bone to permit easy reconstruction of the three-dimensional oral cavity and oropharyngeal anatomy; (5) it is sensate; (6) it is lubricated; and (7) there is minimal donor site morbidity. At the present time no single VBCFF provides all of these soft tissue qualities.

Rib

The rib was the first vascularized bone to be used in mandibular reconstruction. It has been transferred to the oral cavity through a variety of different techniques (Serafin et al, 1980). The direct blood supply to the rib may be based anteriorly on a branch of the internal mammary artery, or posteriorly or posterolaterally on the posterior intercostal vessels. These approaches provide a VBCFF composed of skin and a segment of rib. Alternatively, vascularized rib has been transferred with the pectoralis major, serratus anterior, or latissimus dorsi muscles as the carrier. The primary drawback to the use of the rib is its poor bone stock regardless of the vehicle for maintaining its nutrient blood supply. The osteocutaneous flaps are limited because of the tenuous blood supply to the skin from an anterior approach and the risky dissection via a posterior approach. The rib has been relegated to a flap of historical interest in light of the alternatives now available for oromandibular reconstruction.

Metatarsus

The metatarsus was the next reported VBCFF in mandibular reconstruction (Bell and Barron, 1980). This osteocutaneous flap based on the first dorsal metatarsal artery transfers a segment of thin, sensate skin with the second metatarsal. Use of this flap is advantageous because of the quality of the skin; it is the thinnest sensate flap available in the body. However, the bone volume is limited, and the skin-grafted donor site on the dorsum of the foot is prone to breakdown from direct trauma. For these reasons, this donor site is not often used at this time.

Ilium

The length, natural curvature, and volume of bone that can be harvested from the ilium have made this a valuable source of VBCFFs for oromandibular reconstruction. The iliac crest is the only vascularized bone that has been extensively used with endosteal dental implants, permitting functional dental restoration. The iliac crest and the overlying skin were initially transferred based on the superficial circumflex iliac artery (SCIA). However, this vascular pedicle provided a tenuous supply to the bone and a variable anatomy that made it a difficult flap to harvest. Taylor et al (1979a, 1979b) introduced the use of this donor site based on the deep circumflex iliac artery (DCIA), which provided a more favorable and more consistent vascular pedicle, as well as a hardier blood supply to the bone through both the periosteal and direct endosteal feeders.

The introduction of the osteocutaneous iliac crest flap, based on the DCIA, was one of the major landmarks in free flap reconstruction of the oral cavity. Although it provided vascularized bone of excellent quality, the associated skin paddle was not ideal for relining the oral cavity. The skin and subcutaneous tissue were often too thick or accurate restoration of the three-dimensional anatomy. In addition, the blood supply to the skin may be tenuous. It is derived from fine musculocutaneous perforators that run in an array along the inner aspect of the iliac crest, coursing through the transversus abdominis muscle and internal oblique and external oblique layers of the abdominal wall. That blood supply to the skin may be easily compromised when the skin is manipulated relative to to the bone.

A second soft tissue flap was added to the osteocutaneous flap by Ramasastry, who described the combination of the internal oblique muscle vascularized through the ascending branch of the DCIA. When first introduced in 1984, this osteomyocutaneous flap was used for reconstruction of the extremities (Ramasastry et al, 1986). The attractive feature of this composite flap was that it provided a broad sheet of internal oblique muscle that had an axial pattern blood supply, improving both its reliability and maneuverability relative to the bone (Fig. 82-8). The denervated muscle undergoes atrophy that leaves a thin, fixed soft tissue coverage over the bone. We introduced this flap in 1989 for oromandibular reconstruction. In an effort to restore sulcular anatomy and maintain maximal tongue mobility, a redundant split-thickness skin graft was placed over the muscle (Fig. 82-9) (Urken et al, 1989a, 1989b).

The skin paddle is used as an external monitor or to resurface cutaneous defects when reconstructing composite defects involving mucosa, bone, and skin. When used solely as a monitor, it is subsequently removed to provide a more pleasing contour to the neck. The subcutaneous tissue in the flap can be maintained to augment radical neck deformities.

One of the limitations of this flap is related to the donor site, where a meticulous closure is required to prevent a postoperative hernia. The skin paddle has not been reported as a sensate flap. In addition, the skin overlying the iliac crest is a poor color match for the face and cannot be reliably placed above the level of the oral commissure without risking the skin's vascularity. For massive through-and-through defect that require resurfacing of large portions of the cheek integument, we prefer to combine the iliac crest-internal oblique flap with a regional myocutaneous or cervicofacial advancement flap. Alternatively, the scapular system of flaps provides an abundance of skin with extensive mobility relative to the bone (Urken et al, 1991b).

Scapula

The lateral border of the scapula was introduced as a vascularized bone-containing free flap by Teot in 1980 (Teot et al, 1981). Based on the subscapular artery and vein, a large number and variety of soft tissue components can be harvested, including the scapular cutaneous flap, parascapular cutaneous flap, latissimus dorsi myocutaneous flap, and serratus anterior flap. The large surface area and tremendous flexibility afforded by each of these soft tissue components, supplied through a separate vascular leash, make this the most versatile donor site for VBCFFs. However, there are three major drawbacks to this composite flap: (1) the bone of the lateral scapular border is quite thin and does not readily accept endosteal dental implants; (2) the harvesting cannot be done simultaneously with the ablative procedure, necessitating a sequential approach; and (3) the cutaneous flaps have not been reported as sensate flaps.

Radius

The radial forearm flap has been a workhorse cutaneous free flap for head and reconstruction for over a decade. It offers a thin, well-vascularized supply of skin with an easily identifiable sensory supply. The radial artery and cephalic vein are long, large-diameter vessels that can be reliably revascularized to recipient vessels in the neck. A segment of the radius measuring 10 cm in length and no greater than 40% of the circumference can be transferred. Despite the favorable pedicle and soft tissue component of this VBCFF, its usefulness for oromandibular reconstruction is limited by the small stock of bone that can be transferred. In addition, there is a high rate of donor site fractures that can lead to significant function problems of the hand (Urken, 1991).

Ulna

The ulnar composite flap is quite similar to that of the radius. It is a fasciocutaneous flap supplied by the ulnar artery. This VBCFF has both a favorable vascular pedicle and an excellent cutaneous component for oral lining. However, the stock of bone is also limited to 40% of the circumference of the ulna. The reported experience with this VBCFF is quite small, in large part because of a reluctance to interupt the dominant blood supply to the hand (Lovie et al, 1984).

Humerus

The lateral arm flap is the third sensate, fasciocutaneous composite flap that can be harvested from the arm. This flap is based on the posterior radial collateral artery, which is a terminal branch of the profunda brachii artery. An oval flap of skin 6 to 7 cm wide can be harvested and still achieve primary closure in most cases. A segment of the humerus, measuring 10 cm in length and approximately 20% of the circumference, can be safely harvested. The posterior cutaneous nerve supplies sensation to the skin paddle. As with the ulna, there is limited experience with this VBCFF for oromandibular reconstruction (Martin et al, 1988). Although the donor site is better camouflaged than the two forearm flaps, and the sensate skin paddle and vascular pedicle are quite favorable, the bone stock is limited for functional dental restoration using osseointegrated implants.

Fibula

The vascularized fibular flap is the longest expendable segment of bone that is available for transfer. Frequently used for bridging long bone defects in orthopedic surgery, it has recently been modified and used for oromandibular reconstruction (Hidalgo, 1989). The peroneal artery supplies up to 25 cm of bone, as well as a segment of skin along the lateral aspect of the lower leg. The tenuous vascularity to the skin running through the septocutaneous perforators may be enhanced by harvesting a segment of soleus to capture additional musculocutaneous perforators. The straight segment of fibula must be contoured through numerous osteotomies and ostectomies to simulate the shape of the mandible. To date, use of dental implants in the fibula has been limited. The bone stock is more favorable than that of any other VBCFF, except for the ilium. The length of bone that can be harvested from this donor site makes it the flap of choice for near-total mandibular deformities. The reliability of the skin is questionable and both the surgeon and the patient should be prepared for the possible need for a second soft tissue flap, either free or pedicled, when reconstructing composite defects with the fibula.

Our philosophy on using dental implants is to place the longest possible implant into the VBCFF. It is unknown, at this time, what the rate of marginal bone loss is in vascularized bone grafts. Longitudinal studies using serial panoramic views over a 5-year period are needed to answer this question. If marginal bone loss is no greater than in the edentulous mandible, we will then be able to determine the minimum bone requirements for functional dental restoration.

Combined Free Flaps

As we strive to fine-tune the soft tissue reconstruction of the oral cavity to optimize functional results, a number of points should be emphasized. Restoration of function does not necessarily follow the restoration of form in the oral cavity. The reconstruction of the tongue as a separate unit assists in preventing tethering of this vital organ. Therefore it is helpful to try to separate the mobile tongue from the floor of the mouth and the soft tissue overlying the alveolar ridge. This can be achieved through the use of a redundant skin graft when there has been a limited glossectomy. However, when there has been a significant loss of tongue volume and a disturbance in tongue form, we prefer to reconstruct these defects using a separate sensate cutaneous free flap. In so doing, the shape and volume of the tongue can be restored and the mobility maintained. To achieve this end, we have resorted to the use of a separate radial forearm free flap to reconstruct the tongue following significant glossectomy and an iliac crest osteomyocutaneous flap to reconstruct the mandible and the neoridge (Urken et al, 1991). The restoration of sensation to the mobile tongue is a critical factor in achieving functional mastication. Proprioceptive feedback is needed to manipulate the food particles between the interincisal surfaces, as well as to prevent food trapping in the floor of the mouth. Sensation in the tongue base is probably even more critical in providing a warning system for the larynx to prevent aspiration following significant tongue base resection. Although the early results with this method of reconstruction are quite optimistic, the true efficacy must be delineated through critical functional analyses.

Adjunctive Techniques

A number of additional measures are helpful in select cases of oromandibular reconstruction. Lower lip anesthesia following inferior alveolar nerve resection predisposes to the problem of drooling (Urken et al, 1991c). This is particularly debilitating in individuals with total lower lip anesthesia. This problem can be partially overcome by the use of nerve grafts to bridge the gap between the stumps of the inferior alveolar and mental nerves once frozen sections confirm the absence of neural spread. The recovery of lip sensation has been very valuable in postoperative oral rehabilitation (Urken et al, 1991a).

Limited oral opening as a result of fibrosis of the muscles of mastication following surgery and radiation therapy may cause a significant handicap in dental rehabilitation and overall oral function. This may be addressed through physical therapy, brisement force with the patient under anesthesia, and, finally, coronoidectomy.

Despite our efforts to restore sulcular anatomy at the time of the initial reconstructive procedure, the final result may require intraoral revision through debulking of cutaneous flaps or the interposition of skin or dermal grafts as a vestibuloplasty. The primary indications for doing these procedures is to relieve ankyloglossia, reduce the soft tissue height over the neomandible for prosthetic rehabilitation, or restore the anterior gingivolabial sulcus, which is most important for oral continence.

Dental Rehabilitation

One of the main goals of mandibular reconstruction is rehabilitation of the patient's masticatory function. Restoration of bony continuity without intraoral reconstruction of the denture-bearing surface cannot be considered a successful result. Surgical scarring and the inability to replace the intraoral tissues with a thin, well-vascularized, adherent surface over the neomandible has frustrated surgeons and prosthodontists in their attempts to achieve functional dental rehabilitation. Use of the internal oblique muscle as part of the osteomyocutaneous iliac crest tripartite flap has resulted in restoration of an adequate denture-bearing area. The high success rate of the root form endosteal implants led to their widespread use in the dentulous patient population. Their use in mandibular reconstruction resulted in the ability to offer the patient a fixed, stable dental prosthesis. Patients undergoing this type of dental reconstruction are able to function according to objective criteria at levels equal to those of noncancer patients with similar appliances (Urken et al, 1991a).

Three types of dental appliances can be used in restoration of the occlusal aspect of the masticatory apparatus. The tissue-borne removable denture is the simplest prosthesis. Its stability and retention depend on the presence of a broad denture-bearing area with adequate sulcular extensions. The tissue-borne denture can be either complete or partial. In the case of the latter, the remaining teeth are used to anchor the prosthesis. It is in this select group of mandibular reconstruction patients with residual lower dentition that a partial tissue-borne prosthesis may be used with a fair degree of success (Figs. 82-10 and 82-11). A contraindication to the use of a tissue-borne prosthesis is a history of radiotherapy. Xerostomia, which is often a result of radiation injury, creates problems with retention of the denture. Furthermore, these patients become more prone to osteoradionecrosis through repeated traumatic ulcerations caused by the acrylic base of the denture (Daly et al, 1972).

The use of endosteal osseointegrated implants allows for partial or total unloading of the oral mucosa.

The concept of osseointegration was first described by Adell et al (1981). In a generic sense, osseointegration refers to direct contact of organized living bone to the implant surface without an intervening connective tissue interface. This process results in functional anchorage of the implant to the surrounding bone analogous to that of the tooth root (Fig. 82-12). A variety of materials have been used in the fabrication of the implants, including vitreous carbon, cystal sapphire, and aluminum ceramic. Titanium screw implants seem to offer the best anchorage. The presence of threads allows for an increased surface area of contact with the surrounding bone and for transmission of the axial load to the surrounding bone via compression along the inclined surface of the screw threads (Skajak, 1983).

After initial placement of the implants using a meticulous surgical technique that protects the bone from the surgical trauma, the fixture is covered by the gingiva and left to heal for a period of 4 to 6 months. Following this period the second-stage surgical procedure is performed, which involves the placement of a transmucosal titanium cuff fastened to the fixture via an internal retention screw. The fabrication of the dental prosthesis can then be carried out. The soft tissue requirements for implant-borne dentures are much less stringent, since prosthetic retention is primarily achieved through the fixtures. Deep sulci are therefore not critical.

When implant-assisted prostheses are used, the load is usually shared by two or more implants placed in the symphyseal area and the oral mucosa. A number of denture connectors can be used, including magnets, ball-and-socket connectors, and clip bar-type attachments. The purpose of these implants is to assist in the primary retention of the prosthesis and to help stabilize it functionally against lateral displacement forces. The use of implant-assisted prostheses is very popular, since they are more cost-efective than implant-borne prostheses (Figs. 82-13 through 82-16).

Fixed implant-borne dentures are the most stable form of dental restoration. These dentures are fully supported by five to six fixtures, which are attached to the submerged implants by small fixation screws. These dentures can be removed by the prosthodontist for routine maintenance. The fixed implant-borne denture does not come into contact with the underlying mucosa. It is therefore ideally suited for the radiated patient (Figs. 82-17 and 82-18).

Conclusion

Tremendous advances have been made in reconstruction and rehabilitation of the patient with oral cavity cancer. However, persistent problems continue to thwart our efforts to restore these patients to their predisease state. Radiation-induced fibrosis of the muscles of mastication and radiation-induced xerostomia are difficult problems to overcome. The loss of tongue musculature, however, is perhaps the most debilitating and seemingly the most insurmountable problem. Functional reconstruction following significant glossectomy is one of the great challenges that remain in oromandibular reconstruction.