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Oral and Maxillofacial Surgery

Sampler

Chapter 13: Hard Tissue Reconstruction
From *Management of Complications in Oral and Maxillofacial Surgery.*

Edited by Michael Miloro and Antonia Kolokythas

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Hard Tissue Reconstruction

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INTRODUCTION

Successful bone continuity restoration is the basis for the success of the majority of reconstructive surgery procedures in the oral maxillofacial skeleton. There are a number of preoperative, intraoperative and postoperative considerations the surgeon must be aware of with the use of bone grafts (transfer of free cancellous, cortical, or corticocancellous bone without a blood supply), bone flaps (bone pedicled or transferred free with its own vascular system), or bone substitutes (growth factors, allogeneic, alloplastic, and xenogenic materials). Knowing the potential risks and complications with each method can provide effective informed consent and allow measures for quality control. Ultimately surgeons must provide the best possible care to the patients by minimizing known risks and complications, and having a clear understanding of their effective management.

CONTRIBUTORY PATIENT FACTORS IN COMPLICATIONS

Preoperative Comorbidity

Primary reconstruction with nonvascularized bone graft at the time of pathological resection or during trauma reconstruction, although ideal, is not always undertaken for several reasons. Occasionally the added time or blood loss from harvesting the graft may be limiting factors in certain patients. Bone graft harvesting may be associated with increased risk of surgical site blood loss perioperatively and in the postoperative period that can cause adverse patient outcomes. Risks from significant blood loss especially in older or medically compromised patients include perioperative or postoperative cardiopulmonary complications such as myocardial infarction or cardiac arrhythmias, or even neurologic sequelae, such as stroke. In addition, blood transfusions harbor the risk of several adverse reactions that may even be life threatening, while aggressive crystalloid or colloid resuscitation may add to cardiopulmonary system's stress. Intraoperative hemostasis is essential for minimizing these risks. A complete medical history including cardiopulmonary history and functional status in the preoperative period can provide accurate risk assessment and determine if any additional evaluation is necessary.[1–5] While most grafting procedures are low risk in their overall morbidity and mortality, the frail, the elderly, and the medically unfit should all be carefully evaluated and optimized preoperatively to ensure a safe treatment can be performed with minimal adverse effects. This is especially true in cases of elective reconstructive procedures that can be delayed for a period of time to maximize patient health. In cases of more urgent surgery, preoperative evaluation and discussion of risks

Management of Complications in Oral and Maxillofacial Surgery, First Edition. Edited by Michael Miloro, Antonia Kolokythas.

with both the patient and anesthesiologist can allow for appropriate care and avoidance of adverse outcomes.

Risks of Blood Transfusion

With many maxillofacial surgical procedures, and especially those requiring bone reconstruction, there may be need for blood transfusion in the perioperative period. In the past, patients were transfused more liberally in an attempt to minimize major cardiopulmonary complications; however, good supportive evidence for this practice did not exist. It is well known that numerous risks exist with the transfusion of blood products including: disease transmission, systemic inflammatory response syndrome (SIRS), wound infection, sepsis, pneumonia, acute lung injury (TRALI), acute respiratory distress syndrome (ARDS), extended length of hospitalization, and increased post-transfusion complications.[6–10] Some additionally have cited that there may exist an immunomodulation effect on the host that may increase the risk of cancer recurrence, though it is impossible to define the precise risk involved.[11–27] Currently it is accepted that transfusions do offer some beneficial actions with improved oxygen delivery; however, this should be limited to use primarily in symptomatic patients with hemoglobin levels below 7 gm/dl. There is significant controversy on acceptable transfusion guidelines for cardiovascular and cerebrovascular compromised patients based on overall risk. While some suggest hemoglobin levels between 8 and 10 gm/dl can be tolerated by these patients, others believe transfusions at these levels are acceptable to prevent adverse outcomes.[6,7] Excess blood loss and/or the need for transfusions prolong postoperative recovery with risks associated with increased hospitalization (pneumonia, hematoma, wound infection and breakdown, thromboembolism) among others.[28]

Meticulous hemostasis to the soft tissues from the donor site, along with use of adjunctive agents can effectively minimize procedural and postoperative blood loss. Medullary bleeding has often been minimized with the use of bone wax applied directly on the exposed cancellous marrow. There have been reports of granulomas at the site of bone wax use as well as possible delayed infections[29–37] The use of other hemostatics such as oxidized cellulose (Surgicel® Ethicon, www.ethicon.com) can prove beneficial, but are also known to cause nerve paresthesias when applied directly on or in immediate vicinity to nerves.[38–41] Newer resorbable wax substitutes are also available for use (Ostene®, Ceremed, www.ostene.com).

There has been interest in utilizing perioperative erythropoietin in cases where patients are anemic preoperatively or significant blood loss is anticipated to minimize the risk of blood transfusions.[25,42] This is especially true for patients whose religious beliefs prevent them from receiving autologous blood transfusions.[43,44] Further trials are necessary to demonstrate a reliable cost-benefit for erythropoietin use in elective surgery with minimal to moderate risk. Most recently, the use of hemoglobin-based oxygen-carrying substitutes is being explored. Their benefits include a prolonged shelf life, decreased immunogenic potential, lack of risk for disease transmission, and a potential for greater oxygen carrying capacity.[45] Continued investigation will be necessary to delineate the benefit of these products.

Nutritional Status Issues

Nutritional status is becoming an important determinant of overall success during bone reconstruction procedures. Patients presenting with malnutrition must be identified preoperatively through clinical assessment and appropriate serum laboratory testing. Some studies have noted that 20% to 67% of head and neck cancer patients (many of whom may require bone reconstruction procedures with the use of free tissue transfers) are malnourished based on a number of variables at the time of surgical intervention.[46] Patients with a recent weight loss of greater than 10% prior to surgery are prone to major postoperative complications including wound infection, fistula, respiratory complications, myocardial injury, and even progression to sepsis.[46,47] Albumin, prealbumin, preoperative CRP levels, and BMI have all been described as useful determinants of outcome.[48–52] Those patients with low albumin and prealbumin are more likely to proceed with slower postoperative recovery and delayed soft and hard tissue healing; however, these markers can be affected by renal and hepatic dysfunction as well as acute inflammation and should be used in the context of the patients overall status.[53–56] Conversely, providing patients with protein nutrition preoperatively can decrease hospital stay and improve bone healing as evidenced in the general surgery and orthopedic populations.[57,58] In the postoperative setting, many bone graft and bone flap procedures require intraoral incisions. There is substantial debate and no consensus regarding the use of oral rest postoperatively. Patients do require adequate nutrition for wound healing. It is well documented that early nutrition in the postoperative period equates to better patient outcomes, which is especially true of larger flap reconstructions in a critical care setting.[59,60] In any circumstance, four options are available. First, a period of oral rest for up to a week is sometimes advocated for gastrointestinal procedures but has never openly been advocated for maxillofacial surgery wound healing. It is generally felt that particulate food can harbor bacteria and predispose to infection and wound breakdown if it is not being cleared adequately. For large reconstructions or difficult wounds, enteral feeding tubes may offer the benefit of nutrition by bypassing the oral wound. While the oral tissues are rested, the patient can still achieve appropriate nutritional support. Complications from nasogastric tube placement have been reported, including intracranial placement in trauma patients, intrapulmonary feeding, tracheoesophageal fistula, sinusitis, diarrhea from dumping syndrome, and gastric ulcerations among other problems. For certain cancer reconstructions, a prolonged oral rehabilitation may be encountered and selected patients may benefit from a percutaneous or open gastrostomy tube. Major complications may include peritoneal placement, colon or intestinal perforation, peristomal infection and granulation, and other feed-related problems.[61–64] Some have felt that parenteral nutrition has its advantages in specific populations, but it is associated with a higher rate of sepsis and intestinal atrophy, most notably in a critical care setting.[59,62,65]

Effects of Diabetes Mellitus and the Use of Corticosteroids

Poorly controlled diabetes mellitus as well as perioperative corticosteroid use are shown to decrease bone and tissue healing. High glucose concentrations, as well as prolonged corticosteroid use, inhibit collagen cross-linking, which is necessary for proper bone and soft tissue healing.[66] Additional inhibitive properties on angiogenesis, macrophage and neutrophil chemotaxis, migration, and phagocytosis are also exhibited.[67–69] Bone healing is impaired with alterations in osteoblastic and osteoclastic function as well as vascular ingrowth and remodeling.[69–75] Poor glucose control is a known risk factor for bone graft site dehiscence and subsequent failure.[76] Glucocorticoid therapy is commonly used in the perioperative period with minimal effect on wound healing and infection rates when given over short courses, and without excess dosing. Prolonged corticosteroid use, though, inhibits collagen synthesis and cross-linking, decreases osteoblast and osteoclast differentiation and function, and thus impacts healing.[77–80]

Nicotine Effects

Nicotine has been shown to have substantial effects on the vascularity of all tissues. By eliciting microvascular vasoconstriction, promoting hypercoagulation with increased fibrinogen levels and platelet aggregation, and creating volatile agents and free radicals, an inflammatory environment is produced that limits healing. Even in low doses, nicotine has been shown to have deleterious effects on bone healing with suppression of pro-osteogenic bone morphogenetic proteins.[81–83] Smoking should optimally be stopped well in advance of elective bone reconstructive procedures to maximize bone regenerative capacity. Smoking during the postoperative healing phase has been shown to be detrimental to bone graft survival,[84–86] and smokers may have twice the rate of complications as nonsmokers in monocortical onlay grafts.[87]

The Influence of Active Infections

In rare circumstances, patients may have an underlying infection or severe inflammation to the recipient bed or at the donor site. It is imperative that formal infections be properly evaluated clinically prior to proceeding with any grafting procedure as risks for potential failure or adverse outcomes increase.[88] A vascularized flap does offer some protection to mild inflammation at the recipient site; however, prudence is imperative to minimize graft loss and failure. Appropriate patient selection is essential and use of reconstructive procedures in infected sites is best avoided when possible.

DONOR BONE SELECTION CONSIDERATIONS

Autogenous Bone Grafts

Autogenous bone is the current gold standard of hard tissue transfer, and both bone grafts and bone flaps can be utilized to reconstruct ablative, traumatic, infective, and congenital defects. Autogenous grafts carry some viable cells but require ingrowth of adjacent vascular supply (primarily from periosteum and adjacent marrow) to promote successful healing and integration to the native bone. Data suggest that defect shape and size will determine appropriate reconstructive options, as volume and quality of necessary bone can determine the appropriate donor site. Segmental defects of the mandible are among the largest and most difficult grafting procedures performed in the maxillofacial region due to geometry, chin projection, and curved shape. Complications are commonly related to infection, dehiscence, or nonunion. Postoperative wound dehiscence is the most common complication that can result in loss of a portion or all of the graft.[89–92] While infection among both vascularized and nonvascularized groups range between 8% and 10%, overall complication rates for nonvascularized bone grafts may be as high as 69%. In a retrospective review of 47 maxillary reconstructions, Smolka and Lizuka[93] compared the outcomes and complications of nonvascularized bone grafts, microvascular soft tissue flaps combined with free bone grafts, and composite osteocutaneous microvascular flaps. Postoperative infection occurred in over half the cases of free bone grafts wrapped in vascularized soft tissue, while only 8% of osteocutaneous free flaps developed infection. Complete graft loss was noted in 25% and 16% of free bone grafts and osteocutaneous free flaps, respectively, mainly due to infection. Other complications included wound dehiscence and oroantral/oronasal fistula. One of the largest series of nonvascularized iliac crest bone grafts for segmental mandibular defects in 74 patients was reviewed by van Gemert et al.[94] While 76% of patients ultimately had a successful outcome, 43% of patients had postoperative complications. These complications were significantly associated with the site of the defect and the presence of intraoral communication. The authors concluded that nonvascularized iliac bone grafts for the mandible are best used for lateral defects and only with an extraoral approach. Pogrel has published that segmental mandibular defects less than 6 cm portray only a 20–25% complication rate with use of nonvascularized cortical grafts. When grafts greater than 6 cm are used the risk of failure increases significantly. Although a successful bony union rate of 40% was demonstrated for defects up to 14 cm, vascularized bone offers a more predictable and viable option and should be considered when possible.[95,96] A determination of morbidity based on defect characteristics (including presence of soft tissue coverage), donor site risk, and procedural length must be weighed for defects between 4 and 7 cm. Use of vascularized bone should be limited for defects under 4 cm due to established success with nonvascularized bone, unless a substantial amount of soft tissue is necessary.

For maxillary sinus grafts, postoperative complications are generally related to infection. When a sinus graft is jeopardized by infection, complete removal and healing for 6 weeks may be required to eliminate infection before regrafting.[97] Hematomas in the sinus cavity can occur due to the difficulty in controlling bone bleeding.[98] Patients with a preoperative history of sinusitis have a higher incidence of postoperative complications after sinus augmentation procedures including infections, dehiscence, and development of oralantral fistulas.[99,100] Soft tissue coverage for bone grafting is occasionally necessary and an assessment of appropriate coverage must be made prior to undertaking surgery. While locoregional flaps may be used for soft tissue coverage, they must be accounted for during the initial plan to allow for proper consent for the patient, given the known risks of each soft tissue coverage flap [random pattern mucosal finger flap, facial artery myomucosal (FAMM) flap, palatal rotation flap, anterior- and posterior-based tongue flap, buccal fat pad, temporoparietal galeal flap, superiorly based platysma flap, submental island flap, pectoralis major pedicled flap]. Microvascular soft tissue flaps can be used for coverage with known risks and complications of each flap.

Risks of Allografts and Xenografts

Allografts and xenografts have increasing use given their availability, low cost, lack of donor site morbidity, and sterile shelf-life. Many options are available for use with particulate cancellous, particulate cortical, and corticocancellous sheets being available. There have been some concerns with the risk of disease transmission, but with proper screening procedures and appropriate sterility assurance levels (below 10^{-6}), the chance of organism transmission overall is 1:1 million. Estimations for specific transmission such as HIV range between 1:1.6 million and 1:8 million and substantially lower when using demineralized formulations.[101–104] There are a multitude of techniques used to disinfect and sterilize off-the-shelf graft materials. These include physical debridement, ultrasonic washes, antimicrobial therapy, ethanol soaking, ethylene oxide, electron beam irradiation, and gamma irradiation. Based on the type of bone graft and the techniques employed by the distributer, a combination of these are used while trying to maintain beneficial properties of the graft.[102–104] Xenografts have their own concerns due to recent media concern over prion transmission and bovine spongiform encephalopathy. While no reports for transmission have occurred in the maxillofacial literature, a theoretical estimated risk has been calculated by groups, based on purification techniques. A worst-case scenario has listed the risk on the order of 1 in $10^{10.3}$ correlating to a virtually nonexistent transmission risk based on preparation and animal selection processes.[105,106]

Bone Morphogenetic Proteins

Recombinant bone morphogenetic protein-2 (rhBMP-2) has shown some promise for bony reconstruction, although the indications are still not completely defined at present. Perhaps the most concerning postoperative sequela associated with this treatment relates to the impressive swelling, which ensues after placement of the graft. The use of rhBMP-2 in cervical spine reconstruction has been associated with significant neck swelling and dysphagia in up to 27% of patients, sometimes resulting in prolonged hospital stay or readmission.[107,108] While the relevance for maxillofacial reconstruction is difficult to ascertain, similar concerns have been raised in the use of rhBMP-2 for segmental mandibular defects.[109] Another phenomenon unique to rhBMP-2 is ectopic bone formation.[110,111] This is likely due to intraoperative spilling of the reconstituted solution onto the surgical field around the defect being treated. The most serious consequence of ectopic bone would be ankylosis of the temoporomandibular joint if used around the condyle but to date this problem has not been reported.

Reconstruction of mandibular continuity defects using rhBMP-2 is currently being explored, although only small case series exist at this time. In 2008, Herford and Boyne reported their technique in 14 patients, which resulted in successful outcomes in all 14 patients.[112] Herford later reported on two cases of using rhBMP-2 with demineralized bone in the successful reconstruction of lateral segmental defects.[113] These articles both discuss the need for a technique that maintains space for the graft since the sponge carrier is soft and easily compressed under the soft tissue envelope. A separate series demonstrated successful outcomes using BMP-7 for segmental defects of the mandible in seven patients and a large peripheral ostectomy in three others with no reported complications. Others have not been as successful, as evidenced by Carter et al. in their series of five patients described in 2008. While three patients achieved union, two suffered from nonunion due to chronic infection and collapse of the soft tissue envelope resulting in graft loss.[114,115] Other complications of rhBMP-2 include hematoma, seroma, and bone resorption at the graft site.[111,116]

Specific Donor Site Morbidity and Complications

Autogenous bone reconstruction must take into account the possible complications and morbidity of the donor site. Each donor site has inherent advantages, limitations, and potential complications. For very small defects, intraoral sources are ideal. Extraoral donor sites by contrast imply higher morbidity and risk, but do offer greater amounts of reconstructive material.

Intraoral Donor Sites

Common intraoral sources of bone grafts include the mandibular ramus, symphysis, tuberosity, and coronoid process. A comparison of two sites in 50 patients by Misch suggested that the symphysis donor site is associated with more problems in postoperative healing compared to ramus grafts.[117] Wound dehiscence occurred in 3 of 28 patients who underwent grafting from the symphysis, while all ramus donor sites healed without wound breakdown. The author noted that only the vestibular incisions suffered from healing problems in the symphysis, while sulcular incisions healed with fewer problems. Postoperative neurosensory changes from intraoral donor sites are related to proximity of the long buccal nerve, inferior alveolar nerve, and mental nerve. Patients seem less likely to notice sensory changes in the buccal nerve distribution as compared to the lower lip.[117] Misch reported a 10% incidence of temporary mental nerve paresthesia after symphysis grafts, but all patients eventually recovered. In the same series, 29% of patients with symphysis grafts reported altered sensation to the lower incisors, which lasted up to 6 months. No patients who underwent ramus grafts demonstrated permanent postoperative changes along the inferior alveolar or long buccal nerve distribution, although other authors have reported low rates of temporary neurosensory changes.[118] Postoperative infection seems to be uncommon with intraoral donor sites. A 2009 review of 32 patients who underwent ramus grafts found only one site with a localized postoperative infection, which responded well to incision and drainage.[118] While not directly reported, coronoid bone grafts have inherent risks of trismus related to injury of the temporalis muscle, injury to the inferior alveolar and lingual nerves, and injury to the masseteric branch of the internal maxillary artery, which can cause profound acute blood loss. This latter risk is minimized by performing the osteotomy from medial to lateral. The tuberosity harvest site yields poor quality and limited quantity of bone that lead to early resorption of the graft. In addition, sinus exposure and associated sequelae or oral antral fistulas or sinus infections may occur. For these reasons the tuberosity is rarely used as a donor site.

Iliac Crest Harvest Site

The iliac crest is one of the most commonly used donor sites to reconstruct moderate to large bony defects. Both the anterior and posterior iliac crests are available for harvest. Gait disturbance and pain in the early postoperative period is considered normal sequelae of surgery that should resolve with time.[119–121] Gait disturbance has been attributed to muscle dissection of the gluteus, iliacas, and tensor fascia lata, particularly when block grafts are required. In contrast, when only cancellous bone is harvested this complication may be limited with careful technique. Although repositioning the patient intraoperatively is required to access the posterior crest, this location has gained the reputation of having less morbidity from gait disturbance, less pain, and fewer hematomas.[120,122] The need for repositioning the patient perioperatively carries its own risks of endotracheal tube displacement or occlusion, eyes or nose injury, and requires special attention to taping and padding. In a prospective study of 50 patients that compared the morbidity between the anterior and posterior approaches for iliac crest bone harvest, the authors preferred the posterior ilium due to the lower severity of pain and gait disturbance.[123]

Infection at this donor site is uncommon and usually minor. Resolution can often be obtained simply with local measures that may require removal of sutures and drainage through the incision site.[121,124,125] Postoperative hematomas may occur in up to 6% of cases and are generally minor as well.[121,122,126] Most are the result of blood oozing from the marrow, although the deep circumflex iliac artery and muscular perforators may also contribute to bleeding.[119] While some surgeons recommend the placement of drains,[119,127] this can usually be avoided with use of bone wax, oxidized cellulose, activated thrombin–gelatin matrix (Floseal®, Baxter, www.baxter.com; Surgiflo®, Ethicon, www.ethicon360.com), and meticulous hemostasis of the soft tissues. An exceedingly rare complication of retroperitoneal bleeding with patient death has been reported.[128] Hematoma formation in the posterior ilium may be minimized by postoperative bed rest in the supine position the first night after surgery. Seromas have been reported commonly as a complication and may be treated with aspiration and pressure dressing. If these conservative measures fail, seromas and hematomas may require a return to the operating room for formal evacuation.[129] Fractures of the iliac crest may occur after harvest of the anterior or posterior ilium. While this fracture may occur intraoperatively, postoperative fractures have been described secondary to sudden contraction of the lateral musculature along a weakened iliac crest.[130] Pelvic instability may also occur after posterior iliac crest harvest and is due to weakening of the sacroiliac crest ligaments.[131] Removal of a full thickness segment of anterior ilium has been associated with postoperative contour deformities of the hip.[126,132,133] This may be prevented by leaving the crest intact while harvesting bone only from the medial table when possible. Alternatively, trephination allows removal of deep cores of bone while maintaining the overall integrity of the ilium.

Postoperative paresthesia has been reported most commonly in the distribution of the lateral femoral cutaneous nerve (0–17%).[121,125,134,135] Injury to this nerve may be minimized by avoiding excessive traction and preserving 1 cm of bone at the anterior superior iliac spine. Other nerves at risk include the ilioinguinal, iliohypogastric, cluneal, sciatic, and subcostal nerves. A postoperative hernia may develop (0–0.8%) with poor reapproximation of muscular and fascial landmarks.[135–137] Postoperative ileus is considered extremely rare and has been described in a case report of two patients.[138] Careful dissection with protection of the periosteum along with detailed knowledge of the local anatomy should assist in avoidance of severe complications that usually are due to loss of orientation and aggressiveness.

Calvarial Bone Grafts

The calvarium is commonly used as a corticocancellous bone source for maxillofacial reconstruction. The donor site is easily included in the surgical field, and minimal dissection is required to reach bone. Grafts can be easily and quickly harvested from the calvarium for a wide range of purposes including nasal reconstruction, orbital reconstruction, and mandibular onlays, to name a few. While a fullthickness graft is possible, harvesting only the outer table of bone is generally the safest approach. Postoperative hematoma and seroma are the most common complications associated with calverial bone graft harvest and minimal pain has been reported.[139] Avoidance of hematoma may be minimized by ensuring hemostasis with bone wax or a scalp head wrap dressing. A review of 586 calvarial bone grafts observed five seromas and two intracranial hematomas for a 1% overall complication rate.[140] This report also highlights the potentially serious complication from calvarial bone harvesting in which inadvertent perforation of the inner cortical plate with dural tear or direct cerebral cortex injury can ensue. Neurologic complications, including postoperative hemiparesis, were reported although these were ultimately found to be temporary. Overall, inner table violation has been reported in the range of 0 to 13% resulting variably in subdural hematoma, cerebrospinal fluid leak, central nervous system infection, and sagittal sinus penetration. A number of surgical considerations are important to avoid this complication. First, the surgeon should consider the location of the graft carefully. Some have advocated grafting from the nondominant hemisphere to limit the extent of injury should complications occur. In addition, regardless of side, the overall thickness of calverial bone, which is variably based on the location of harvest, needs to be considered. The thickest and most desirable for grafting in the adult is generally located high on the parietal bone but at least 2 cm lateral to the midline to avoid the region of the sagittal sinus. Preoperative imaging with computed tomography (CT) scanning has been advocated by some surgeons but would generally not be required in the adult population. In children, cranial bone split procedures are generally not undertaken prior to 3 years of age, and at that point a CT scan to assure a diploic space may be warranted. At around 9 years of age, the parietal bone reaches a thickness of approximately 6 mm. Surgical techniques have been variably reported. For outer cortex grafts, carefully outlining the donor site to diploic bone followed by judicious beveling of a least one edge will allow for appropriate angulation of the osteotome for cortical separation. Surgeon preference regarding osteotomy size, shape, and thickness is likely secondary to meticulous technique.[139–143] Dural exposure without a tear is generally not a serious event, but dural coverage with pericranium or off-the-shelf dural substitutes is warranted as well as extended spectrum antibiotic coverage. Consideration for neurosurgical input is warranted, particularly when the complication results in dural tear requiring repair or frank injury to the intracranial contents.[140]

Postoperative donor site infections tend to be superficial and may resolve with drainage.[144] Progression to central nervous system infection is rare but may have devastating results. Delayed wound healing of the scalp is uncommon and was reported in only two cases of a series of 247 cranial bone harvests over a 6-year period.[142] Postoperative contour deformities of the skull tend to be minimal, although patients may be bothered when the defect is palpable.[142,145] These defects may be minimized by generous beveling of the defect edges after graft harvest.[140,146] Alternatively, the surgeon may place cranial bone shavings in the defect to augment the contour.[142]

Alopecia, scarring, or keloid formation along the incision line can occur, and there may be significant cosmetic complications associated with cranial bone graft harvest especially when these sequelae are visible. Care not to transect hair follicles, avoiding the use of hemostatic clips and electrocautery on the scalp flap, and placement of the incision with consideration to the hair receding along hair line, coupled with meticulous wound closure, will assist in minimizing occurrence of these potential complications.

Costochondral Grafts

Costochondral grafts are frequently employed for bony reconstruction of the face particularly when both bone and cartilage are needed. Postoperative complications include atelectasis, pneumonia, pneumothorax, and wound infection. Normal postoperative pain leads to splinting of the chest wall by the patient to decrease movement and further pain. An additional consideration for this pain occurs when the graft is harvested is from the left chest where pain can mimic the findings of acute chest pain from myocardial infarction. Surgeons should consider this carefully particularly in patients with higher risk for cardiac complications. This reduced inspiratory effort can promote atelectasis and pneumonia. A series of 300 patients who underwent rib harvesting noted pneumonia was the most common complication (eight patients) while persistent atelectasis occurred in two patients.[147] Postoperative respiratory difficulty is increased as the number of harvested ribs increases.[148] Since pain control plays a vital role in the

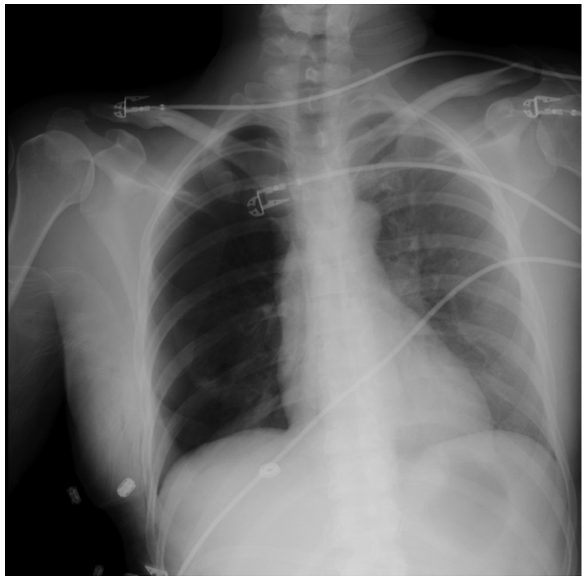

Fig. 13.1. Right pneumothorax following rib harvest.

postoperative respiratory recovery of these patients, the surgeon may consider an intercostal nerve block with a long-acting local anesthetic at the termination of the procedure.[149] Aggressive use of incentive spirometry and chest physiotherapy should be employed to minimize risk of postoperative respiratory sequelae that could progress to pneumonia.

Intraoperative pneumothorax is generally avoided with wide access and precise surgical technique. The complication is increased when multiple ribs are harvested in a single setting or when large portions of cartilage are removed. As an average, this complication occurs in approximately 5% of patients (Fig. 13.1). Care should be taken particularly when unwrapping the periosteum from the deep portions of the rib and when working in the area of the cartilage to avoid damage to the underlying tissues. Careful inspection of the surgical site should be undertaken after harvest is completed with underwater examination of the wound while the anesthesiologist applies positive pressure. Notation of any clinical tear or bubbles on positive pressure is indicative of pleural tear. Treatment of pleural tear depends on the size and extent of injury. Repair may be attempted over a small Foley or red Robinson catheter with evacuation of pleural air underwater prior to final closure. Muscle patches for larger tears may be helpful, and ultimately a decision for chest tube placement may need to be made. In addition, it should be recognized that a delayed pneumothorax may occur if sharp edges of the remaining cut ribs lacerates the pleura during respiration.[149] These remaining ends of cut ribs should be inspected and smoothed if necessary prior to closure. Regardless of intraoperative perception, a postoperative radiograph for evaluation of pneumothorax is indicated given that pneumothorax can be present despite the lack of corroborating intraoperative findings. Treatment of pneumothorax is dependent on size, symptoms, and patient-related factors.

Wound infections following rib harvest are fortunately rare and occur in fewer than 3% of cases.[132,150–152] Long-term pleuritic pain has been described[132] and may be attributed to scar formation that tethers the pleura to the chest wall. Chest scars occasionally become widened[133] and often heal with suture tracks.[132] These deformities may be minimized by placing adequate deep dermal sutures,[149] removing skin sutures early, and by placing incisions in lines of minimal tension such as the inframammary crease.

Intraoperative and postoperative complications at the recipient site with costochondral grafts deserve consideration. The current role of costochondral grafts tends to be in condylar reconstruction where rib and cartilage are used. Placement of the appropriate amount of cartilage has been debated, particularly in the growing child where some have suggested that the resulting mandibular growth potential, including the risk for excessive growth, is determined by the cartilaginous component. Though not studied prospectively, a 3-mm cartilaginous cap has generally been accepted to be adequate for reconstruction without risking the potential for excess growth or its accidental severance from the rib perioperatively. To avoid this latter complication, some have advocated maintaining a cuff of periosteum and pericondrium at the junction of these tissues. This technique may add to the durability of the costochondral junction but does increase the risk of pneumothorax.

Additional complications arise in the placement of the rib into the glenoid fossa and its ability to remain in place during the postoperative period. Intermaxillary fixation is employed to assist in joint stability during the healing process. In addition, some have described the use of wires or nonresorbable sutures suspended from the glenoid fossa or temporal region to the rib providing additional support. Immediate and long-term malocclusion is a complication attributed to intraoperative failure and the innate growth potential or lack thereof of the graft. Overall, patients should be prepared for the potential need of a period of occlusal elastic therapy to assist in train the musculature to the new joint characteristics.

Tibial Bone Grafts

Tibial bone has gained popularity due to the ability to harvest distant bone in an in-office setting with relatively low morbidity. Postoperative complications include delayed wound healing, infection, gait disturbance, fracture, and persistent pain or paresthesia. A review of 230 tibial bone grafts from the orthopedic literature revealed an overall complication rate of 1.3%.[153] Delayed wound healing may occur in the range of 0 to 4.5% of cases.[153–155] One review noted delayed wound healing in an obese patient who developed a seroma requiring surgical debridement and closure over a suction drain.[154] Ecchymosis is commonly reported although it resolves with time.[154,156] Pathologic fractures may occur at the donor site in up to 2.7% of cases.[153,157] Gait disturbance is usually short-lived and resolves within 10 days,[158] although ambulatory difficulty as long as 3 weeks after surgery has been reported.[155] Persistent pain at the donor site occurs in up to 5% of cases.[153,155] A series of 44 tibial bone grafts noted one patient with persistent postoperative joint pain due to surgical entry into the joint space during harvest, which can be prevented by avoiding bone excavation in the region of the tibial plateau.[154] Neurosensory disturbance may occur in up to 7.5% of cases, although the paresthesia tends to resolve within a few weeks.[156]

Pedicled Bone Flaps

A number of harvest sites are available for bone transfer with a pedicled blood supply. Calvarial bone as described above can be transferred with the blood supply from a temporoparietal fascia pedicled flap into the lateral maxilla, orbit, or lateral mandible region. Transfer of the fascia can allow for a larger bone graft to be harvested from the outer cranium;[159] however, the resultant bony and soft tissue defect can be more prominent following the reconstruction. In addition, there are additional risks associated with temporoparietal galeal harvest, such as alopecia, facial nerve injury, and trismus.[159–163]

A variety of other pedicled bone flaps have been described with similar risks and complications as their free bone graft counterparts. While they may provide a larger volume of bone due to the pedicled periosteal blood supply, their applications can be limited due to the amount of soft tissue bulk provided and the limitations in orientation. Such examples are costochondral rib grafts pedicled on pectoralis major muscle or latissimus dorsi muscle, scapula tip pedicled on latissimus dorsi, and clavicle pedicled on sternocleidomastoid.[164,165]

ADJUNCTS TO MICROVASCULAR BONE FLAPS

Fibula Myoossesous (Cutaneous) Flap

Vascularized fibula bone grafts are often required for reconstruction of larger composite or segmental defects. Preoperative considerations focus on the suitability of harvesting the peroneal vessels while maintaining adequate leg perfusion via the anterior and posterior tibial vessels. Although palpable dorsalis pedis and posterior tibial pulses have been recommended as reliable guides,[166] this is no guarantee that sacrifice of the peroneal artery is safe given the possibility of peripheral vascular disease and normal anatomic variants. Kim et al. reviewed 495 lower extremity angiograms and noted hypoplasia or the absence of anterior

Fig. 13.2. Right dominant peroneal artery.

tibial arteries in 4% of patients.[167] Hypoplasia or absence of posterior tibial arteries was noted in 2%. Peroneal arteria magna may occur when both the anterior and posterior tibial arteries are inadequate, resulting in only the peroneal artery supplying blood to the foot. Peroneal arteria magna is estimated to be present in up to 7% of the population (Fig. 13.2).[168,169] An absent peroneal artery occurs in 0.1 to 4.0% of the population. Importantly, normal pedal pulses are present in both peroneal arteria magna and with absent peroneal arteries.[170] Choice of preoperative lower extremity imaging is often based on surgeon preference and available services in the surgeon's practice environment. While arteriography is considered by many to be the gold standard, this is an invasive study that carries a 3–5% complication rate. Such problems include contrast allergy, renal failure, hematoma, aortic dissection, and arterial occlusion.[168] While the least invasive modality is color flow Doppler imaging, this study is highly technique-sensitive and requires an experienced technician.[171] Computed tomography angiography (CTA) and magnetic resonance angiography (MRA) have become standard preoperative modalities in many institutions. MRA has been suggested to be nearly equal to conventional angiography in the preoperative assessment of fibula harvest.[170] High sensitivity and positive predictive value have led some authors to utilize this modality routinely in all patients.[172] An additional advantage of MRA over conventional angiography is the ability to view the lower extremity vasculature in three dimensions.

Intraoperative complications in fibula free flap harvest are often related to maintaining the vascular integrity of the skin paddle. While septocutaneous perforators are more easily incorporated into the flap, musculocutaneous perforators are commonly encountered and require inclusion of a muscle cuff around the perforators. Schusterman et al. reported only 33% of skin paddles survived based on a septocutaneous supply, while survival rose to 93% with the inclusion of a muscle cuff.[173] Additional complications may occur if the vascular pedicle to the bone is injured. Extreme care should be taken when proximal dissection of the pedicle is undertaken, for injury to the pedicle at this level may render the flap unusable. Distally,

Fig. 13.3. Fibula flap with skin paddle harvest site in a diabetic patient that was closed primarily with wound breakdown and infection treated with debridement and wound dressings.

aggressive retraction of the osteotomized bone prior to pedicle division may cause separation of the blood supply to the distal bone. To avoid this scenario, some authors recommend removing a small segment of bone at the distal osteotomy.[174] This maneuver provides a window through which the pedicle may be accessed and divided prior to lateral mobilization of the fibula.

The fibula donor site occasionally suffers from delayed wound healing, orthopedic complications, contour or cosmetic deformities, and weak or diminished great toe function. Donor site wound healing difficulty is mainly related to the soft tissue component of a composite flap (Fig. 13.3). Incomplete skin graft healing can lead to tendon exposure requiring local wound care for several weeks as healing progresses. A suprafascial dissection under the skin paddle may provide a wound bed more amenable to skin grafting by minimizing the exposure of peroneus longus tendons. Similar wound healing problems may occur if primary closure is attempted after harvesting a skin paddle greater than 3 cm in width. The increased tension along the closure often leads to dehiscence and requires prolonged wound care. The temptation to close the soft tissue defect primarily to avoid a skin graft should be weighed carefully against the possibility of wound breakdown that results in the same cosmetic outcome as a skin graft. Compartment syndrome is fortunately a rare postoperative phenomenon that occurs in less than 1% of cases.[175] Orthopedic problems are related to the detachment of muscles from the fibula, injury to the peroneal nerve, or joint instability. The fibula serves to stabilize the ankle joint during function, which requires a 6- to 8-cm distal segment to remain in place. A 10-year follow-up study by Hidalgo[176] studied donor site morbidity of 20 patients who underwent fibula free flap harvest. Three of the 20 patients reported intermittent leg weakness or pain and only one was unable to perform rigorous activities such as jogging. One patient in the group was able to run a marathon without difficulty. Postoperative physical therapy should be routinely instituted to minimize functional disturbances.[177]

Deep Circumflex Iliac Artery Myoosseous (Cutaneous) Flap

The iliac crest free flap based on the deep circumflex iliac artery is an excellent source of bone for maxillofacial reconstruction. However, significant donor site morbidity precludes the use of this donor site as a first choice in many institutions. In contrast to nonvascularized corticocancellous grafts, the extent of dissection required for free tissue harvest significantly increases morbidity. Common postoperative problems include ambulatory difficulty, abdominal wall hernia, and chronic pain.[178] Hernias may form in up to 12% of patients.[179–181] Long-term abdominal wall weakness is most likely to develop into a hernia when a portion of the abdominal wall musculature is harvested. In these cases, a mesh repair of the defect is recommended at the time of harvest.[182] Two cases have been reported in the literature describing bowel obstruction due to herniation at the donor site requiring emergent surgery.[183] A 2008 review of 24 iliac crest flaps revealed only one donor site hematoma that upon exploration was found to be caused by oozing bone marrow.[184] A similar small study found two seromas in 12 patients, which resolved spontaneously.[185] No other early postoperative complications were noted in either study. A small number of patients report chronic pain or long-term neurosensory changes. Chronic pain may be related to the use of synthetic mesh for repair of the abdominal wall defect.[186] Rare complications reported in the literature include ureteral injury, pelvic instability, and tumor seeding.[179]

Radial Forearm Osteofasciocutaneous Flap

Preoperative evaluation of the radial forearm donor site must assess the ability of the ulnar circulation to maintain hand viability after sacrifice of the radial artery. Communication between the superficial and deep palmar arches must be present for safe harvest of the flap. This assessment is traditionally performed using the Allen test. The donor radial and ulnar arteries are occluded by the examiner's thumbs while the hand is exsanguinated by repeated fist clinching. The ulnar artery is released to reveal the extent of hand perfusion while the radial artery remains occluded. Although this test is easily performed at bedside, the assessment is subjective and variable amounts of pressure may be required to reliably occlude the radial artery. Additional error can be introduced if the donor hand is hyperextended. The reliability of the Allen test is well accepted, although some others recommend an objective Allen test using Doppler imaging and photoplethysmography. Nuckols et al. compared the traditional Allen test with an objective Doppler-assisted Allen test in 65 patients and noted an improved ability to detect vascular variations using the Doppler.[187] Notably, of the 25 patients found to have equivocal or poor subjective Allen tests, the Doppler exam revealed that 18 of these could safely undergo radial forearm harvest.

The radial forearm free flap is occasionally harvested as an osteocutaneous flap incorporating a segment of the radius. Fracture of the remaining radius is the most feared postoperative complication, occurring in up to 40% of cases.[188] Some authors recommend routine prophylactic plating across the radius defect to minimize the chance of fracture.[188–190] Others employ postoperative casting of the arm for 6–8 weeks or bone grafting the donor site, although these techniques seem to be utilized infrequently.[189] More common donor site problems include decreased pinch and grip strength, reduced sensation over the dorsum of the hand, delayed wound healing, and cosmetic deformities.[191–194] A retrospective review of 52 patients who underwent osteocutaneous radial forearm free flap harvest revealed a 7.7% rate of donor site complications.[190] These included one radius fracture and three cases of delayed wound healing with exposed tendons. The fracture occurred on postoperative day 3 despite prophylactic plating and was felt to be due to a loose screw. Reoperation and cast immobilization for 4 weeks was required.

Scapula Myoosseous (Cutaneous) Flap

The scapula is a versatile source of vascularized bone that can be tailored to complex defects. Postoperative donor site complications include hematoma, seroma, infection, wound breakdown, shoulder weakness, and chronic pain. While hematoma formation is likely minimized by the normal postoperative bed rest and sleeping supine, seroma formation is common after such extensive dissection of the back. Donor site problems in 36 patients were reviewed that revealed a 25% rate of persistent seroma.[195] Little long-term data exist regarding the functional compromise after harvesting the scapula. A 2009 publication reviewed 20 patients who underwent scapula harvest to assess shoulder function 1 and 6 months after surgery.[196] Compared with the nondonor arm, the study demonstrated limited mobility in the operated shoulder at 1 month with improvement at 6 months.

BONY RECONSTRUCTION

Distraction Osteogenesis

Distraction osteogenesis has become increasingly common in bony reconstruction as an alternative to standard grafting techniques, with the advantage to generate bone from adjacent sites. Transport disc distraction for segmental defects and alveolar distraction for atrophic ridges are specific examples. Difficulties and complications with distraction have tempered much of the initial enthusiasm with these techniques. While limitations do exist, many of the common complications can be avoided with careful presurgical planning and surgical precision.

The majority of complications relate to the distraction hardware, and the need for exposure through the skin or mucosa. While infection is uncommon, pin-track infections may occur secondary to the open wound, which must be maintained through mucosa or skin during the distraction phase. Because these openings allow drainage, local wound care and irrigation are usually all that are required. Mechanical device failure, instability, or breakage occurs uncommonly and is described as less than 6% for all types of distraction in two large case series.[197,198] In two retrospective case series of 37 and 45 patients who underwent alveolar distraction, only one case of a broken distractor was noted.[199,200] Other complications were reported as minor (up to 75% of cases), including soft tissue dehiscence (14% to 38%) with infections in 6% to 7%. Major complications included fracture of the basal bone and/or transport segment (8% to 17%).[199,200] Another review of 20 patients undergoing alveolar distraction revealed a 55% overall complication rate including fracture of the transport segment in one patient.[201] Other reported complications include paresthesia (14% to 28%), hematomas (4%), and postoperative bone defects at the site of the distractor.[199,200] Transport distraction is not as widely used with free flap techniques being at the forefront of treatment protocols; however, one series presented 28 patients of maxillary, mandibular, and skull defects with a failure rate of 21% through a variety of causes, including three patients (10%) who died of disease prior to completion of distraction: one patient had device failure with screw loosening on two occasions in an irradiated site, one patient developed early consolidation, and one patient with fulminant infection. Defects up to 80 mm were reported as being successfully distracted.[202] Other authors report small case series with custom fabricated distraction devices.[203] Additional complications arise when distraction does not result in a bony matrix adequate for healing. This is of particular importance in patients following radiation treatment, where some believe distraction may be of limited use and bone quality is poor; however, a small case series of six patients has shown beneficial results with only one failure (17%). There was soft tissue dehiscence over the distractor that was successfully treated conservatively in two patients.[204] Further evaluation of larger case series with both transport and alveolar distraction methods is needed as there is substantial variability of success comparing maxilla to mandible and anterior to posterior with supraperiosteal and subperiosteal methods used.

The most frequent complication for larger defects results from the inability to position the final bone matrix in the desired location. This complication may result from hardware failure itself or more commonly from the surgeon's inability to appropriately place the distraction device consistent with the desired vectors.[197,198,202,205–207] In order to overcome this limitation surgeons have employed computer modeling for accuracy[208] and devices that can be adjusted mid-distraction.[209] Computer-assisted surgery with surgical planning and modeling allows for the creation of templates, which will guide distractor placement in the operating room.[208,210,211] Still, care must be taken to assure that the templates accurately reflect the anatomy since many do not "lock in" to a single position. In addition, the bulky nature of the templates often requires additional surgical exposure, which should be weighed when considering their use.

Hyperbaric Oxygen

Hyperbaric oxygen therapy (HBO) has been recommended by some authors[212–217] in the treatment of osteoradionecrosis (ORN) in conjunction with surgical reconstruction. While the initial data seemed promising, the utility of HBO has been challenged by recent more strenuous scientific investigations.[218] Conceptually, it seems plausible that HBO therapy would promote angiogenesis and revascularization; however, Annane's randomized controlled trial evaluating the effectiveness of HBO compared to a control without HBO was halted prematurely due to a demonstration of worse outcomes in using HBO therapy.[218] Microvascular reconstruction with free tissue transfer makes possible the reconstruction of bone and soft tissue that is reliable even in the vascularly compromised wound setting and avoids the costs, potential complications, and current uncertainty of the utility of HBO therapy.[219–226] Complications from HBO include barotrauma to the middle ear and sinuses, myopia, and oxygen toxicity to the lungs or central nervous system.[227,228] An additional consideration is that one study has demonstrated trends toward increased complications with free tissue transfer after HBO therapy compared to patients who have never been exposed to this modality.[222] There continues to be substantial debate over the application of HBO for maxillofacial practitioners as highlighted by two recent articles.[229,230] Further randomized controlled trials are currently being undertaken.

Fixation Schemes

There is substantial variability in usage of reconstructive plates in bone reconstruction. Many have debated size and rigidity of plate with supporters of both miniplates and rigid reconstruction plates. Plating technology in North America and Europe has advanced substantially over the past 30 years with the advent of more biocompatible and rigid titanium alloys with improving success rates.[231] While it is known that the plate must offer rigidity for stabilizing the bone segments to allow for healing, fracture healing concepts and the identification of stress shielding have evolved significant changes in treatment philosophy.[232–234] If a plate is used and torque from muscle pull provides detrimental forces on the plate, it may proceed to weakening screws and result in failure of the graft with malunion or nonunion. Similarly, bending plates puts undue stress into the metal and with repetitive use in cases of malunion/nonunion, the plate can run the risk of fracture (Fig. 13.4). There are additional debates regarding the use of standard nonlocking screws versus threadlock screws for plate-to-bone adaptation, with many studies evaluating the advantages and disadvantages of each technique the fracture literature.[235–245]

When reconstructing continuity with grafts and flaps, both rigid and nonrigid/semirigid fixation has been employed and advocated in the literature. Despite the beneficial characteristics of locking plate systems through stabilization of the screw to the plate for spatial maintenance of the segments, the screw may not be fully engaging the bone. The locking mechanism, though, of the screw to the plate prevents identification of this problem intraoperatively, with subsequent risk of graft failure due to inadequate stabilization. In addition, absorption of all masticatory forces by the plate and stress shielding of the graft may prevent healing and union with the native mandible. Overall, complications from plates result from screw loosening (0.8% of locking screws), plate exposure (10–15% intraorally and extraorally), plate fracture (0–8%) with resultant acute and chronic infections (up to 30%), orocutaneous fistulas, and malunion/nonunion (0.7–8%) (Fig. 13.5).[238,246–259]

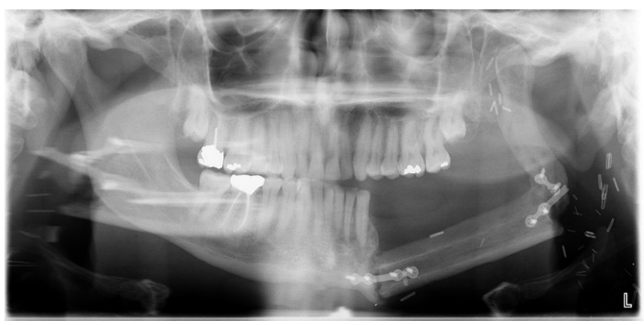

Fig. 13.4. Postoperative fibula flap with plate fracture and condylar dislocation.

Fig. 13.5. Plate exposure in an anterior mandibular defect reconstruction.

Newer resorbable techniques have been shown to be of use with certain clinical applications, especially in the pediatric population, where less rigidity is required for fixation.[260] Some authors have demonstrated success with resorbable screws used to fixate small bone grafts for preprosthetic applications, so as to obviate the need to retrieve screws when implant placement occurs.[261–265] Further evaluation is necessary to determine the overall success and indications for resorbable systems in bone reconstruction.

SPECIAL CONSIDERATIONS

Bone Necrosis and Infection

One of the most difficult situations to reconstruct is the exposure of bone without soft tissue coverage intraorally and/or extraorally. Chronic nonhealing wounds can be related to various factors resulting in nonviable bone. This could be from tissue loss from ballistic wounds or avulsive traumatic defects, infected segments from osteomyelitis or hardware failure, necrotic bone from failed bone reconstruction (vascularized and nonvascularized osseous tissues), osteoradionecrosis (ORN), osteonecrosis of the jaws (ONJ), etc. (Figs. 13.6 and 13.7). In any situation, the soft tissues are often chronically inflamed or infected and fibro tic.[220,225,226,266–274] The soft tissue envelope retracts to expose more bone and often a composite defect may result. Managing this complicated situation is onerous and must be dealt with in a strategic manner that considers both the hard tissue and soft tissue needs as well as the reality that native bone involvement may be more extensive than what is appreciated clinically or radiographically. Determining an intraoperative margin of normal bone is an important and often difficult task. In these cases, strong consideration should be given for the use of vascularized tissue transfer.

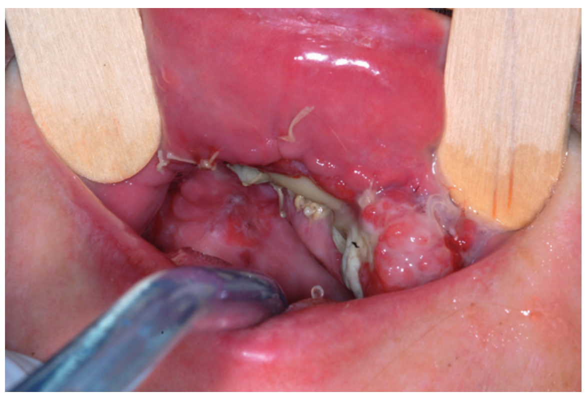

Fig. 13.6. Exposed necrotic fibula flap following maxillary reconstruction.

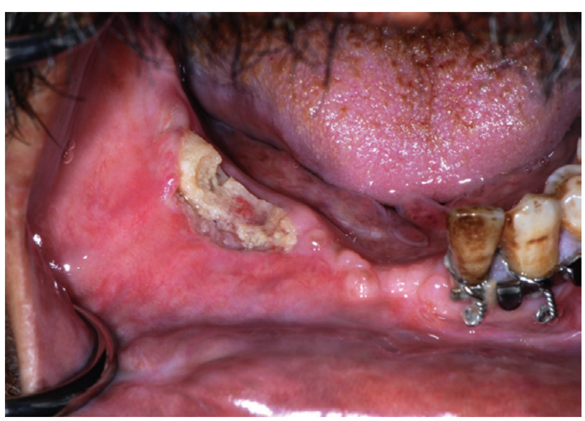

Fig. 13.7. Necrotic mandibular reconstruction with iliac crest bone graft.

Debridement Issues

While specific management for necrotic infected bone may vary based on etiology it is universally accepted that broad spectrum antibiotics are initiated and accordingly changed based on cultures and sensitivity results. Management with antibiotics and drainage of fluid collections as necessary will often settle the inflammatory process, and on occasion soft tissue healing and coverage may result. If persistent exposure of nonviable bone is evident, debridement may be necessary. Bone may be curetted and debrided to viable bleeding bone when possible with an attempt at preserving nerve function. If necessary, a load-bearing rigid reconstruction plate with locking screws can be applied to support segmental defects or weakened areas of the mandible.[89,275–277] In addition, maxillomandibular fixation can assist with segment positioning intraoperatively.[89]

Hardware Removal

Hardware can elicit a foreign body reaction when stability is not achieved and gross mobility of the segments with function occurs. Hardware failure can result from various causes: poor engagement of screws at the time of placement (locking and nonlocking), overheating of bone (drill hole preparation or osteotomy sites), lack of stability at time of placement, small thickness plates that cannot appropriately share or bear the functional load, poorly adapted plates with nonlocking screws, and use of nonbiocompatible materials.[238,258,259] The latter is less common due to rigorous standards imposed by FDA for product approval. It is routinely recommended that chronically exposed or failed hardware be removed once it is identified to allow for soft tissue healing and possible coverage. Assessment of healing and consolidation at the time of hardware removal is essential. Grafts that have consolidated and been replaced by an adequate quantity and quality of viable noninfected bone can tolerate hardware removal without difficulty. In contrast, early hardware removal may result in long-term failure if osseous healing has not occurred. Consideration should be given to replacement of hardware, external fixation, or intermaxillary fixation to stabilize bony segments when necessary. If infection is noted at the time of removal, appropriate cultures and antibiotic coverage are warranted.

RECIPIENT SITE CONSIDERATIONS IN RECONSTRUCTION

Based on numerous individual patient factors and the reconstructive needs, different strategies can be implemented. As mentioned earlier, the preoperative status of the patient and availability of donor sites is one level that will determine the reconstructive options. Poor functional status, nonoptimized cardiopulmonary disease and poor health may preclude the patient from being able to undergo a microvascular free tissue transfer due to the length of general anesthetic needed. Case selection is often dependent on operator and anesthesiologist skill and comfort level as well as facility capabilities for intraoperative and postoperative care; however, good surgical results can be achieved in elderly patients and those with comorbidities.[278–282] A poor nutritional status with hypoalbuminemia, poor glucose control, or high-dose steroid use may need to be optimized prior to considering an operation. Patients may require extensive preoperative nutrition using nasogastric tube feedings for both protein nutrition and to avoid further contamination of the wound. Though previously reviewed to some extent in our review of donor sites, several clinical scenarios deserve specific mention and/or reiteration.

Anterior Mandibular Defects

The anatomic complexity coupled with the multidirectional muscle pull on the anterior mandible make defects in this region difficult to manage. Reconstruction should establish bony continuity in order to prevent hardware failure and/or exposure. If mandibular continuity is not established, the lack of lip and tongue support will result in the characteristic "Andy Gump" deformity and associated catastrophic functional outcomes.[252,253,283,284] Mandibular continuity with the use of a reconstruction plate alone should be avoided or used as temporary measure for stability until final reconstruction is undertaken; nonvascularized block bone grafts are well documented to offer very good results when placed in noninflamed defects ideally measuring less than 6 cm. Defects greater than 6 cm are fraught with a greater number of complications and have a lower success rate. As tissues can be quite tense anteriorly, an extraoral approach will avoid oral contamination and can offer a more reliable result due to ease in achieving water tight closure of the tissues intraoperatively.[94] Particulate bone grafts in the anterior region[285–288] should be avoided for larger defects as the particulate matter does not offer any resistance to compression caused by the soft tissue envelope in this area.

Vascularized osseous, myoosseous, and osteocutaneous options provide very good results for reconstruction of larger osseous defects and composite defects of all sizes. It may remain difficult to achieve complete bony union in ORN or ONJ cases, but successful wound closure and restoration of function can be achieved. Various free flap options are available, and reconstruction is tailored to each patient based on operator skill and preference and site selection. While some may advocate vascularized bone transfer for all defect sizes, the morbidity related to donor site harvest and prolonged anesthetic time must be taken into account. For larger defects in the anterior mandible, vascularized bone has a significant advantage with capabilities of providing soft tissue coverage with a single flap.

Lateral Mandibular Defects

A greater number of reconstructive options exist for lateral mandibular defects. Nonvascularized block and particulate bone grafts or vascularized bone flaps can be employed, and the choice depends on the defect size to be reconstructed.[289–294]

Condylar Defects

The condyle should be preserved if at all possible. Even a small condylar stump can be maintained if at least two screws can be passed and secured to the reconstructed bone.[295] When the condyle must be removed, costochondral grafts have proven to be quite effective in maintaining articular function of the mandible.[296] Additionally, they can be attached to vascularized bone flaps to offer function, though many believe they are unnecessary, and direct placement of bone into the fossa can be effective, with or without the presence of an articular disk.[295,297–303] Both custom and stock condylar–fossa replacements are available and can reestablish the hinge function of the mandible.[296,304–307] Custom implants can be manufactured to reconstruct larger defects even to the angle of the mandible. While they can be quite effective and successful for 10 years and more, they can have their own complications and should never be placed into an inflamed tissue bed as they will invariably fail and require removal.[305–307] Long-term placement of stock condyle replacements without an imposing fossa implant must be avoided as they can erode and migrate into the cranial fossa over time.[308] If the condyle can be maintained with resection without compromising postoperative outcome,[303] then this should be the reconstructive option of choice.

Maxillary Defects

Patients can do well with maxillary defects even without reconstruction. Many tolerate obturation of anterior and posterior defects using a properly fitting prosthesis fabricated by a maxillofacial prosthodontist.[309–312] Speech and swallowing can be optimized with this technique if stability of the prosthesis is ensured. This can be difficult with large defects, anterior defects, and minimal remaining palatal support. Occasionally zygomatic implants can offer additional stability.[313] Soft tissue closure of oroantral and oronasal fistulas can be accomplished with locoregional soft tissue transfer (one or a combination of buccal advancement, buccal fat pad, palatal rotation or facial artery myomucosal soft tissue flaps)[314,315] or with soft tissue free flaps (radial forearm, rectus abdominis, parascapular).[316,317] For definitive fixed prosthetic rehabilitation, bone is necessary, and nonvascularized grafts can only be utilized if soft tissue coverage can be achieved. Larger defects warrant soft tissue transfer including myoosseous or osteocutaneous flaps.[272,317–320]

COMPUTER-ASSISTED SURGERY

In the process of planning and executing the surgical plans, emerging technology has given the surgeon of the 21st century the ability to preoperatively plan major bony reconstruction as well as the ability for intraoperative guidance that can assist the surgeon. It is our impression that the authors' adoption of this technology has significantly limited complications and optimized outcomes by simulating the surgical plan, including prefabrication of plates and surgical templates, which adds to the operative efficiency with a resulting decrease in operative times (thereby decreasing the risk of bleeding that might require transfusion, and the need for long-acting anesthetics), augmenting the surgical accuracy of bone placement for future implant reconstruction. With that in mind, consideration of computer-assisted surgery (CAS) is appropriate for discussion in this chapter, which has the ultimate goal of assisting surgeons in limiting the complications of major bony reconstruction.

Thanks to advances in CAS, such surgery will have an expanding role to play with bony maxillofacial reconstruction. The use of in-office cone beam computed tomography and the decreased intraoperative time achieved with rapid prototyping techniques such as stereolithography are very marketable to the head and neck surgeon, and they certainly have the potential to decrease complications.[321,322] There is an increasing use of cutting guides as well to optimize osteotomies for bone reconstruction that use free tissue transfer.[210,323–327]

With bone reconstruction, the goals are to recapitulate preoperative form so that function can follow. While perfect bone replacement does not guarantee complete restoration of function, every effort is made to support the soft tissues for rehabilitative purposes. It has recently become apparent that CAS has numerous advantages to the surgeon. While these highlight decreased operative time, preoperative planning and intraoperative use of prefabricated templates and navigation has aided the operator to foresee difficulties in advance and avoid them in a coordinated fashion.[210,322–336] This ultimately allows for improved predictable outcomes.

Software programs for preoperative planning are becoming ever more powerful; among these are Brainsuite®, Brainlab, www.brainlab.com; Mimics® and Surgicase®, Materialise, www.materialise.com; Voxim®, IVS technology GmbH, www.ivs-technology.de/en; InVivo, Anatomage, www.anatomage.com; Nobelguide, NobelBiocare, www.nobelbiocare.com; and 3dMDVultus, 3dMD, www.3dmd.com. The surgeon now has many options to reduce operating time and attempt more predictable results (Figs. 13.8–13.10).

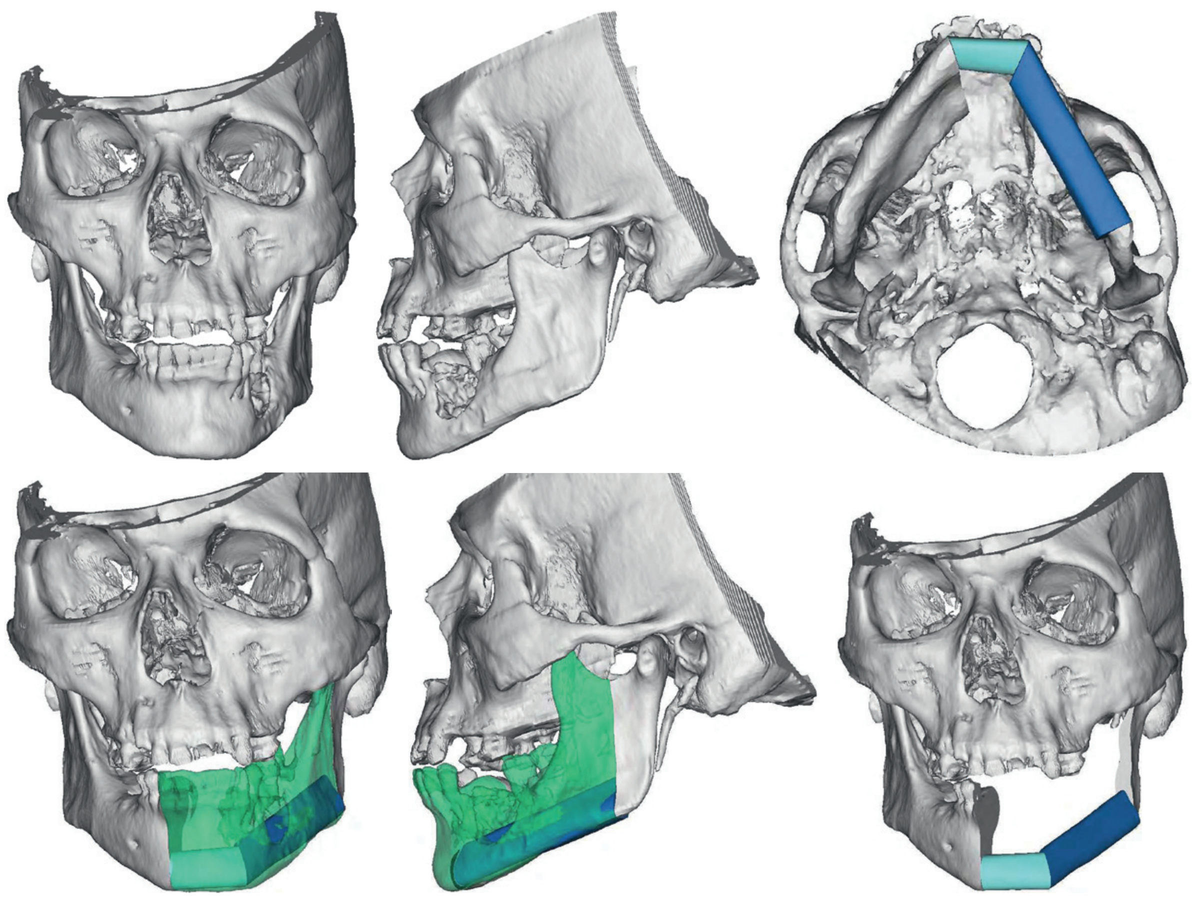

Fig. 13.8. Preoperative computer modeling of surgical plan for mandibular resection and reconstruction.

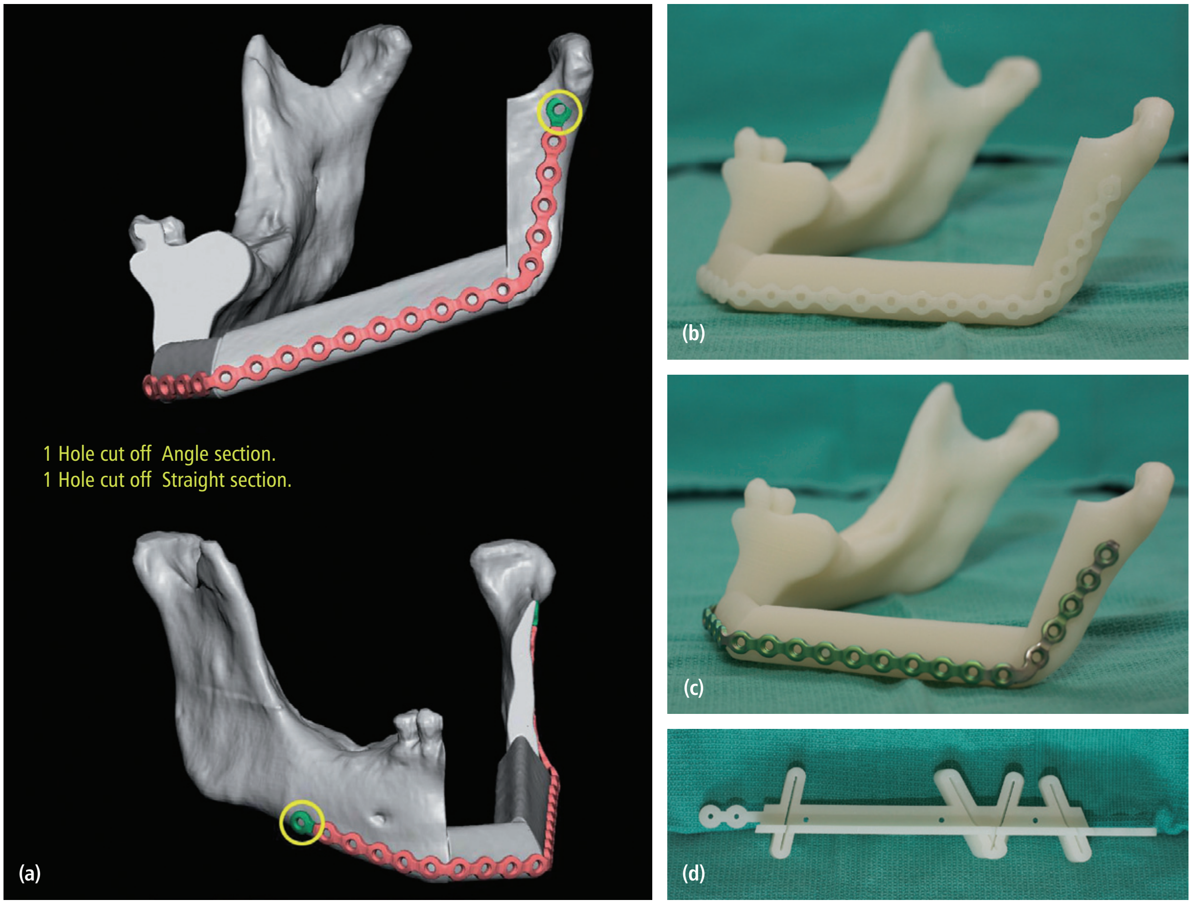

Fig. 13.9. Computer model (a) and prototype templates (b, c) with fibula cutting guide (d).

Unfortunately there is no single unified program for all modalities, but each has its own application. We can therefore separate CAS modalities into imaging, tactile models, preoperative planning, and intraoperative navigation.

Digital Imaging and Communications in Medicine

The ever-improving accuracy of imaging and a standardized image format [digital imaging and communications in medicine (DICOM)] has allowed computed tomography (CT) and magnetic resonance imaging (MRI) scans to be readily accessed and easily visualized by multiple viewers for interactive purposes. Technological advances afford improved clarity of images at decreased slice intervals for CT and MRI studies with ever-decreasing radiation doses due to improvement in scanner and sensor sensitivities.[337,338] Image scatter caused by radiodense objects in the visualized field (dental restorations, piercings, implants, and hardware), continues to be problematic for seamless image viewing. Software programs now offer image processing to clean up the data loss caused by artifact.[210,339] These programs offer advanced imaging strategies to allow the surgeon to identify key structures and landmarks. Not only can linear measurements and angles be identified as with cephalometry, but areas and volumes can also be appreciated.[339] Surgeons can appreciate anticipated defect size and plan appropriately in advance.[340] Three-dimensional (3D) image reconstruction can afford an appreciation of fracture displacement for trauma victims and extent of bone involvement for pathological cysts and tumors requiring resection. Key structures (nerves, vessels) can be identified along their entire course and margin involvement predicted for anatomical resection. Current studies are ongoing to predict area and volume airway measurements pre- and postoperatively for successful outcomes with surgery.

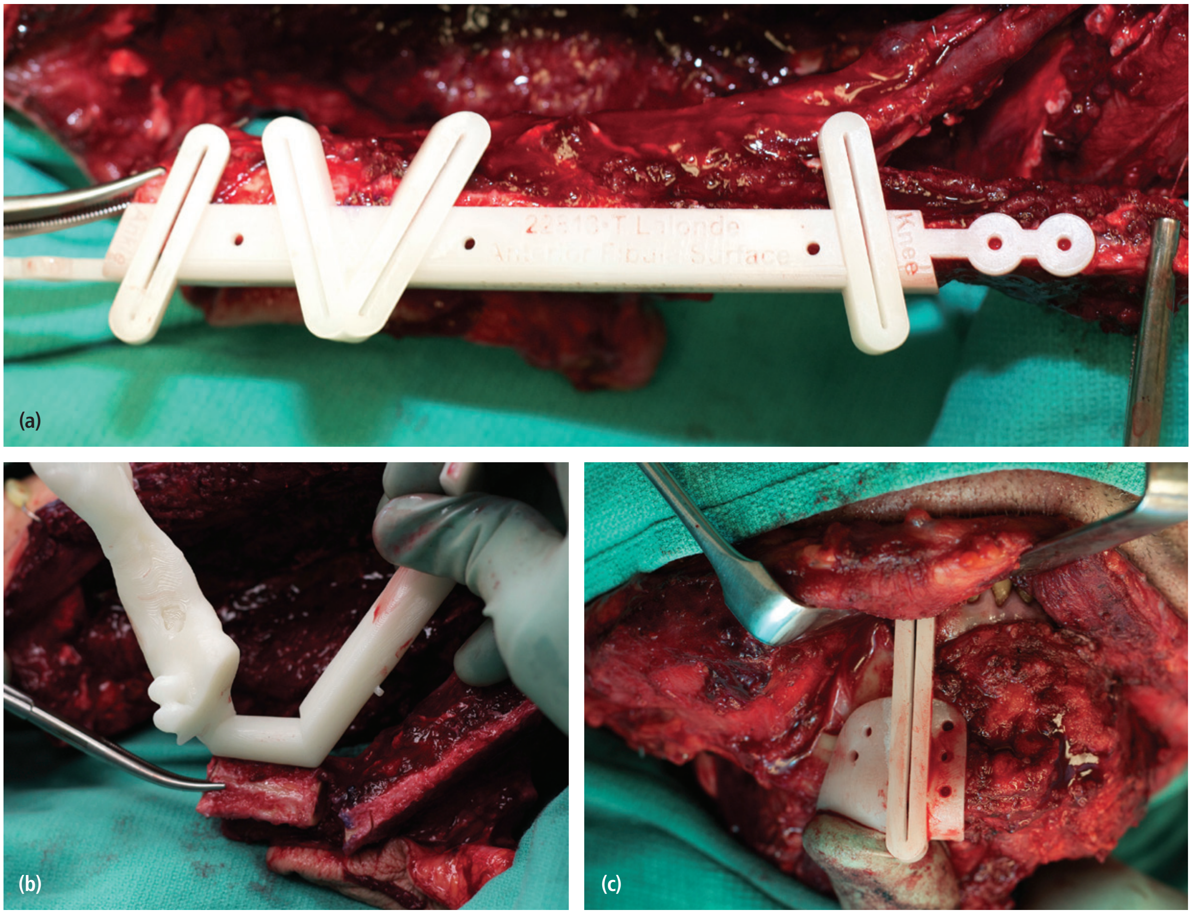

Fig. 13.10. Fibula (upper and lower left) and mandibular (lower right) cutting guides used intraoperatively.

Orbital Reconstruction

There is a large amount of supportive literature on the use of volumetric data records for orbital reconstruction. While it had been previously felt that orbital floor reconstruction could be undertaken with titanium mesh, porous polyethylene, resorbable polydioxanone (PDS) or calvarial bone, suboptimal results became evident for several reasons. These included improper access procedures causing difficult scarring of the lids (entropion and ectropion), but more importantly errors in repositioning the globe in the anteroposterior and superoinferior planes. This becomes an important factor in reconstructing an orbital floor or orbital rim that was lost due to trauma or pathological resection.[341–346] Metzger and Schmelzeisen have demonstrated through orbital volume analysis, that while humans are individually unique, the image data mapped and noted average values of specific orbital contours. This afforded the fabrication of two sizes (small and large) of precontoured titanium plates to three-dimensionally recreate orbital volume of males and females. These plates can be extremely useful in the vast majority of patients and greatly reduce operating time while minimizing volumetric problems after primary orbital reconstruction.[347–349] Synthes (www.synthes.com) is currently the only company that offers precontoured plates for this application.

Tactile Rapid-Prototyped Models

Conversion of DICOM files to a universal format (.stl) results in a loss-less reconstruction of surface anatomy to allow for fabrication of a representative tactile model. A model can be made to replicate, in a 1:1 fashion, the areas of interest. This then allows an operator several advantages preoperatively and intraoperatively. Anatomical definition of the model is limited by accuracy of the scan and can be lost if

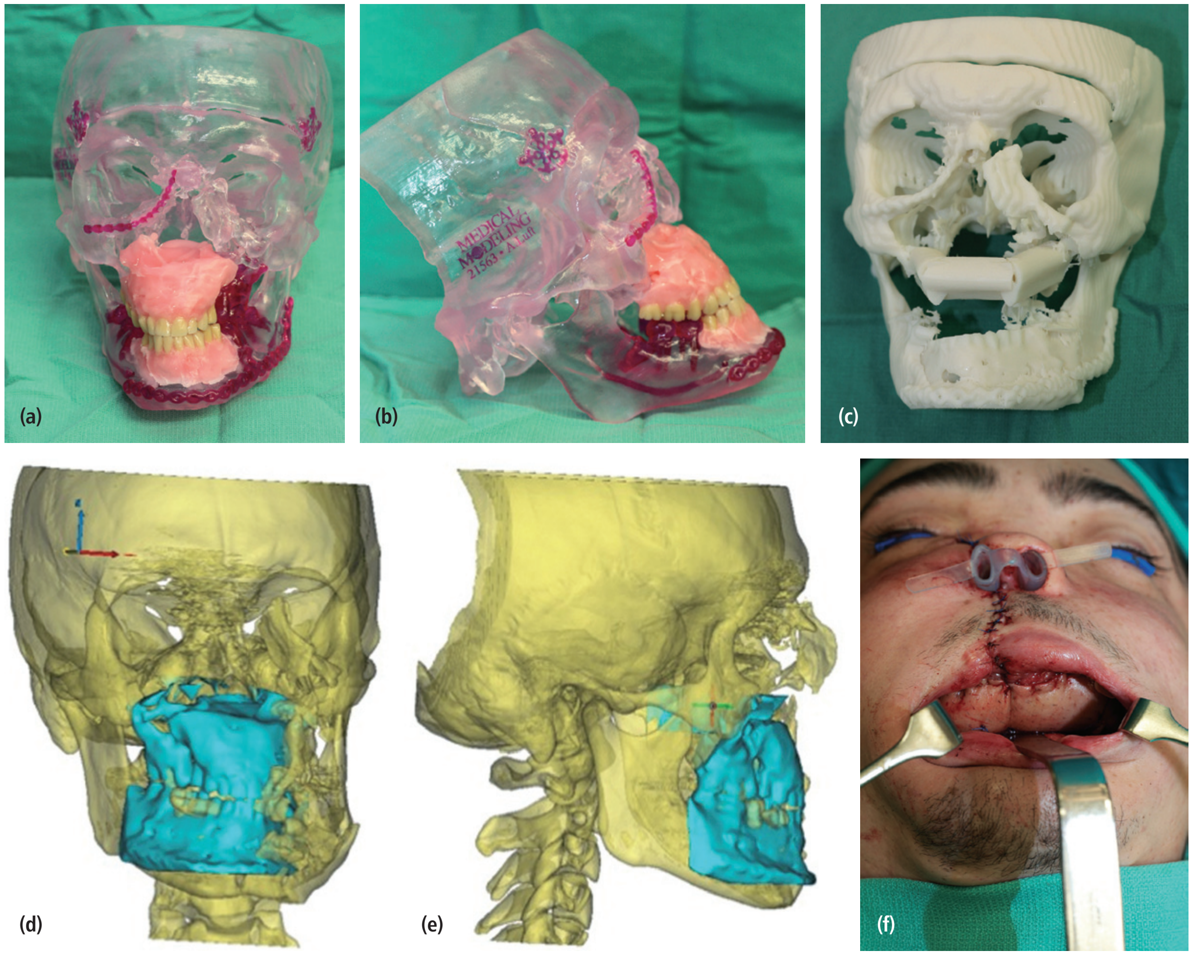

Fig. 13.11. Preoperative surgical plan with wax-up of anticipated implant supported prosthesis (upper right and middle); image fusion (lower right and middle). Preoperative computer-generated fibula placement (upper right); intraoperative placement (lower right).

image processing does not reduce the artifact prior to fabrication. In addition, regions of thin bone may appear as defects on the models due to the inherent limitations of prototyping technology unless the image is manipulated in advance. There are numerous prototyping techniques available including stereolithography, selective laser sintering, 3D printing, fused deposition modeling, and multijet printing. Each has its own advantages and can be readily accessible, but stereolithography and selective laser sintering can be more expensive. Stereolithography has the unique capability of being able to produce clear models with a second color to highlight predetermined areas of interest (teeth, nerves, vessels, tumors, or other unique structures) (Fig. 13.11). There is increasing familiarity of commercial stereolithographic models and services produced by companies such as Medical Modeling® (www.medicalmodeling.com); however, access to local prototyping facilities is becoming more widespread. The costs for rapid prototyping printers and materials are decreasing, and they are becoming more readily available to the mass market for both sterile and nonsterile use. Using the model, a surgeon can make preoperative measurements to determine bony osteotomies for pathological resection and similarly know the approximate dimensions for osseous reconstruction. Some surgeons even carry out the surgery on the models preoperatively. Titanium plates can be prebent to closely adapt to the underlying bone with free exposure and less work hardening the metal. This greatly reduces intraoperative time and can improve patient outcomes with reduction of further complications.[321,322,335,350,351] Custom temporomandibular joint (TMJ) implants are fabricated directly on the model as a wax-up prior to being cast in metal.[306] One can hypothesize that reconstruction plates in the future can be manufactured to the specific requirements of each individual patient; unfortunately their properties cannot be reliably reproduced for customized applications at this time.

Preoperative Software Planning

Some programs offer the capabilities of virtual surgery to allow a surgeon to have a better understanding of what will occur intraoperatively. Reconstructive procedures requiring manipulation of bone structures (orthognathic surgery, distraction osteogenesis, craniomaxillofacial surgery, trauma reconstruction and pathological resection) can all be planned to offer an avenue toward more predictable outcomes. This strategy is most commonly applied in both 2D and 3D for patient education and postoperative prediction with orthognathic surgery, although many more avenues are evolving. While soft tissues can be manipulated individually, normative algorithms have been established to offer the closest estimation of results.[352] It is impossible to accurately predict each individual patient and this must be relayed appropriately so they do not have unreasonable expectations. Contour deformity caused by pathological or developmental processes can undergo virtual planning to mimic the nonaffected side or create a normal template. A sterilizable tactile model can be created to prebend plates or shape bone grafts/flaps intraoperatively. Orthognathic surgery splints/wafers can be manufactured based on preoperative virtual plans that use rapid prototyping strategies and avoid the pitfalls of laboratory planning with articulators and their inherent inaccuracies. For various reconstructive procedures, preoperative planning can allow the surgeon to perform the osteotomies virtually and develop cutting guide templates through rapid prototyping strategies to be used on the maxilla or mandible. This can minimize damage to vital structures caused by wayward osteotomy cuts. In addition, bone grafts and osseous flaps can be shaped, contoured and positioned virtually to allow for an individually tailored reconstruction. Cutting guide templates with known predetermined measurements can also be prepared for predictable osteotomies, thereby decreasing operative time.[210,322–336] Lastly, distraction devices can be virtually planned to ensure proper orientation in all three planes of space. Rapid prototyping can create positioning templates for reliable placement, thereby avoiding early consolidation or premature binding of the devices.[210]

In all surgical fields there is an aim for functional reconstruction, and this is always imperative with maxillofacial surgery. As reconstruction of underlying bone has an impact with the surrounding teeth, comprehensive oral rehabilitation requires recapitulation of not only bone in an anatomical position but also placement of implants in a functional position to allow proper restoration of functional dentition. Using surgical planning and guidance, the underlying bone can be placed in a proper location and implants can be positioned where they will be in stable bone and properly oriented to accept functional loads. Using preoperative planning, multiple surgeries can be planned at once to offer optimal results and minimize future complications with other necessary procedures.

Navigation and Intraoperative Imaging

Computer-assisted surgery has drastically improved the outcomes related to neurosurgical procedures by offering identification of instrument positioning in 3D in real time (also known as 4D when performed real time). Thin-cut preoperative imaging is necessary to be able to register the patient accurately. Registration on hard tissues such as teeth and bone offers improved accuracy, although laser scanners and electromagnetic sensors are improving the accuracy of soft tissue measurements. Maxillofacial surgery has evolving applications for its use particularly in the fields of pathological resection and post-traumatic reconstruction. Many tumors can be accessed and resected with avoidance of critical vital structures by being able to identify their proximity and safe tissue planes. This is especially true for tumors that involve the skull base or the posterior naso- or oropharynx.[210,323,328,329,332,334] Osteotomy cuts can be performed with precision, and vessels and nerves can be avoided by using locating devices on the handpiece.[210,323] Orbital reconstruction procedures are optimized with navigation through identification of instruments and their proximity to the orbital nerve, as well as proper positioning of implants posteriorly. Preoperative planning software can also be used for reconstructive procedures to allow for accurate positioning of bone in complex cases and when other stable landmarks are lost. Intraoperative navigation using virtual plans can help with confirmation on bone placement minimizing critical errors.[323,336]

Intraoperative imaging has become standard of care for many orthopedic and vascular procedures while its use for maxillofacial procedures is in its infancy. The literature supports the use of intraoperative CT as a quality assurance measure to identify correct bone positioning in post-traumatic reconstruction.[353,354] More predictable outcomes are noted for orbital floor reconstruction and zygoma repositioning, while further procedure applications are continuing to evolve.

Computer-Assisted Surgery Complications

It should be recognized that while assisting to avoid complications, the technology described in this section does innately have its own potential set of complications that the surgeon should recognize. Templates can provide the surgeon with some difficulties intraoperatively despite their increasing use. In an ideal situation, guides can be used to reposition bone reconstructive segments, but on occasion there may be bony interferences that may limit the perfect adaptation of the graft/flap. An astute surgeon must be cognizant that they be used only as guides and if intraoperative judgment involves any concerns, appropriate measures must be taken to ensure an optimal result (whether it relates to following the template/guide or surgical judgment). For instance, there are guides for osteotomizing fibula flap segments but these may not allow for perfect adaptation of the flap or create unwarranted gaps when positioned into the donor site with a prebent plate. Prebending a plate to a rapid prototyped model is dependent on the accuracy of the scan, the similarity in tumor size as compared to when the scan was first obtained, and the bone graft shape to be able to closely adapt to the plate.[355] In the end, computer guidance can significantly augment surgical technique but should never completely replace clinical judgment.

CONCLUSIONS

It has been said that the best way to manage complications is to avoid them. Considerations that have to be addressed, and which are among those that need be taken into account for each patient, include patient comorbidities, availability of donor sites, body habitus, defect size and location, defect type (bone vs. composite), and recipient site condition. In addition, frank discussion with patients is important as a part of informed consent with the realization that a number of approaches may be feasible, each with specific risks and benefits particular to the patient. Allowing patients to be involved in the decision process is important when a number of options may ultimately lead to similar results. Computer technologies offer one new avenue to attempt to limit a number of the potential complications of bony reconstruction.

There are ample data from the literature in other surgical specialties to support the fact that complications arise from a number of avoidable and unavoidable sources. In addition, the complication rate of each surgeon, surgery, and patient will be unique. Surgeons should utilize procedures they can perform competently in order to optimize the outcome for each patient and monitor their complications in a way that allows for optimization of their techniques.

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