REVIEW ARTICLE

Oral and Maxillofacial Surgery Advances in Implant Dentistry

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Today, dental implants are synonymous with osseointegration. The concept of osseointegration and its clinical application have positively impacted dentistry and revolutionized the ability to reconstruct the dentition and the craniofacial complex. The ability of the surgeon to precisely place bone-anchoring devices to support prostheses via osseointegration has markedly influenced the approach to reconstruction. Treatment planning, clinical procedures, laboratory techniques, material science, and biologic science have all been influenced by the observations and persistence of scientists and clinicians such as Brånemark.[1]

Oral and maxillofacial surgery has been both a participant in the development of clinical procedures aimed at capitalizing on the concept of osseointegration, as well as the beneficiary of expanding the scope of practice. Defects of the entire craniofacial complex, including esthetic and functional problems, can now be addressed much more predictably and completely than ever before. Osseointegration technologies have led to improved methods of restoring the dental complex through hard and soft tissue grafting and utilization of distant support sites (ie, zygoma and pterygoid plates) to provide solid support for prostheses. Additionally, anchorage can be provided for orthodontic tooth movement for both routine and difficult clinical situations. The bone-anchoring that is achieved with osseointegration has further stimulated the reconstructive surgeon to develop techniques for correction of severe atrophy, ablative procedures, and continuity defects that truly allow restoration of form, function, and esthetics for patients. In this context, an attempt to explore some of the important advances that have come about as a result of development of the concept of osseointegration has been undertaken.

BONE GRAFT AUGMENTATION

Bone loss in the dental complex is usually associated with dental disease and tooth loss, but may also be the result of traumatic injuries, developmental defects, and ablative procedures used to treat pathologic entities. A major challenge the clinician faces in restoring the lost dentition or facial structure is insufficient bone. In the dental complex, alveolar bone is critical for the fabrication and stabilization of prostheses, both conventional and implant-supported. In the normal progression following tooth extraction the alveolar bone is lost at a rapid rate during the first year. This atrophy is progressive and irreversible.[2] Alveolar bone loss is also seen with advanced periodontal disease, sometimes creating a major osseous deficiency. The restoration of bone loss, whatever the etiology, has significantly improved since the introduction of the osseointegration concept. Through the development of predictable implant technology, clinicians have expanded techniques to replace severely compromised anatomic structures and have provided skeletal anchorage for a dental prosthesis using osseointegrated endosseous implants.[3] This technology allows dental rehabilitation with a bone-anchored fixed prosthesis, rather than a soft tissue mucoperiosteal-supported removable prosthesis, and is superior in function, longevity, esthetics, and patient satisfaction.[4]

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In 1980, Breine and Brånemark were the first to describe onlay composite bone grafts for reconstruction of the compromised severely atrophic edentulous arch (maxilla/mandible).[5] They used autogenous, corticocancellous block tibial bone grafts that were secured to the residual resorbed arch with commercially pure titanium threaded endosseous implants. The original technique was a 2-stage procedure. At stage I, the proximal tibia was exposed, the graft was outlined with osseous cuts through the cortical bone, the implants were placed, and the soft tissues were closed. At stage II, the site was reentered, and the graft containing the implants was transferred to the atrophic arch and secured to the residual ridge with additional implants. Because the rate of survival for the implants used to secure the graft to the residual ridge was higher (50%) than that for the 2-stage implants placed in the tibia (42%), Brånemark modified the technique and used the lateral anterior iliac crest in a 1-stage reconstruction.[4,5] This modification employed a template to outline the graft shape on the lateral surface of the ilium. This resulted in a U-shaped monocorticocancellous block graft, which was transferred to the resorbed arch (maxilla/mandible) and secured with implants in a 1-stage procedure.[1,4] Subsequent modification included a 1-stage graft technique utilizing the anterior medial rather than anterior lateral iliac crest,[6] which provided a more anatomically desirable concave contour on the cortical surface which interfaced with the convex resorbed residual alveolar and palatal bone. This modified donor site technique also reduced potential surgical morbidity.[4,6,7] Others have duplicated this technique, and some have employed the posterior iliac crest (lateral harvest) to reduce donor site morbidity and increase the amount of available bone.[8]

One of the problems seen with the 1-stage approach has been unpredictable resorption of the graft during the initial consolidation, which at times results in significant vertical bone loss and implant thread exposure. Verhoeven et al reported 30% resorption of mandibular bone grafts after 1 year and 36% after 3 years.[9] This group evaluated 6 other studies, including onlay grafts, sandwich osteotomies, and onlay grafts plus hydroxyapatite augmentation and concluded that significant resorption is seen in the first year after bone grafting and can continue for up to 3 years. However, the resorption rate generally decreases to 0.1 or 0.2 mm per year after the onset of implant loading. Strategies to minimize early loss include prevention of loading the graft by dentures and/or function during initial bone healing, and loading the implants at 5 to 6 months to stimulate bone repair. Other modifications include the maxillary Le Fort I downgraft procedure with immediate placement of implants.[3,10–14]

Collins further applied autologous onlay grafting principles to reconstruction in conjunction with dental implants to improve the technical application. These included autogenous inlay grafts (for a single tooth), veneer grafts (to augment a thin ridge), saddle grafts (to provide both height and width), and split grafts (1 veneer on each side of the ridge). Collins further developed 9 requirements for successful onlay grafting with implants, which are valid and worthy of discussion. These are:

- Presurgical/prosthetic work-up to determine the desired definitive prosthesis. This will allow fabrication of a surgical splint, identification of the area of augmentation, and direction for the surgeon to provide an adequate site for precise implant placement.
- Anatomic replacement. Onlay grafts should come as close as possible to replacing alveolar bone and adnexal basal bone.
- Intimate interfacial mortising. The graft and host bed interface should be adjusted for complete contact. Dead space should be eliminated.
- Rigid fixation. This is essential to successful onlay grafting. The use of titanium screws and 2-point fixation is recommended to secure the graft after intimate contact between the graft and host is achieved. Without rigid fixation, varying degrees of resorption or infection will result, leading to graft failure.
- Solid graft anchorage in native bone. If implants are to be placed immediately in an onlay graft, solid anchorage of the implant in host bone is required. At least 3 to 4 mm of host bone must be engaged by the implants.
- Minimum 1.5 mm thickness of graft bone covering the implant. If such minimal coverage is not accomplished, graft resorption and subsequent exposure of the implant surface can occur.
- Flap closure without tension. The flap should drape the graft loosely, with an approximated margin prior to suturing the wound edges, which should be slightly everted.
- Provisional restoration without pressure. Pressure on grafts or transmucosal loading of implants within grafts invariably causes shrinkage of the graft and may cause loosening of the implants. Provisional or definitive removable prostheses should not touch the grafted site in any way.
- Reasonable expectations. Patients should be carefully selected and be thoroughly informed.[14]

Bone Grafting Concepts

Several basic concepts in bone grafting should be mentioned. The importance of gentle bone harvesting has been well-documented by Albrektsson,[15] who demonstrated early revascularization and bone remodeling in minimally traumatized bone grafts. It is important for the surgeon to understand the 3 types of autologous bone graft healing mechanisms. These include bone induction, bone conduction, and transfer osteogenesis. All 3 mechanisms potentially occur simultaneously in the same grafted site, depending on the status (fresh) and the type (cortical or cancellous) of the graft and the ability of the recipient site to provide nutrition, rapid revascularization, and cellular viability (periosteal and endosteal). The importance of this concept is much greater than is generally appreciated.[4]

The harvest of bone should be performed in a manner that controls heat production and maintains cellular viability, especially in the cellular-rich cancellous portion of the graft. The graft should be transplanted to the recipient site as soon as practical and should be stored in a cool, moist environment if there is delay between harvest and transplantation. This is particularly important in large defects and in compromised recipient sites. Maintenance of cellular viability at the recipient site is crucial for enhancing healing by bone induction that is needed for predictable success of autologous bone grafts, either free or vascularized.[4] At the recipient site, it is important for the surgeon to recognize factors that may potentially enhance bone healing. These include: *(1)* proper incision and flap design to avoid extensive surgical undermining, because this may reduce feeder vessels from the skin or overlying mucosa and subsequent vascularity to the wound edge and graft coverage; *(2)* conservative use of cautery; *(3)* conservative periosteal reflection in mandibular discontinuities because the residual mandibular blood supply is primarily from the enveloping periosteum; *(4)* avoidance of heat trauma (overheating) to the residual bone from cautery and high-speed burs; *(5)* use of an aseptic technique; *(6)* rigid skeletal fixation of corticocancellous block grafts; *(7)* watertight, everted, tension-free closure; and *(8)* meticulous hemostasis and elimination of dead space.[16]

Autologous grafts may also successfully be combined with allogeneic bone and alloplastic materials such as hydroxyapatite or calcium phosphate. Bone substitutes have most frequently been used in conjunction with regeneration technologies based on the principles of guided tissue regeneration using a barrier membrane. Guided tissue regeneration was developed to regenerate periodontal tissues and can be also applied to bone augmentation, either prior to implant placement or in conjunction with implant placement. These principles dictate that a membrane or physical barrier be positioned in the wound in such a way that it separates the overlying gingival connective tissue from the underlying implant or osseous defects, creating a space in which the desirable cells can then migrate. The principle of creating a secluded space is basic to this concept. The work of Buser et al[17] in site preparation using the principles of guided tissue regeneration has significantly advanced the science of implant dentistry. Buser created ideal sites by using guided tissue regeneration principles and encouraged adequate preparation before implants were placed. Today, with the advent of resorbable membranes, these principles are used on a daily basis by almost any surgeon who deals with less-than-ideal osseous conditions.

Maxillary Sinus Grafting

The first use of bone grafting to the maxillary sinus to increase depth and bulk of osseous tissue for prosthetic reasons was presented in the 1960s by Boyne.[18] He performed this procedure to subsequently allow tuberosity reduction in cases of insufficient interarch space in the molar region. Boyne employed a Caldwell-Luc opening in the maxillary sinus and elevated the sinus membrane. An autogenous particulate cancelleous bone and marrow graft was placed in the sinus floor. Approximately 3 months later, the tuberosity could be reduced without exposure of the sinus. During the late 1970s, grafting of the maxillary sinus was performed on a patient with a pneumatized sinus to provide support for a blade implant, which was placed 3 months after grafting. Tatum was the first to become involved with antral grafting in conjunction with metallic implants and lectured extensively on the subject.[19] In 1980, Boyne and James published the first report of the use of bone grafting to the maxillary sinus to allow placement of metallic implants.[20]

With the advent of osseintegration and the development of onlay bone grafting, various practitioners developed different surgical techniques to allow elevation of the sinus membrane and graft placement.[18] Three anatomic locations have been described for performing the maxillary sinus floor graft:

- The classic Caldwell-Luc opening located just anterior to the zygomatic buttress and above the apices of the premolar and molar teeth[18]
- The midmaxillary entrance, between the crest of the alveolar ridge and the zygomatic buttress[18,21]
- A low position along the anterior surface of the maxilla, practically at the level of the existing alveolar ridge[20]

Summers described a new approach to grafting the floor of the maxillary sinus using a series of increasingly wide round osteotomes, which allowed site preparation for the implant while also expanding the apical portion of the alveolus into the sinus.[22] If this is performed in a controlled, gentle manner, the sinus membrane is maintained intact. Bone then forms beneath the elevated membrane, and 3 to 4 mm of floor height is effectively gained. This technique has been further developed to allow the placement of various graft materials through the osteotomy site, thus combining the floor infracture with a graft. The concept of tenting up the membrane in either the sinus floor or nasal floor, however, was first described by Brånemark.[1]

To study the entire subject of maxillary sinus floor grafting, a consensus conference was organized under the auspices of the Academy of Osseointegration to determine the efficacy and safety of sinus bone-grafting procedures.[23] It was held in Wellesley, Massachusetts, in November 1996. This conference examined several variables that influence implant survival in the grafted sinus. The data presented failed to demonstrate a clear difference in the survival of implants placed at the time of grafting and implants placed after a period of graft healing. Implants with a rough surface demonstrated better survival than smooth-surface implants. Hydroxyapatite-coated implants performed better than plasma-sprayed implants. Block and particulate autologous bone grafts performed well, with no significant difference in implant survival rates.[24] A recent review of material choices for sinus augmentation[24] concluded that autogenous bone remains the gold standard because it is osteoinductive, osteoconductive, and contains osteoblast and osteoprogenitor cells. Although other materials can be used to expand the volume of autologous bone, no determination of the success of these materials is possible because current studies have too many uncontrolled variables to permit direct comparison of the results.[24]

IMPLANTS IN COMPROMISED AND IRRADIATED TISSUE

Two of the more difficult reconstructive and prosthetic rehabilitation conditions currently faced by endosseous implant teams are the care of patients with distorted anatomy and patients whose oral regions have been treated with therapeutic radiation for malignant disease. In these situations, distorted anatomy makes the fabrication of stable, esthetic, and functional restorations extremely difficult. In patients who have received radiation therapy, nonstable tissue-supported prostheses are at risk for causing mucosal ulceration, bone exposure, and, ultimately, osteoradionecrosis. This problem is compounded by the lack of and poor quality of saliva, where the absence of good oral lubrication further heightens the potential for soft tissue injury.

Avulsive injuries and ablative surgery for both aggressive benign and malignant disease, even when well-reconstructed, leave anatomy that provides no effective means of stabilizing a prosthesis. For such patients, implant-stabilized or, preferably, implant-supported restorations have become the ultimate goal. Newer reconstructive techniques and innovative utilization of endosseous implants, along with a revival of older preprosthetic surgical procedures, have helped surgeons and prosthodontists to achieve these goals.

Newer reconstructive techniques currently include pedicled or free microvascular flaps, which transfer both bone and soft tissue to the compromised oral area. These include such procedures as pedicled pectoralis major, sternocleidomastoid, or scapular flaps, in which the transferred bone and soft tissue retain their original blood supply through a soft tissue pedicle. They also include free flaps from the radius, the iliac crest, and the fibula. In the latter procedures, both bone and soft tissue are transferred to the oral regions from the donor site, and the feeding vessels are anastomosed to arteriovenous areas in the neck. These procedures are of particular value when the area being treated is deficient in both soft tissue and bone and when the area has a compromised blood supply as a result of trauma, surgery, or radiation therapy. Endosseous implants can be placed into grafts of this type, either immediately at the time of tissue transfer or secondarily after consolidation and remodeling of the graft have occurred. The authors' preference has been to place the implants secondarily, 4 to 6 months after grafting. This allows careful planning of the most ideal implant position and angulation for the ultimate prosthetic reconstruction with the prosthodontist. It also allows time to "fine tune" the grafted site with vestibuloplasties or other soft tissue surgical procedures to provide better implant emergence into the oral cavity.

Older, more predictable techniques, newly revised in this era of endosseous implants, include free bone graft augmentation of atrophic edentulous areas in the maxilla or mandible or for reconstruction of continuity defects in either arch. The success of these free grafts is dependent on several factors, the most important of which are the presence in the recipient site of adequate soft tissue to

fully cover the graft with a tension-free soft tissue repair, and tissue with adequate vascularity to maintain graft viability throughout healing and consolidation. The usual donor sites for free osseous grafts to the maxillofacial region are the iliac crest, both anterior and posterior, or the temporal bone in the cranium. Once thought to be unpredictable because of uncontrolled resorption over the 2-year period following their placement, free grafts of this type are now more predictable because they can be rigidly fixed to the recipient site with titanium bone screws and miniplates. Rigid fixation prevents micromovement of the graft, which was common when grafts were stabilized with transosseous wires alone. Micromovement contributed to graft exposure, graft resorption, and, frequently, graft loss if there was a soft tissue breakdown along the intraoral incision line.

With the placement of free iliac or cranial bone grafts in the oral cavity, endosseous implants can also be placed either simultaneously with the grafting procedure or secondarily. The advantages of immediate implant placement include using the implants to help stabilize the graft to the host bone, which promotes graft survival. Another theoretical advantage is that immediate implant placement with the graft speeds up the patient's treatment because secondary surgery is not needed to place the implants. Once again, however, the authors' preference has been to graft first, to allow a 4- to 6-month period for graft consolidation and remodeling, and to place implants secondarily. By waiting to secondarily place the implants, their location and angulation can be optimized for ideal prosthetic restoration. In 4 to 6 months, the graft recontours, the overlying soft tissues can be modified to improve the implant sites, and the prosthodontist has the opportunity to develop surgical guiding templates to help optimize the location where the implants are ultimately placed. Implant success rates over the long term, in both free and pedicled grafts, should be 85% or higher, especially if the implants are placed secondarily.

Patients who have received radiation therapy for the treatment of malignant head and neck tumors may present the ultimate challenge to the implant team. These individuals not only have significant anatomic defects as a result of ablative surgery, but they also have a vastly compromised blood supply to the affected area secondary to radiation therapy. Most of these patients have received 6,000 cGy or higher doses of megavoltage radiation, the results of which are small-vessel endarteritis and obstruction. Radiation-induced changes are progressive over time and are not reversible.

Fortunately, more modern oncologic surgical approaches to malignant disease in the head and neck include more aggressive reconstruction of the surgical defect, either as an immediate or delayed procedure. Once again, these reconstructive procedures include pedicled, free microvascular, or free autologous bone grafts selected by the reconstructive surgeon based on the defect created by the oncologic surgery. These reconstructive procedures help improve maxillary and mandibular continuity, facial form and function, and the patient's ability to speak, eat, and function in modern society. For such patients, the ability to place endosseous implants and the timing of implant placement are critical to the success of their rehabilitation.

The majority of head and neck oncology patients will receive postoperative tumoricidal radiation therapy. Even in immediately reconstructed patients, this makes prosthetic rehabilitation difficult. Local anatomy is compromised by the surgery, even though the arches are intact. The soft tissues overlying the bone may not be native to the oral cavity and are usually thick and overly mobile. The vascularity of both the bone and the soft tissues is compromised by the radiation therapy.

Endosseous implants are desirable in this type of patient for many reasons. Standard removable complete denture prostheses are difficult to fabricate because of the altered anatomy and are difficult, if not impossible, for the patient to wear because of lack of stability and potential mucosal ulceration and bone exposure when the prosthesis is mobile. Bone exposure, which can result from a poorly stabilized prosthesis, may lead to osteoradionecrosis, a chronic, morbid condition that may lead to further bone exposure, bone devitalization, and pathologic fractures.

Fortunately, endosseous implants are now used successfully for prosthetic rehabilitation in oncology patients, even in the face of postoperative radiation therapy. Furthermore, implants can be successfully placed and restored in both native, residual alveolar bone in either arch, or in the free or pedicled bone grafts used to reconstruct the oncologic surgical defect. Ideally, implants placed in these patients will provide for the fabrication of restorations that are totally implant-supported. This is especially important in the mandibular arch, where prosthesis impingement and movement on mucosal tissue is more likely to cause bone exposure. Implant-retained prostheses are an alternative and have also proven to be successful if well-designed and maintained.

The timing of implant placement in irradiated patients is important, as previously mentioned. Radiation injury to tissue is cumulative, progressive,

and irreversible. There appear to be 2 periods of opportunity for implant placement in irradiated bone: in the first 3 months after completion of radiation therapy, before the full effects of the radiation on the blood supply have been reached, or after, at 13 months following completion of radiation exposure.[25,26] At this time, the full effects of the radiation treatment have occurred, and any expected recovery has been completed.

Fortunately, the most predictable location for implant placement in the irradiated oral areas is the anterior mandible, the site where implants will be the most useful for prosthetic rehabilitation. Other oral sites, such as the maxilla and the posterior mandible, are less predictable for implant success. The anterior mandible is the most predictable area for implant success in this setting for 2 reasons: the bone quality for implant placement is better than it is in other areas, and the anterior mandible is less likely to be exposed to the total radiation doses used to treat most head and neck tumors.

Hyperbaric oxygen therapy (HBO) is an adjunctive treatment used to improve the success of implant osseointegration in irradiated patients. In oral sites other than the anterior mandible, it has been shown to markedly improve both the implant success rates and the percentage of direct bone-to-implant contact in osseointegrated implants.[27,28] Effective HBO protocols include a minimum of 20 pre–implant placement "dives" and 10 postoperative sessions.[29] Hyperbaric oxygen therapy is both time-consuming and expensive, but in irradiated patients, its use is highly recommended in all oral implant placements, except perhaps in the anterior mandible. In the maxilla, zygomatic, and perinasal regions of irradiated patients, HBO improves implant success rates considerably.[30] Although it does not markedly improve osseointegration rates in the anterior mandible, it has been shown to improve the direct bone-to-implant contact in this and other areas as well, and thus contributes to long-term prosthetic success.[28]

IMPLANTS IN CONGENITAL ALVEOLAR CLEFT PATIENTS

The presence of an alveolar cleft is a major obstacle to good dental arch morphology. Since the early 1970s, autogenous particulate cancellous bone and marrow grafting has been used to repair primary alveolar and residual palatal clefts. Ideally, alveolar clefts are grafted to restore the contour of the dental arch before canine eruption. If successful, this allows the canine to erupt into the arch and be orthodontically repositioned in a satisfactory occlusal relationship. Prosthetic treatment is often needed for patients with repaired and grafted alveolar clefts, especially if the canine has not been maintained or if other teeth in the area have been lost or are congenitally missing. When this need arises, the ideal replacement for the missing teeth are dental implants.

Achieving an adequate amount of bone in the grafted alveolar cleft and the timing of implant placement and restoration are the critical elements in the treatment of these patients. Alveolar clefts and the accompanying oronasal fistula are usually grafted and closed when the patient is about 11 years of age. The typical closure eliminates the oronasal fistula and establishes alveolar continuity, but it may or may not provide a sufficient bulk of bone for successful implant placement and retention. Even if a sufficient bulk of bone were achieved in the initial graft, implant placement at this age is not desirable. Even though growth of the maxilla is usually complete by this age, continued tooth eruption and alveolar development would ultimately leave an implant in a submerged, palatally located position. As a result, implant placement in grafted alveolar clefts is usually delayed until the patient has reached the late teens.

Even though the ideal timing for alveolar cleft closure and grafting is usually agreed to be prior to canine eruption, many patients do not have this procedure completed until later in life. Autologous particulate cancellous bone and marrow is still the graft of choice, and fistula closure and alveolar continuity is established. However, whether closure and grafting is accomplished by age 11 or later, the implant surgeon and prosthodontist must understand that the initial graft, however successful, does not always provide sufficient bulk or height for ideal placement of endosseous implants. This is because local soft tissue flaps must be recruited to close the fistula and provide adequate, tension-free closure over the graft. In the initial procedure, this may result in achieving a stable, continuous alveolus, but it may not provide sufficient osseous bulk to allow implant placement or satisfactory osseous and soft tissue contours to provide a good implant emergence profile.

Thus, secondary procedures are often needed in the alveolar cleft patient after the initial fistula closure and grafting.[31] These procedures may include either secondary epithelialization or mucosal grafting vestibuloplasties, connective tissue grafts, and additional grafts of autologous bone to achieve good ridge bulk and contour and healthy periimplant soft tissues. Under ideal circumstances, the alveolar cleft bone graft or augmentation graft is completed and implant placement follows 4 to 6 months later. This allows adequate time for bone

graft consolidation, but positions the implant(s) before the graft has resorbed and lost its contour. Necessary soft tissue procedures can be accomplished at the time of implant placement or secondarily before, during, or after abutment connection.

In alveolar cleft grafting or augmentation procedures, guided bone regeneration techniques using occlusive barrier membranes have been very useful in encouraging graft consolidation and preventing graft resorption. While the "gold standard" graft material is autologous particulate cancellous bone and marrow, especially when large grafts are needed, smaller areas of osseous deficiency, especially those noted at the time of implant placement, may be successfully grafted using allogeneic bone or resorbable alloplastic materials with guided bone regeneration techniques.

With careful planning and good timing, alveolar cleft defects can be predictably repaired, augmented, and restored with endosseous implants. When appropriately done, these implant restorations should provide functional and esthetic restorations that are equally as predictable as implants placed in other oral areas.

NEW DEVELOPMENTS/NEEDS

Zygomatic Implants

Prosthetic rehabilitation of the patient with an extremely atrophic maxilla is an especially difficult problem. Most often, these patients would ideally be treated with a large autologous onlay or veneer bone graft to the entire alveolar process, combined with sinus and perhaps nasal floor augmentation. However, some patients are either unwilling or medically unable to undergo iliac harvest, a long period of graft consolidation, and a further extended period for implant placement and osseointegration. In this setting, a possible solution may be available in the newly introduced zygomatic implants (Nobel Biocare, Göteborg, Sweden). These implants have been designed specifically to engage another available source of midfacial bone, the zygoma, yet enter the oral cavity in the second premolar/first molar region to provide stabilization to a fixed maxillary prosthesis.

Zygomatic implants are placed with a patient under deep sedation or, preferably, general anesthesia. They are available in lengths of 30, 35, 40, 45, and 50 mm, with a diameter of 4.5 mm in the portion that engages the residual maxillary alveolar process and 3.75-mm diameter at the apical portion of the implant, which is placed in the body of the zygoma. Preparation of the implant site utilizes a modified Le Fort I osteotomy incision, which exposes the entire maxillary alveolar process from zygomatic buttress to zygomatic buttress. This access allows the creation of an opening in the anterior wall of the maxillary sinus bilaterally, access to the alveolar crest in the premolar and first molar regions, and access to the anterior maxillary alveolus and the nasal piriform rims. Long twist drills of gradually increasing diameter are used to prepare the zygomatic implant sites. The preparations extend through the residual alveolus laterally and superiorly, through the anterior portion of the maxillary sinus, and through the body of the zygoma. The prepared site ends at the junction of the zygomatic arch and the lateral orbital rim. The zygomatic implant ultimately engages bone for osseointegration in both the zygoma and the maxillary alveolus.

Successful use of the zygomatic implants for prosthetic rehabilitation of the atrophic maxilla requires at least 2 additional implants in the anterior maxilla. Ideally, these are located in the available bone at the junction of the piriform nasal rim and the anterior wall of the maxillary sinus. A standard osseointegration time of 6 months is allowed before the implants are loaded. The ideal prosthetic restoration supported by zygomatic implants is a fixed, palateless unit with cross-arch stabilization.

To date, the zygomatic implants are in use in only a few centers, but they are being introduced through seminars, conferences, and continuing education courses. They will, with experience, provide another means of dealing with extreme maxillary atrophy in patients who are unwilling or unable to undergo more extensive augmentation procedures.

Recombinant Human Bone Morphogenetic Protein 2

Dental practitioners have been experimenting for years with various bone substitutes to increase patient acceptance of bone regeneration procedures and to reduce the surgical morbidity and limitations associated with autogenous bone grafting. Recombinant human bone morphogenetic protein 2 (rhBMP-2) is an osteoinductive protein that, when administered locally, results in new bone formation at the site of implantation. A large number of preclinical studies using a variety of animal models have demonstrated that rhBMP-2, when combined with a variety of delivery systems, can heal critical-sized cranial, long bone, and mandibular defects. These studies have demonstrated the ability of rhBMP-2 to augment alveolar bone in dogs and the maxillary sinus floor in the goat.[32,33]

Recent human studies of maxillary sinus floor grafting have demonstrated the ability of rhBMP-2, delivered on an absorbable collagen sponge (ACS), to induce new bone formation in the sinus without adverse sequelae.[34] Safety and efficacy studies have shown the material to be safe, predictable, and effective. The only abnormality noted during these studies was a transient reduction in red blood count in 1 patient, which may have been related to the surgical procedure rather than the rhBMP-2 treatment. None of the patients tested developed antibody titers to rhBMP-2 following treatment with rhBMP-2/ACS. However, 2 patients developed an antibody to bovine Type I collagen. This did not cause any clinical problems or interfere with bone formation. There was no evidence of abnormal, overexuberant, or ectopic bone formation on periapical radiographs, computed tomographic scans, or clinical evaluation. The data from the initial studies demonstrated that the rhBMP-2/ACS placed in maxillary sinuses produced new bone that was capable of supporting dental implants. These implants have functioned well over the 2-year period they have been followed.[35] Currently a pivotal multicenter study is underway, which should result in approval of this material for clinical use by the United States Food and Drug Administration. This will represent a crucial step in the advancement of implant dentistry. It will simplify reconstructive surgery, reduce surgery time, and shorten recovery time, while providing adequate bone for implant placement in areas of osseous deficiency.

Implants for Orthodontic Anchorage

Anchorage affects all aspects of orthodontic treatment. Orthodontic tooth movement is compromised in conditions where there is inadequate anchorage. Often, unidirectional tooth movement may be needed but not achievable when teeth are used as anchorage. Anchorage is defined as resistance to unwanted tooth movement. Usually the amount of force required to move teeth is small and may range from 50 to 150 g. In orthodontics, Newton's third law of motion applies: "For every action there is an equal and opposite reaction." If 100 g of force is needed to translate a canine tooth along an archwire, then another 100 g of force is necessary to overcome the friction of the movement, and 200 g of force becomes necessary. The concept of obtaining rigid skeletal anchorage for tooth movement was first mentioned in 1945.[36] However, the concept of osseointegration was developed and clinically applied, rigid skeletal anchorage for orthodontic tooth movement was not obtainable. Recently, several international centers have documented the efficacy of using osseointegrated implants as rigid anchorage for the orthodontist to move teeth in all planes of space. Higuchi[36] summarized the results of a multicenter study of implant survival rates associated with orthopedic tooth movement. In 2 groups of patients, 1 mandibular implant was placed in each retromolar region to provide anchorage. The forces utilized were in the range of 150 to 400 g. A full range of orthodontic tooth movement, including tipping, bodily movement, intrusion, extrusion, torquing, and rotation, was done. Also, a range of 2 to 10 mm of positional tooth movement in all planes of space was obtained. Thirty-seven implants were placed, and only 1 was lost, for a 97.3% survival rate. After the orthodontic treatment was completed, these retromolar implants were "slept." Several patients developed recurrent fistulae over these sleeping retromolar implants, which ultimately required their removal.

Hoffman and Block have developed a palatal implant for maxillary anchorage.[37] This "onplant" utilizes a hydroxyapatite-coated disc, which is serrated on the side placed against the palate. It has a port for the abutment on the oral side. The device is placed submucosally in the midpalatal area and it osseointegrates over a 2-month period. Orthodontic appliances may then be connected to the implant, which can be used as anchorage for tooth movement. Straumann also has recently introduced an implant for maxillary anchorage that is placed in the anterior palate.[38]

The application of osseointegration to orthodontics holds significant promise, particularly in patients who are missing several posterior teeth. Although this technology will not replace conventional orthodontic techniques, it is a powerful adjunct for dentally compromised patients who require orthodontic treatment.

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