Contemporary Maxillary Sinus Augmentation

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INTRODUCTION

The placement of dental implants has revolutionized our ability as oral healthcare practitioners to manage and restore the edentulous posterior maxilla with a fixed prosthesis. The challenge of dental implant therapy in the posterior maxilla has driven the profession to develop new techniques for the management and treatment of the deficient maxillary alveolar ridge. Unlike the posterior mandible, where avoidance and management of the inferior alveolar nerve is paramount, the critical structure in the posterior maxilla is the sinus. Although Tatum[1] was first credited with augmentation of the maxillary sinus for implant placement, Boyne's[2] landmark paper described the use of autogenous bone grafting with long-term follow-up. From those initial investigations, a multitude of materials and techniques have become available to the implant surgeon. As a result, an understanding of wound biology and graft physiology have become even more critical. The maxilla itself is different in its function, physiology, and bone density than the mandible. This, in combination with a unique and varied anatomy, poses a challenge to the surgeon in creating bone height and width sufficient for implant placement in harmony with planned prosthetic rehabilitation. However, a thorough knowledge of contemporary augmentation procedures mitigated by proper patient selection can lead to effective and long-term solutions in the management of the deficient posterior maxilla.

ANATOMY AND PHISIOLOGY OF THE MAXILLARY SINUS

The maxillary sinus, or the antrum of Highmore, is most frequently the largest of the paired paranasal sinuses.[3] It has a volume of approximately 15cc (each) and is generally pyramidal is shape. The sinus has two growth phases, the first up until the first three years of life followed by a second phase beginning at age seven continuing until 18 years of age, paralleling the eruption of the maxillary permanent dentition. From a space perspective, it occupies the vast majority of the maxillary bone with its inferior surface just above the maxillary teeth and extending superiorly to just beneath the orbit. Anteriorly, it is found just behind the anterior wall of the maxilla and the medial extension forms the lateral nasal wall. Posteriorly, it is bounded by the infra-temporal surface of the skull, from which it is separated by the infratemporal fossa. The average dimensions of the sinus are 33mm high, 23mm wide, and 34mm in an anterior-posterior length. The floor of the maxillary sinus is most often in most direct relationship with the three

posterior maxillary molars, although it may extend to the apices of the premolars and rarely to the canine. The sinus may "invade" (**Figure 1**) the alveolar bone surrounding the roots of the posterior maxillary teeth, where it may pose a surgical hazard when operating in this area. The formation of septae (Underwood's septa), both complete and incomplete, within the sinus is often noted. Velasquez-Plata et al, reported an incidence of septa in 24% of patients studied by CT scan.[4] However, even in this group of patients where complete septations are present there usually exists accessory ostia which allows for drainage of the affected compartment.

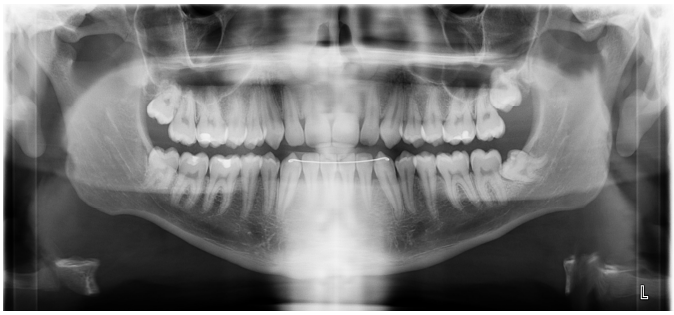


Figure 1. *A panoramic image demonstrating sinus pneumatization around the roots of the maxillary molars.*

Both the innervation and blood supply to the sinus are provided by the anterior superior alveolar, infraorbital, and posterior superior alveolar nerves and arteries. Drainage of the sinus is provided by the maxillary ostium which provides egress of mucous and lymphatic fluid into the nasal cavity. It should be noted with care that the ostium is located on the highest and most medial aspect of the sinus wall, making dependent drainage difficult at best. The ostium drains into the semi-lunar hiatus of the middle meatus of the nasal cavity potentially further complicating drainage. In a septated sinus accessory ostia are usually found to facilitate drainage of the separated compartments.

There are many theories regarding the function of the paranasal sinuses, however none are widely accepted.[5] Postulated physiologic functions include: decreasing skull weight; providing vocal resonance; improvement in olfaction; air humidification; and regulation of intra-nasal pressure. The sinus is lined by a thin, ciliated mucous membrane of respiratory mucosa. The cilia move the overlying mucous blanket toward the ostium at an incredibly high rate, approximately 6mm per minute, helping to overcome its relatively non-dependent drainage position. In addition to removing particulate matter the sinus, the mucous blanket also acts to prevent desiccation of the tissues.

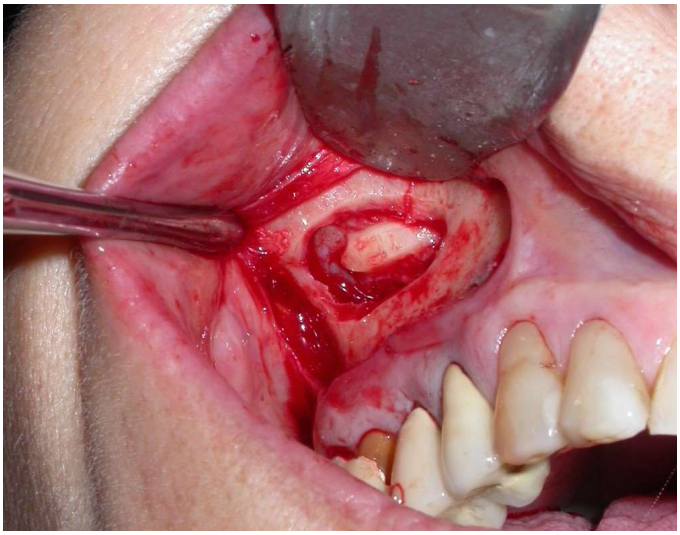
SURGICAL APPROACHES

There are many well documented approaches for augmentation of the maxillary sinus in preparation for implant therapy ranging from very simple to complex. The inherent difficulty for the surgeon is to determine which approach is best suited for the management of specific deficiencies in posterior maxilla. This is most commonly elucidated by the severity of the maxillary alveolar atrophy and the requirements for the patient's planned restorative treatment.

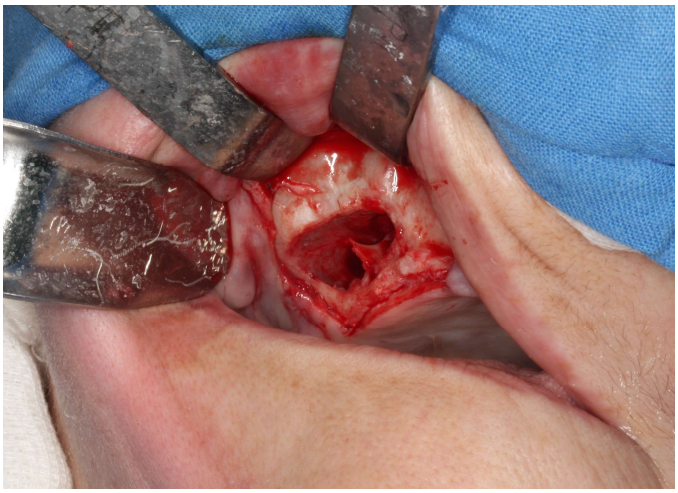
In its most simple, yet aggressive form, the Le Fort I osteotomy is a necessary tool in the surgeon's arsenal of maxillary bone grafting techniques for the patient with severe maxillary atrophy.[6] First described for use in this manner by Sailer in 1989, the maxilla is separated from the skull base in a controlled manner through intra-oral access.[7] The accomplishment of maxillary down fracture allows the surgeon unparalleled access to the maxilla. From this vantage the surgeon removes the sinus mucosa from the down-fractured maxilla and places cortico-cancellous grafts in large volumes to the floor and lateral aspect of the maxillary sinus. In addition, simultaneous maxillary advancement for the severely deficient

maxilla permits a more ideal dental relationship for prosthetic treatment planning. In most circumstances, dental implants can also be placed at the same time, with primary stability afforded by block cortical bone graft. The decision to proceed with a Le Fort I osteotomy should be mitigated by the severity of maxillary atrophy, as well as the surgeon's concern for risks imposed by anesthesia and major surgery in an often elderly patient population, many of whom may present with significant medical problems. Of note, in the skeletal facial deformity population, the sinus membrane is routinely transgressed and in some cases stripped entirely. However, this has not been clinically shown to adversely affect bone healing at the osteotomy sites or grafted areas of the maxilla. Chiapasco et al, reported on 39 patients who underwent a Lefort I osteotomy with simultaneous bone grafting for a mean follow up time of 45.9 months and reported an implant survival rate of 94.5%.[8]

The far more utilized lateral window approach is essentially a variation of the classic Caldwell-Luc technique for access to the maxillary sinus. (**Figures 2AB**) This approach permits the implant surgeon to elevate the Schneiderian membrane and access the floor of the sinus. An incision is made at the height of the crestal bone with releasing incisions as needed posteriorly and/or anteriorly to reduce flap tension. An osteotomy is created in the lateral maxillary sinus wall, with an attempt to protect the sinus mucosa.



A)



B)

Figure 2. ***A****, Intraoperative image demonstrating a lateral window approach to sinus augmentation. The island of bone will then be elevated to form the "roof" under which the grafting material will be placed.* ***B****, Intraoperative view demonstrating the elevated Schneiderian membrane and clear access to the sinus floor which has a septation.*

The lateral maxillary wall is then either fractured medially off a superior "hinge" and pushed bodily into the sinus, or dissected off of the membrane and removed. The mobilized lateral maxillary wall segment then essentially forms a "roof" under which grafting can proceed along the maxillary sinus floor. Dental implants can be placed simultaneously with this technique, and with the implants in place, opportunity is afforded

to the surgeon in meticulously placing the graft material as needed around the exposed fixtures. However, primary stability of the implants requires a minimum of approximately 4mm of bone height. In the severely atrophic maxilla (less than 4mm of bone height), consideration must be given to a staged approach where the bone graft is allowed to consolidate before the dental implants are placed.

Other approaches to the maxillary sinus can be made through the lateral nasal wall, or through the alveolus itself. The nasal approach is primarily an antrostomy approach utilized by oral and maxillofacial surgeons as well as otolaryngologists for the management of sinus pathology and is not discussed in the scope of this article. First described by Summer in 1994, augmentation of the sinus through the alveolus can be performed through an osteotome technique whereby progressively larger osteotomes are "tapped" through the alveolus into the sinus floor, pushing bone superiorly and therefore creating vertical height through the implant osteotomy.[9] First the implant osteotomy is underprepared axially as well as 2mm short of the sinus floor apically. Correct sized osteotomes are then used to up fracture the sinus floor and to elevate the membrane. Grafting material can then be placed into the osteotomy and be used to fill the space of the elevated membrane adding bone apically. Multiple studies have also demonstrated success even without the use of bone grafting material, only the implant is in place to tent the membrane up and create space for a blood clot to form that will eventually remodel into bone.[10-12] Essentially, a blind technique, care must be taken by the surgeon to prevent completely perforating through the sinus with the osteotome to decrease the chance for oral-antral fistula. In addition, there is no opportunity to ensure adequate volume or proper placement of the "pushed-up" bone graft to facilitate dental implant placement. The transalveolar approach, also referred in the literature as an "indirect" sinus augmentation, is most useful in patient's who have 6-8mm of residual alveolar height. Literature reports that between 2-4mm of height can consistently be gained through the indirect technique.[13]

ALLOPLASTIC MATERIALS FOR AUGMENTATION

Alloplastic grafting materials have surged in popularity in recent years. (**Table 1**)

Graft Material	Brand name	Physical Characteristics	Advantages	Disadvantages
Deproteinized Sterilized Bovine Bone	BioOss (Osteohealth, Shirley, New York)	Natural bone mineral with trabecular architecture.	Osteoconductive bone substitute	Non-living
Hydroxyapatite (Bovine) (Coral) (Non-ceramic)	Interpore (Interpore International, Irvine, California) Osteogen (Stryker, Kalamazoo, Michigan)	Porous	Osteoinductive	Non-living
Demineralized Freeze Dried Bone		Blocks, granules.	Osteoinductive. Essentially no disease transmission	Non-living
β Tricalcium Phosphate	Cerasorb (Curasan, Research Triangle Park, North Carolina	10-65 micron porous granules	Bone regeneration	Resorption
Calcium Sulfate	Calforma Osteoset (Wrighty Medicalk Technology, Arlington, Tennessee) Capset (LifeCore Biomedical, Chaska, Minnesota)	Porous crystals. Pellets. Powder.	Osteogenic	Resorption

Bioactive Glass	Biogran (3I Implant Innovations, Palm Beach Gardens, Florida)	90-710 microns resorbable spheres composed of Silicon, Calcium, Sodium and Phosphorous	Osteogenic	Resorption
Poly methylmethacrylate	Bioplant HTR (Bioplant, South, Norwalk, Connecticut)	Highly porous co-polymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrilate with barium sulphate and calcium hydroxide/carbonate coating	Radiopaque, osteopromotive, hypoallergenic, hydrophilic	Nonresorbable

Table 1*. Characteristics of some common alloplastic and allogeneic materials.*

They may be used alone or in combination with autogenous bone, demineralized bone, blood or other substances. They have the potential to eliminate, or at least reduce the magnitude of second surgical site morbidity, are easy to use, and are frequently less expensive that the overall cost for bone harvest. The majority of these materials are composed of some form of hydroxyl apatite (HA) or more specifically calcium phosphate ceramics.[14-17] By itself, HA is composed of dense, porous osteoconductive structure which forms a scaffold for bone in-growth. A subsection of these materials, the calcium poor carbonate apatites, instead are resorbed by osteoclastic activity. This resorption is then followed by a phase of osteoblastic new bone formation. However, argument exists as to how efficiently this process occurs.

Another of these materials is the β- tricalcium phosphate.[18] This is a material that has been certified for the regeneration of bone defects in the entire skeletal system. It is completely resorbed and replaced by natural, vital bone within three months to two years. It is composed of porous granules generally 10-65 micrometers in diameter. Collagen and blood vessels invade the porous granular system and provide a matrix for new bone deposition. It is reported to be mechanically stable, without induction of immunologic reactions or infection.

Calcium sulfate, commonly referred to as "gypsum", is another material that has been used to assist in the augmentation of the maxillary sinus.[19-21] It has been used in bone regeneration as a graft material, graft binder/extender and as a barrier for guided tissue regeneration. Calcium sulfate comes in an α-hemihydrate and a β-hemihydrate – one porous with irregular crystals, and the other with rod and prism-shaped crystals. Similar to tri-calcium sulfate, it also is completely resorbed over time (six to eight weeks) and

does not evoke any substantial host response. Calcium sulfate is purported to be osteogenic, with the ability to induce new bone formation. Recent studies focusing on the use of calcium phosphate in maxillary sinus augmentation have compared favorably with the use of autogenous bone. Pecora et al, prospectively examined the success rate of dental implants placed in the sinus grafted with calcium phosphate and noted an implant success rate of 98.5% after one year as well as the formation of type II or III bone during histological analysis.[22]

Bioactive glasses are rather unique, in that these materials actually bond to bone.[23] Bioactive glasses generally contain silica, calcium and phosphate. These are usually delivered as granules that are 90-710 microns in diameter with sub-micron sized pores (mesopores) that increase the overall surface area. They are extremely biocompatible and evoke not inflammatory response when implanted. While bioactive glasses do bond to bone, they also appear to have an osteogenic effect that induces osteoblasts. In another study of sinus augmentation concerning bioactive glasses (BG), Tadjoedin et al, compared "high concentrations" of BG particles (300-355 microns) with autogenous bone (AG) obtained from the iliac crest.[24] Results were evaluated histologically at intervals post-augmentation. Histomorphometry was used to quantify the amount of bone formed. The conclusions provided several notable points. When the bioactive glass is grafted alone, maturity of the graft as it relates to implant placement is longer (one year) than when combined with autogenous bone (six months). In addition, further study by the same group found that as the time interval lengthened to 16 months, sites where bioactive glass and autogenous bone are grafted in a 1:1 mixture assume almost exactly the same density of bone as sites of autogenous bone graft only.[25] Cordioli et al, further examined simultaneous implant placement with grafting of a 4:1 mixture of bioactive glass and autogenous bone. They reported that where sufficient bone is present pre-operatively to permit primary implant stability, this mixture of grafting material provides sufficient quality and quantity of bone for long-term implant success.[26]

A specialized form of polymethylmethacrylate is yet another material for augmentation of the sinus. It is a highly porous co-polymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrylate with a barium sulfate and calcium hydroxide/carbonate coating.[27,28] It is considered to be radiopaque, osteopromotive, hypoallergenic and hydrophilic. While it is biocompatible, it does not resorb.

Xenografts are also used for sinus augmentation. Most commonly bovine in origin, the grafts are prepared by the laboratory to eliminate graft host antigenicty by removal of bioactive material. In a similar fashion to demineralized bone, they function to provide a scaffold for bone formation. Although the risk of disease transmission is essentially negligible, the remote possibility of contracting one of the prion diseases such bovine spongiform encephalopathy (mad cow disease) does exist. It should be noted that there is no reported incidence of transmission from bone graft therapy. Wallace et al, reviewed the efficacy of xenografts and reported that it also compares favorably with autogenous bone.[29]

A review of the literature demonstrates relatively poorer bone formation when using these materials for sinus augmentation and a longer period of time until graft consolidation unless combined with some amount of autogenous bone. Despite these limitations, alloplastic materials can occasionally be useful in the management of small areas requiring augmentation in the sinus, especially in combination with demineralized or autogenous bone to expand graft volume.[30]

ALLOGENEIC MATERIALS FOR AUGMENTAION

Allogeneic grafts are available in two different types, mineralized and demineralized as well premixed combination the two types.[31,32] Mineralized allograft contains both the inorganic mineral portion of bone as well as the organic bone morphogenic proteins (BMPs). Demineralized allograft is decalcified to remove the inorganic mineral portions of bone and therefore leaves behind a relatively higher concentration of the BMP proteins, which is believed to increase the osteogenic potential.[33] A histological evaluation by Cammack et al, demonstrated no significant difference in new bone formation between demineralized allograft and mineralized allografts used for sinus augmentation and alveolar ridge preservation.[34] One benefit of mineralized allogenic bone grafting is volume stability. Gultekin et al, demonstrated less reduction in graft volume at six months after sinus augmentation with mineralized allogenic graft versus a composite mineralized and demineralized grafting material.[35] A meta-analysis on sinus augmentation in 2016 demonstrated that demineralized allografts resorbed more than mineralized allografts and induced less new bone growth.[36] Mineralized allograft is available commercially in cortical and cancellous chips. Cortical particles have the benefit of maintaining space due to the larger size and the slower resorption rate. Cancellous chips are more readily resorbed, which allows for an ingrowth of bone and remodeling. Premixed commercial combinations are available as well that try to maximize the benefits of both the cortical and cancellous grafting materials and have demonstrated success with sinus augmentation.[37]

AUTOGENOUS BONE

Autogenous bone is the gold standard by which all other graft materials are measured. Its advantages include high osteogenic potential, unquestioned biocompatibility, and no possibility of disease transmission. As implied, a second surgical site is required, with the attendant donor site morbidity. In addition, the length and cost of the procedure can be significantly elevated. A number of donor sites have been routinely used in maxillary sinus bone grafting. These include the anterior and posterior ilium, tibia, and various intra-oral sites such as the maxillary tuberosity, mandibular ramus, and mandibular symphysis.

The ilium is one of the most common sites for obtaining graft bone in sinus surgery where extra-oral harvest is performed. The ease of surgical access, low postoperative morbidity, and large amounts of readily available cancellous and cortical bone contribute to the popularity of the procedure. (**Figure 3**)

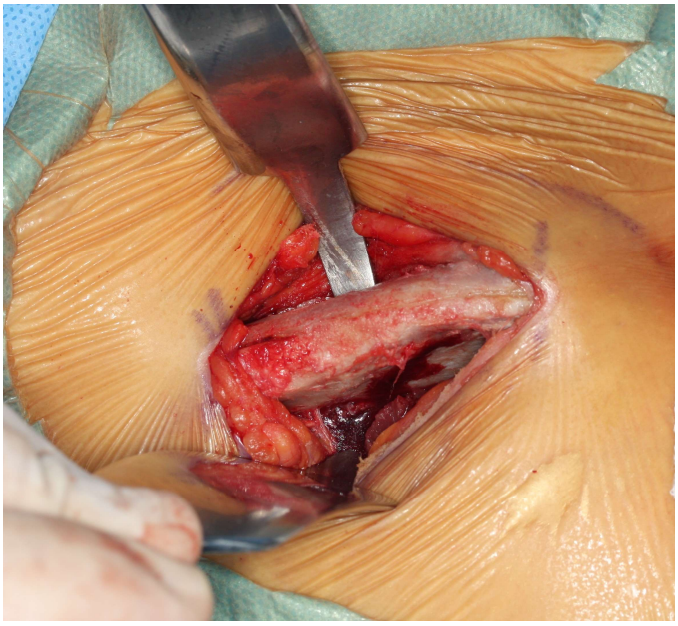


***Figure 3**. The anterior iliac crest is easily accessible and has a large amount of bone available for grafting.*

The operation for graft harvest is performed under general anesthesia, usually in the hospital in-patient setting. However, a trephine technique has been developed which can be modified for use in the outpatient setting. This technique can provide an adequate amount of bone for sinus augmentation, however it is a "blind" procedure with inherent risks such as perforation medially into the abdominal cavity. Formal iliac crest harvest begins with an incision made lateral to the anterior iliac spine with reflection of soft tissue medially. The dissection is carried to bone through the overlying fascia and the medial aspect of the ilium is exposed. An osteotomy is then created along the superior aspect of the iliac crest with medial extensions and the cortical bone is then removed for grafting or fractured medially to expose cancellous bone. Approximately 20-40cc of bone is available from the anterior ilium and almost double this amount is available from the posterior ilium. The iliac harvest is usually reserved for those patients in whom cortical as well as cancellous bone is required for structural support or for additional implant stability. Although complications can occur, the risk of long-term gait disturbance is relatively low especially with a medial approach and care not to strip the lateral musculature of the pelvis.

The tibia has a long and well documented success rate associated with autogenous grafting. The advantages of tibial bone graft harvest are that it can be performed in the operating room or the office in the outpatient setting. Large amounts of cancellous bone are available and patients are ambulatory immediately after surgery. An incision is made adjacent to Gerdy's tubercle on the lateral aspect of the tibia. Dissection proceeds to the lateral aspect of the tibial bone where a circular osteotomy exposes the underlying cancellous bone. Perforation of instrumentation into the knee joint can cause serious complications. However, when executed with proper technique, the risk of surgical complications is minimal. Cortical bone, however, is not available in significant quantity when this site is chosen for bone graft harvest. Therefore, the procedure lends itself to sinus augmentation where only cancellous bone is required.

The intra-oral sites for autogenous bone graft harvest have been relatively popular for sinus augmentation secondary to the ease of harvest near the operative site without the need for external incisions. Popular sites of harvest include the anterior mandible, the lateral-posterior mandible, and the tuberosity of the maxilla itself. Limitations of harvest from these sites include the relatively small amount of bone that can be harvested and the nature of the graft, which becomes mostly cortical because of the anatomy of the jaws. In addition, the risk of dental injury as well as jaw fracture is also present.

Harvesting of graft from the anterior mandible is particularly appealing because of the mandibles' embryonic derivation from membranous bone and thus improved resistance to graft resorption. There is some controversy in the literature regarding the difference in long-term graft stability when comparing endochondral and membranous bone. However, in the author's experience, when obtaining grafts from areas of relative hypovascularity during formation (cranium and mandibular symphysis), these bones are ideally suited for grafting. For mandibular symphyseal bone harvest, an incision is made in the anterior mandibular vestibule or sulcus of the mandibular dentition and the dissection is carried through the mucoperiosteum to the bone. The dissection continues in the subperiosteal plane until the inferior border of the mandible is identified. Taking care to remain below the roots of the anterior dentition, an osteotomy is designed through the facial cortex of the mandible. Graft harvest can then proceed in two different

methods depending on augmentation requirements. If cortical bone is required, the facial cortex of the mandible is then outlined with a bur and the cortex is subsequently removed utilizing an osteotome. A small volume of remaining cancellous bone can then be harvested for grafting with a curette. If particulate bone is the primary requirement, a trephine drill is used to mill and harvest bone from the anterior mandibular cortex which is recovered from a suction trap. Closure after hemostasis is achieved then proceeds with special attention directed at the reconstructing the paired mentalis musculature to prevent soft tissue sag (witch's chin).

Harvest of grafts from the posterior mandible proceeds in much the same fashion, except the incision is made in the posterior vestibule of the mandible or sulcus of the posterior teeth. The prominent external oblique ridge is ideal for harvest if present. Of course, care must be exercised to avoid injury medially to the teeth or to the inferior alveolar nerve at the inferior extent of the graft harvest and the lingual nerve medially. As with the mandibular symphysis, harvesting block grafts from the posterior lateral mandible carries with it the potential risk of mandibular fracture.

The maxillary tuberosity harvest remains straightforward and is perhaps the least technically difficult procedure for intra-oral autologous bone harvest. However, only approximately 2-3cc of bone can be harvested, which limits its usefulness, even if mixed with alloplasts or allogeneic materials. In addition, the bone obtained is somewhat "fatty" in constitution and may not be ideally suited for some grafting procedures. Graft harvest begins by making a full thickness incision along the height of the tuberosity with subsequent reflection of a mucoperiosteal flap and protection of the pterygomaxillary fissure. Care must be directed as to not fracturing the posterior maxilla during the procedure and cause further communication into the sinus.

The use of membranes in dentistry has greatly improved the ability of the clinician to decrease the amount of soft tissue in-growth during graft healing and consolidation. There is evidence to suggest that the use of membranes improves graft volume in general. However, its use in sinus bone grafting is less clear because the graft is in direct contact with the bony maxillary sinus floor. Perhaps the most compelling reason for the use of membranes during sinus augmentation is an adjunctive measure when the sinus membrane is disrupted during the grafting procedure. Specifically, placement of the barrier helps to seal the communication between the disrupted sinus membrane and the graft. Membranes can also be used to cover the lateral window to aid in graft consolidation. A systematic review published in 2019 evaluated the use of membranes over the lateral window. The reviewed concluded that there was no statistically significant difference in implant success amongst the experimental groups. The literature did suggest that membrane use increases new bone formation, decreases soft tissue ingrowth, and helps prevent displacement of grafting material. [38]

COMPLICATIONS OF MAXILLARY SINUS AUGMENTATION INCLUDING SINUSITIS

As noted above, because the maxillary sinus does not have a dependent drainage system, susceptibility to infection and fluid sequestration remains a distinct possibility. The anatomy however, also favors the implant surgeon in one important respect with regard to the location of the ostium. Because

of the high location of the ostium on the medial wall of the sinus, it is unlikely to become obstructed by routine maxillary augmentation in the inferior region of the sinus.

Acute maxillary sinusitis is often heralded by pain in the operated sinus with associated congestion and with increasing severity, fever as well as general malaise.[39] Acute infection is managed after surgery with antibiotic therapy directed at flora of the upper respiratory tract. The spectrum of flora in the sinus is similar to that found throughout the respiratory tract. However, coverage for *H. Influenzae* must be included in any antibiotic choice. The extended spectrum penicillins, such as amoxicillin are a reasonable choice in the non-allergic patient. Drainage may occur spontaneously through the wound margins or fistulize through the oral mucosa into the vestibule. Culture and sensitivity should always be obtained to further narrow the appropriate antibiotic coverage. If spontaneous drainage does not occur, surgical drainage should be provided for resolution of the infection. Unfortunately, in either case, the graft is compromised and will likely fail. It should be noted that the use of decongestants is somewhat controversial in the post-operative management of patients undergoing sinus augmentation as they often act by vasoconstriction, which further decreases blood supply vital to healing in an already low oxygen tension environment present in the sinus.

If dental implants are placed immediately at the time of grafting, immediate stability is vital for maintaining implant position and parallelism. Drifting of the implant can occur when adequate stability is not achieved. This is primarily a problem when the residual maxilla is only several millimeters in height and cortical grafts are not employed as a further anchor. If cortical grafting is not planned and the residual maxillary height is not sufficient for primary implant stability, consideration should be given to allowing graft consolidation to occur before attempting fixture placement. For patients with autogenous bone grafts, consolidation takes approximately four to six months in the maxilla. This is considerably longer in the patient with alloplastic only grafting. For those patients with a combination of autogenous grafts and alloplastic or allogeneic grafts, consolidation follows the timeline of autogenous grafts. Assessment of graft consolidation can be evaluated by several methods. Radiographs of the graft site should demonstrate increasing opacity architecturally similar characteristics of the surrounding areas of bone. A second less desirable, but effective, method is to wait for a graft appropriate amount of time to pass and then visually examine the graft for consolidation with placement of the implants or addition of further graft material if necessary.

ADVANCES IN BIOTECHNOLOGY

The science of bone grafting has made great changes recently in biotechnology. Two recent advancements are the use of platelet concentrates and recombinant bone morphogenic protein (rBMP). Bone morphogenic proteins are osteoinductive proteins discovered by the work of Dr. Marshall Urist in 1965. Since the discovery of BMP multiple different BMPs have been isolated and cloned. Recombinant human BMP-2(rhBMP-2) was first approved for use in orthopedic surgery in 2002, followed by approval for maxillofacial use in sinus augmentation and socket preservation in 2007. In 2009, Triplett et al, performed a randomized, multi-center clinical study that compared sinus augmentation with a bone graft compared to rhBMP-2 on an absorbable collagen sponge. Using 8mL of 1.5mg/mL of

rhBMP-2 compared to autogenous or allogenic bone grafting it was demonstrated that the rhBMP-2 group gained 7.83mm versus 9.46mm in the bone-grafting group.[40] It also demonstrated no statistically significant difference in implant survival rate after six months. The most significant side effect was significantly more facial edema associated with rhBMP-2. A 2011 follow up study evaluated implants placed 15 years earlier in sinuses augmented with rhBMP-2 and demonstrated a 100% implant survival rate. The newest use of rhBMP-2 includes the use of hydroxyappetite in which rhBMP-2 demonstrated a statistically significant volume increase when compared to allogenic and bone allograft.[41]

Platelet rich fibrin (PRF) is yet another example of tissue engineering which has significant clinical applications in maxillofacial bone grafting. PRF is a second-generation platelet concentrate that has also proven useful in maxillofacial reconstructive procedures. The first platelet concentrate used in maxillofacial reconstruction was platelet rich plasma (PRP) which was proposed by Marx et al.[42] PRP was able to concentrate vascular endothelial growth factor (VEGF), platelet-derived growth factor (PDGF), and transforming growth factor-beta (TGF-ß) to aid in wound healing and tissue remodeling. One disadvantage of PRP was the complex preparation protocol that required multiple rounds of centrifugation as well as addition of anticoagulants. Choukroun et al, in 2001, developed the protocol for PRF, which removed the anticoagulant and only required one round of centrifugation but still had the increased concentration of growth factors to aid in tissue remodeling.[43] PRF is useful in sinus augmentation, alone or combined with grafting materials, because it stabilizes any perforation in the Schneiderian membrane, improves handling characteristics of grafting materials and improves healing capacity by increasing blood flow.[44] Due to the handling properties of PRF and the "stickiness" it has proven to be very useful in the repair of membrane perforations at the time of sinus augmentation.[45] Oncu and Kaymaz investigated implant placement and sinus augmentation in groups with non-perforated Schneiderian membranes compared to groups with perforated membranes repaired with PRF.[46] They reported a 100% implant survival rate after six to12 months in both groups as well as no difference in the amount of bone gain. PRF has also demonstrated the ability to reduce the healing time associated with sinus floor augmentation. Chukroun et al, compared sinus augmentation with demineralized allograft with and without the addition of PRF.[43] After four months of healing, the PRF group demonstrated equivalent ratios of vital to non-vital bone as the control group demonstrated at eight months. This report suggests that PRF can decrease the healing time of sinus augmentation procedures as well as reduce the volume of allograft required.

CONCLUSION

Attention to the principles of bone grafting, knowledge of bone healing, and a thorough understanding of maxillary sinus physiology as well as anatomy is critical to the successful placement of dental implants in the posterior maxilla. The integration of these principles must take into account the restorative dental requirements and the patient's autonomy in guiding implant reconstruction.

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