ELSEVIER
SAUNDERS

Dent Clin N Am 50 (2006) 409–424

THE DENTAL
CLINICS
OF NORTH AMERICA

Maxillary Sinus Augmentation

Paul S. Tiwana, DDS, MD, MS[a,b,*],
George M. Kushner, DMD, MD[b],
Richard H. Haug, DDS[c]

[a]*Kosair Children's Hospital, 501 South Preston Street, Louisville, KY 40202, USA*
[b]*University of Louisville School of Dentistry, 501 South Preston Street, Louisville, KY 40202, USA*
[c]*University of Kentucky College of Dentistry, 800 Rose Street, Chandler Medical Center, Lexington, KY 40536-0297, USA*

The placement of dental implants has revolutionized our ability as oral health care 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 are 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, many materials and techniques have become available to the implant surgeon. As a result, an understanding of wound biology and graft physiology has become even more critical. The maxilla itself is different in its function, physiology, and bone density than the mandible. These differences, in combination with the unique and varied anatomy of the maxilla, pose 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 long-term solutions in the management of the deficient posterior maxilla.

* Corresponding author. Department of Surgical & Hospital Dentistry, University of Louisville School of Dentistry, 501 South Preston Street, Louisville, Kentucky 40292.
E-mail address: paul.tiwana@louisville.edu (P.S. Tiwana).

doi:10.1016/j.cden.2006.03.004

Anatomy and physiology of the maxillary sinus

The maxillary sinus, or the antrum of Highmore, is usually the largest of the paired paranasal sinuses [3]. Each maxillary sinus has a volume of approximately 15 cc and is generally pyramidal is shape. The sinus has two growth phases. The first phase occurs during the first 3 years of life. The second phase begins at age 7 and continues to age 18, paralleling the eruption of the maxillary permanent dentition. From a space perspective, the maxillary sinus 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, the maxillary sinus is found just behind the anterior wall of the maxilla and the medial extension forms the lateral nasal wall. Posteriorly, the maxillary sinus is bounded by the infratemporal surface of the skull, from which the sinus is separated by the infratemporal fossa. The average dimensions of the sinus are 33 mm high, 23 mm wide, and 34 mm in an anterior-posterior length. The floor of the maxillary sinus usually is directly above the three posterior maxillary molars, although the sinus floor may extend to the apices of the premolars and also, but rarely, to the canine. The sinus may ''invade'' the alveolar bone surrounding the roots of the posterior maxillary teeth, where it may pose a surgical hazard when extracting teeth in this area (Fig. 1). The formation of septa (ie, Underwood's septa), both complete and incomplete, within the sinus is often noted. Velasquez-Plata and colleagues recently reported an incidence of septa as revealed by computed tomogram in 24% of the sinuses in 156 patients [4].

The anterior superior alveolar, infraorbital, and posterior superior alveolar nerves and arteries provide both the innervation and blood supply to the sinus. The maxillary ostium provides drainage of the sinus and egress

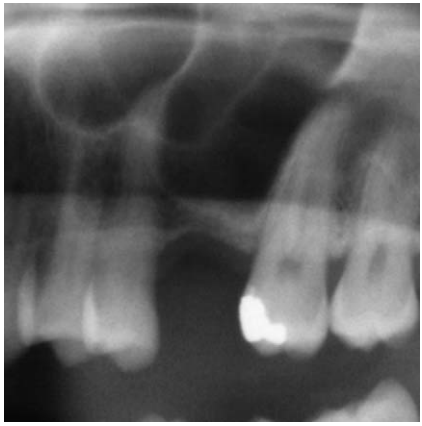

Fig. 1. Pneumatization of the maxillary sinus prohibits dental implant placement until the antrum can be augmented sufficiently to receive an implant.

of mucous and lymphatic fluid into the nasal cavity. The ostium is located on the highest and most medial aspect of the sinus wall, making dependant drainage difficult at best. The ostium drains into the semilunar hiatus of the middle meatus of the nasal cavity, a configuration that can further complicate 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]. According to these postulations, the physiologic functions of the paranasal sinuses include decreasing skull weight; providing vocal resonance; improving olfaction; adding humidity to air to keep tissues in the nose, mouth, and throat moist; and regulating intranasal pressure. The sinus is lined by a thin, ciliated mucous membrane of respiratory mucosa. The cilia move the overlying mucous blanket toward the ostium rapidly at a rate of approximately 6 mm per minute, helping to overcome its relatively nondependant drainage position. In addition to removing particulate matter from 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. These approaches range from very simple to complex. Some investigators have even suggested augmenting the sinus immediately following the extraction of a maxillary molar [6]. In a given clinical situation, the surgeon must determine which approach is best suited for the management of specific deficiencies in the posterior maxilla. This determination is usually elucidated by the severity of the maxillary alveolar atrophy and the requirements for the patient's planned restorative treatment. In most cases, insufficient high-level evidence is available to formulate evidence-based guidelines for practitioners.

In its simplest form, the Le Fort I osteotomy is an aggressive and necessary tool in the surgeon's arsenal of maxillary bone grafting techniques for the patient with severe maxillary atrophy [7]. Here, the maxilla is separated from the skull base in a controlled manner through intra-oral access. The accomplishment of maxillary down fracture allows the surgeon unparalleled access to the maxilla. From this vantage, cortico-cancellous grafting in large volumes proceeds unimpeded. The surgeon is afforded the opportunity to graft the maxillary floor as well as the lateral walls. In addition, simultaneous maxillary advancement for the severely deficient maxilla permits a better 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 grafting. The decision to proceed with a Le Fort I osteotomy should be mitigated by the severity of maxillary atrophy, as well as risks imposed by anesthesia and major surgery in patients

who are often elderly and may also present with significant medical problems. 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.

The lateral approach, which is used far more often, is essentially a variation of the classic Caldwell-Luc technique for access to the maxillary sinus (Fig. 2). This approach permits the implant surgeon to gain access to the inferior aspect and floor of the sinus. An incision is made at the height of the crestal bone with releasing incisions as needed posteriorly or anteriorly to reduce flap tension. An osteotomy is created in the lateral maxillary sinus wall. Measures should be taken to protect the sinus mucosa. The lateral

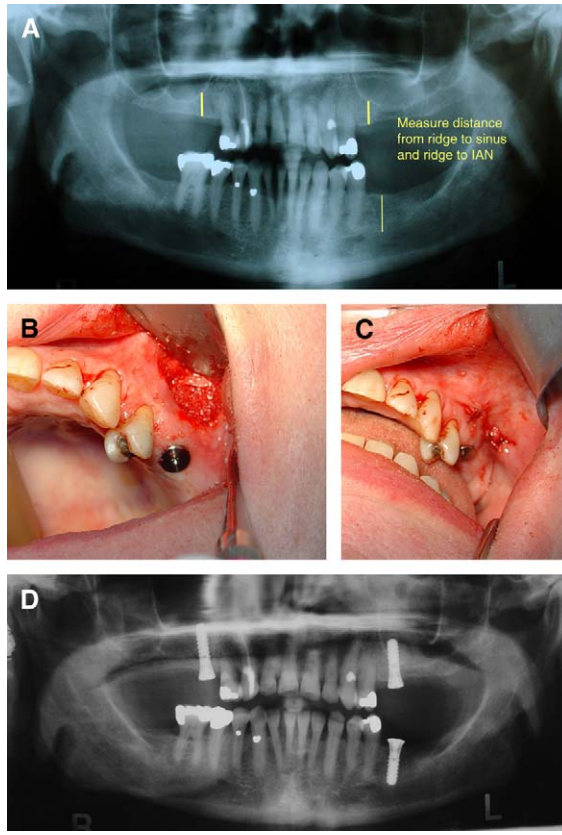

Fig. 2. (*A*) A typical maxillary sinus augmentation case begins with imaging, measurement, and diagnosis. (*B*) After incision, flap reflection, sinus mucosa lift and implant placement, the augmentation material can be packed around the implant. (*C*) The flap is replaced and incision closed. (*D*) An image confirms appropriate implant placement and adequate sinus augmentation. *Abbreviation:* IAN, inferior alveolar nerve.

maxillary wall is then either fractured medially off a superior ''hinge'' or pushed bodily into the sinus. The mobilized lateral maxillary wall segment forms a ''roof'' under which grafting can proceed along the maxillary sinus floor as necessary. Dental implants can be placed simultaneously with this technique, and with the implants in place, the surgeon has the opportunity to meticulously place the graft material as needed around the exposed fixtures. However, primary stability of the implants requires approximately 4 mm of bone height. In the severely atrophic maxilla (ie, <4 mm 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, which is an approach used by oral and maxillofacial surgeons as well as otolaryngologists for the management of sinus pathology and is not discussed further in this article. 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, ostensibly pushing bone superiorly and therefore creating vertical height through the implant site. This approach is essentially a blind technique. Therefore 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.

Alloplastic materials for augmentation

The popularity of alloplastic grafting materials has surged in recent years (Table 1). Such materials 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 second surgical site morbidity. Also, they are easy to use and are frequently less expensive than the overall cost for bone harvest. The most common alloplastic grafting materials are those composed of some form of hydroxyapatite (HA) or, more specifically, calcium phosphate ceramics [8,9]. By itself, HA has a dense, porous osteoconductive structure, which forms a scaffold for bone in-growth. Studies have shown clinical success with these materials, but most involve relatively small samples [10]. Some alloplastic grafting materials made mostly of HA or calcium phosphate ceramics, also contain calcium-poor carbonate apatites, which are resorbed by osteoclastic activity. This resorption is then followed by a phase of osteoblastic new bone formation. However, the efficiency of this process remains open to argument.

Another alloplastic grafting material is β-tricalcium phosphate (TCP) [10]. This material has been certified for the regeneration of bone defects in the

Table 1
Characteristics of some common alloplastic and allogeneic materials

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	Nonliving
Hydroxyapatite (bovine) (coral) (nonceramic)	Interpore (Interpore International, Irvine, California); Osteogen (Stryker, Kalamazoo, Michigan)	Porous	Osteoinductive	Nonliving
Demineralized freeze-dried bone		Blocks, granules	Osteoinductive; essentially no disease transmission	Nonliving
β Tricalcium phosphate	Cerasorb (Curasan, Research Triangle Park, North Carolina	10–65 μm 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 (Implant Innovations (3i), Palm Beach Gardens, Florida)	90–710 μm resorbable spheres composed of silicon, calcium, sodium, and phosphorous	Osteogenic	Resorption
Polymethylmethacrylate	Bioplant HTR (Bioplant, South Norwalk, Connecticut)	Highly porous co-polymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrylate with barium sulphate and calcium hydroxide or calcium carbonate coating	Radiopaque, osteopromotive, hypoallergenic, hydrophilic	Nonresorbable

entire skeletal system. It is completely resorbed and replaced by natural, vital bone after 3 months to 2 years. TCP is composed of porous granules generally 10 to 65 μm 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. A recent study shows that an anorganic bovine bone graft material is superior to TCP in promoting new bone formation in the sinus [11].

Calcium sulfate, commonly called gypsum, is another material that has been used to assist in the augmentation of the maxillary sinus [12]. Calcium sulfate 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 form. In the α-hemihydrate form, calcium sulfate is porous with irregular crystals. In the β-hemihydrate form, calcium sulfate has rod- and prism-shaped crystals. Similar to tricalcium sulfate, calcium sulfate also is completely resorbed over 6 to 8 weeks and does not evoke any substantial host response. Calcium sulfate is purported to be osteogenic, with the ability to induce new bone formation.

Pecora and colleagues performed a series of studies in which they used calcium sulfate as a graft material for the maxillary sinus [13]. Following a successful case report, these investigators performed a prospective, longitudinal study in which 65 sinuses were grafted using different applications of calcium sulfate [14]. Implants were then placed and followed for at least 1 year, with an overall success rate of 98.5% for 130 implants. Histological analysis indicated mature bone in all specimens.

Bioactive glasses, another class of materials, are unique in that they actually bond to bone [14,15]. Bioactive glasses generally contain silica, calcium, and phosphate. These are usually delivered as granules that are 90 to 710 μm in diameter with submicron sized pores (ie, mesopores) that increase the overall surface area. They are extremely biocompatible and evoke no inflammatory response when implanted. While bioactive glasses do bond to bone, they also appear to have an osteogenic effect that induces osteoblasts.

Tadjoedin and colleagues compared bioactive glass particles measuring 300 to 355 μm with autogenous bone obtained from the iliac crest [16]. Results were evaluated histomorphometrically at 4, 6, and 15 months postaugmentation. The test sinuses received 80% to 100% bioactive glass mixed with 0% to 20% iliac crest bone particles, while the control group received only autogenous bone. The control group (autogenous only) sinuses contained 42% bone compared with 39% for the group that received bioactive glass and autogenous bone. Based on the histologic outcomes noted in the study, Tadjoedin and colleagues recommend that 12 months healing time is required if 100% bioactive glass is used for sinus augmentation, while 6 months is sufficient for mixtures of 80% autogenous bone and 20% bioactive glass. An earlier study by this group showed that sites where bioactive glasses were used and sites where autogenous bone was used were indistinguishable at 16 months [17].

Cordioli and colleagues evaluated the use of bioactive glasses for sinus augmentation in a group of 12 patients [18]. Titanium implants with 2-3 threads were placed in the grafted sites at the time of sinus augmentation. All sinuses had dimensions from crest to sinus floor of 3 to 5 mm. After 12 months post-loading, 26 of the 27 implants were stable, with one failure.

A specialized form of polymethylmethacrylate is yet another material for augmentation of the sinus. It is a highly porous copolymer consisting of polymethylmethacrylate and polyhydroxymethylmethacrylate with a coating made of barium sulfate and calcium hydroxide or of barium sulfate and calcium carbonate [15,16]. It is considered to be radiopaque, osteopromotive, hypoallergenic, and hydrophilic. While it is biocompatible, it does not resorb.

It has been suggested that alloplastic materials are not suitable for sinus augmentation due to incomplete resorption and poor bone formation. Indeed, some investigators suggest that only 20% of the graft eventually forms bone and that this bone forms densely along the sinus floor rather than uniformly throughout the graft. However, a recent systematic review of this literature examined 893 studies and concluded that ''the use of grafts consisting of 100% autogenous bone or the inclusion of autogenous bone as a component of a composite graft did not affect implant survival'' [19]. 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.

Allogeneic materials for augmentation

Allogeneic grafts are composed of two different types—mineralized and demineralized [20,21]. Mineralized bone is of little use in sinus augmentation because of its lengthy process of bone formation in the hypovascular environment of the sinus. However demineralized bone is commonly used because, as a result of processing, the inherent bone morphogenetic protein (BMP) remains behind. The BMP proteins work to form an osteoinductive graft by stimulating adjacent undifferentiated cells to form bone. These graft materials are available from tissue banks. However, there remain some concerns associated with their use, including cost and the risk, albeit low, of disease transmission. More often, these materials are combined with autogenous grafts to expand their volume but can be used alone with relative success. Recent advances in biotechnology have allowed for the isolation and engineering of pure BMP proteins for bone grafting. These materials have undergone initial testing and have proved very promising, but have been approved only for certain orthopedic problems. If made available for wider use, the prospect of improved results in nonautogenous maxillary sinus grafting is a possibility.

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 are both significant. A number of donor sites have been routinely used in maxillary sinus bone grafting. These include the anterior and posterior ilium; the tibia; and various intra-oral sites, such as the maxillary tuberosity, the mandibular ramus, and the mandibular symphysis (Table 2).

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. The operation for graft harvest is performed under general anesthesia, usually in the hospital inpatient setting. However, a trephine technique has been developed that can be modified for use in the outpatient setting (Fig. 3). This technique can provide an adequate amount of bone for sinus augmentation. However, the technique 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. The cortical bone is then removed for grafting or fractured medially to expose cancellous bone. Approximately 20 to 40 cc 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 an established and well-documented success rate associated with autogenous grafting (Fig. 4). 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 misadventure is minimal. This site does not provide a significant quantity of cortical bone. Therefore the procedure lends itself to sinus augmentation in cases where only cancellous bone is required.

Table 2
Characteristics of various autogenous bone harvest sites

Graft material	Advantages	Disadvantages	Amount of bone available	Complications
Anterior ileum	Most reliable grafting source; cortical and cancellous bone can be harvested	Distant second surgical site; requires general anesthesia	20–40 cc	Gait disturbance, hernia, paresthesia, infection
Trephined anterior ileum	May be performed as an outpatient with sedation and local anesthesia; most reliable grafting source	Distant second surgical site	20–40 cc	Infection
Tibia	May be performed as an outpatient with sedation and local anesthesia	Distant second surgical site; cortical bone not available in significant quantities	20–40 cc	Gait disturbance, infection, tibial plateau fracture
Posterior mandible	Local second surgical site	Limited quantity and quality of bone	5 cc	Infection, jaw fracture, paresthesia
Anterior mandible	Local second surgical site; cortical and cancellous bone can be harvested	Limited quantity and quality of bone	5 cc	Pain, dental injury, infection, jaw fracture
Maxillary tuberosity	Local second surgical site	"Fatty" consistency of bone	2–3 cc	Infection, antral perforation, alveolar fracture

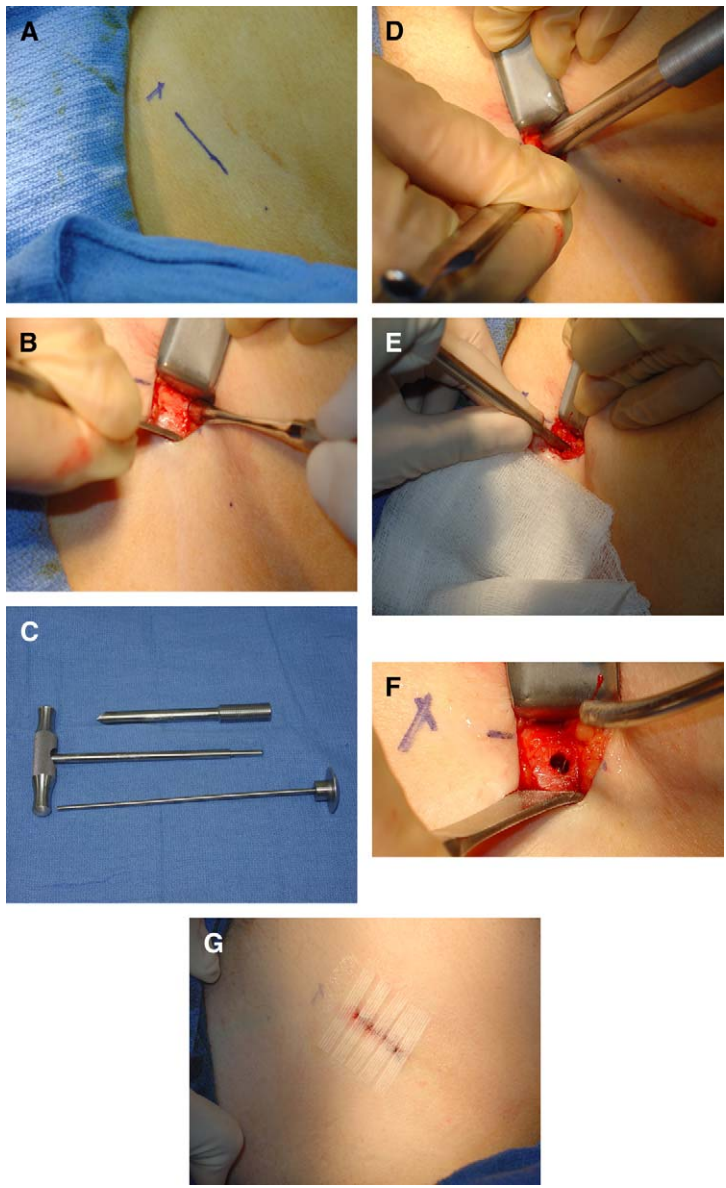

Fig. 3. (*A*) The surgical approach to the ileac crest begins by outlining the incision over the crest, posterior to the ischial tubercle. (*B*) Dissection is carried through skin, subcutaneous tissue, and fat, to Scarpa's fascia and periosteum. (*C*) A trephine is a tool for harvesting bone in a minimally invasive manner. (*D*) The sleeve of the trephine engages the bone. (*E*) The blade is rotated and advanced to traverse the cortical plate and engage cancellous bone. (*F*) The core is removed. (*G*) The incision is closed in layers.

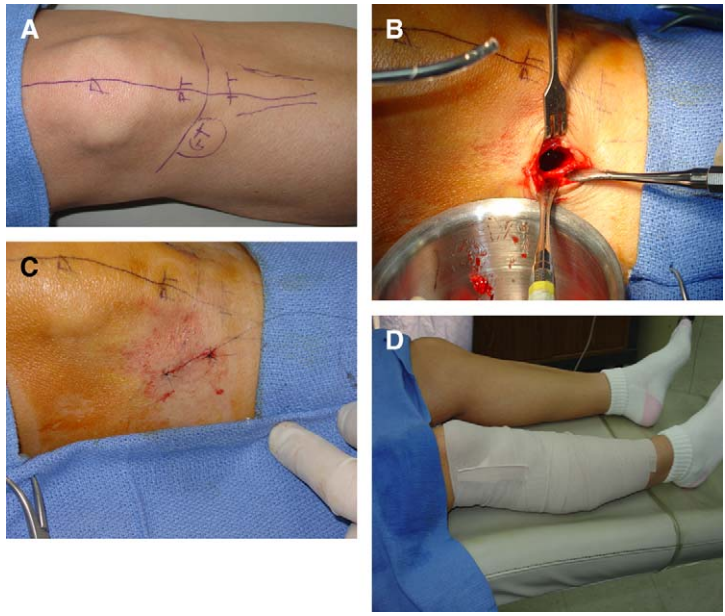

Fig. 4. (*A*) The surgical approach to the tibia begins by identifying the important landmarks. (*B*) Incision and dissection are carried down to the periosteum. (*C*) The incision is closed in layers. (*D*) The surgical site is dressed.

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 specific 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, harvesting from these sites poses risks of dental injury and jaw fracture.

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. Here, 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 using one of 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 using 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 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 (ie, 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. 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 to 3 cc of bone can be harvested, which limits its usefulness, even if mixed with alloplasts or allogeneic materials (Fig. 5). 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 an incision along the height of the tuberosity to bone with subsequent reflection of a full thickness flap. Ensure that the pterygomaxillary fissure is protected during surgery. Care must be taken to avoid fracturing the posterior maxilla during the procedure.

Complications of sinus augmentation

As noted above, the maxillary sinus does not have a dependent drainage system and therefore is susceptible to infection and fluid sequestration. The anatomy, however, also favors the implant surgeon in one important respect

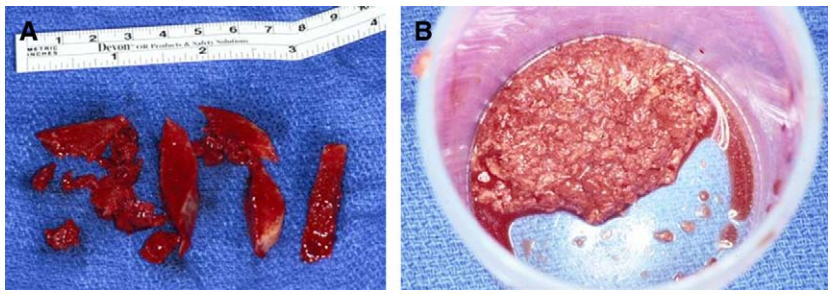

Fig. 5. Autogenous bone can be morselized and used alone (*A*) or mixed (*B*) with alloplastic or allogeneic material.

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. Other signs are fever and general malaise [22]. Acute infection is managed after surgery with antibiotic therapy directed at flora of the upper respiratory tract. Drainage may occur spontaneously through the wound margins or fistulize through the oral mucosa into the vestibule. 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. The use of decongestants is somewhat controversial in the postoperative management of patients undergoing sinus augmentation because decongestants 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.

Advances in biotechnology

The science of bone grafting promises great changes for dental implants. The relevant recent advances in biotechnology include those related to stem cell therapy and recombinant bone morphogenic protein. The pluripotentiality of human progenitor cells is well documented. Stem cell research seeks to capture this ability by obtaining these pluripotential cells and stimulating them to differentiate down specific cell lines. The stimulation of stem cells to form osteoblasts and subsequently form bone would be a tremendous advance in the realm of bone grafting. Meanwhile, the biotechnology of recombinant bone morphogenic protein has already arrived for direct patient care [23]. Currently, its use is restricted to certain clinical orthopedic applications by the US Food and Drug Administration. However, even with ultimate approval for use in the maxillofacial region, cost may limit its application for routine dental implant therapy. Platelet-rich plasma is yet another example of tissue engineering that has potential clinical applications in maxillofacial bone grafting [24]. This process involves the separation of autologous blood by centrifuge to yield platelet-rich plasma. This plasma concentrate contains elevated platelets and white blood cells. The platelets contain platelet derived growth factor, amongst other growth factors.

Theoretically, these factors significantly enhance wound and bone healing. This technology is used commonly for sinus augmentation procedures and is often combined with autogenous bone grafting. While some studies have shown encouraging results, others have failed to demonstrate an effect [25,26]. Thus, it is difficult to prescribe unequivocal evidence-based guidelines for the use of platelet-rich plasma [19].

References

[1] Tatum H Jr. Maxillary and sinus implant reconstructions. Dent Clin North Am 1986;30(2): 207–29.
[2] Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1980;38(8):613–6.
[3] Hollinshed WH. Anatomy for surgeons: the head and neck. Philadelphia: Lippincott; 1982.
[4] Velasquez-Plata D, Hovey LR, Peach CC, et al. Maxillary sinus septa: a 3-dimensional computerized tomographic scan analysis. Int J Oral Maxillofac Implants 2002;17(6):854–60.
[5] Ballenger JJ. Ballenger's otorhinolaryngology head and neck surgery. Hamilton (Canada): BC Decker; 2003.
[6] Nemcovsky CE, Winocur E, Pupkin J, et al. Sinus floor augmentation through a rotated palatal flap at the time of tooth extraction. Int J Periodontics Restorative Dent 2004;24(2): 177–83.
[7] Bell WH. Le Fort I osteotomy. In: Bell WH, editor. The surgical correction of dento-facial deformities—new concepts. Philadelphia: WB Saunders; 1985. p. 15–45.
[8] Hallman M, Sennerby L, Lundgren S. A clinical and histologic evaluation of implant integration in the posterior maxilla after sinus floor augmentation with autogenous bone, bovine hydroxyapatite, or a 20:80 mixture. Int J Oral Maxillofac Implants 2002;17(5):635–43.
[9] Artzi Z, Nemcovsky CE, Tal H, et al. Histopathological morphometric evaluation of 2 different hydroxyapatite-bone derivatives in sinus augmentation procedures: a comparative study in humans. J Periodontol 2001;72(7):911–20.
[10] Artzi Z, Nemcovsky CE, Dayan D. Nonceramic hydroxyapatite bone derivative in sinus augmentation procedures: clinical and histomorphometric observations in 10 consecutive cases. Int J Periodontics Restorative Dent 2003;23(4):381–9.
[11] Artzi Z, Kozlovsky A, Nemcovsky CE, et al. The amount of newly formed bone in sinus grafting procedures depends on tissue depth as well as the type and residual amount of the grafted material. J Clin Periodontol 2005;32(2):193–9.
[12] Thomas MV, Puleo DA, Al-Sabbagh M. Calcium sulfate: a review. J Long Term Eff Med Implants 2005;15(6):599–607.
[13] Pecora GE, De Leonardis D, Della Rocca C, et al. Short-term healing following the use of calcium sulfate as a grafting material for sinus augmentation: a clinical report. Int J Oral Maxillofac Implants 1998;13(6):866–73.
[14] De Leonardis D, Pecora GE. Augmentation of the maxillary sinus with calcium sulfate: one-year clinical report from a prospective longitudinal study. Int J Oral Maxillofac Implants 1999;14(6):869–78.
[15] Thomas MV, Puleo DA, Al-Sabbagh M. Bioactive glass three decades on. J Long Term Eff Med Implants 2005;15(6):585–97.
[16] Tadjoedin ES, de Lange GL, Lyaruu DM, et al. High concentrations of bioactive glass material (BioGran) vs. autogenous bone for sinus floor elevation. Clin Oral Implants Res 2002; 13(4):428–36.
[17] Tadjoedin ES, de Lange GL, Holzmann PJ, et al. Histological observations on biopsies harvested following sinus floor elevation using a bioactive glass material of narrow size range. Clin Oral Implants Res 2000;11(4):334–44.

[18] Cordioli G, Mazzocco C, Schepers E, et al. Maxillary sinus floor augmentation using bioactive glass granules and autogenous bone with simultaneous implant placement. Clinical and histological findings. Clin Oral Implants Res 2001;12(3):270–8.
[19] Wallace SS, Froum SJ. Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol 2003;8(1):328–43.
[20] Karabuda C, Ozdemir O, Tosun T, et al. Histological and clinical evaluation of 3 different grafting materials for sinus lifting procedure based on 8 cases. J Periodontol 2001;72(10): 1436–42.
[21] Haas R, Haidvogl D, Dortbudak O, et al. Freeze-dried bone for maxillary sinus augmentation in sheep. Part II: biomechanical findings. Clin Oral Implants Res 2002;13(6):581–6.
[22] Daley CL, Sande M. The runny nose. Infection of the paranasal sinuses. Infect Dis Clin North Am 1988;2(1):131–47.
[23] Wozney JA. Biology and clinical applications of rhBMP-2. In: Lynch S, Genco RJ, Marx RE, editors. Tissue engineering applications in maxillofacial surgery and periodontics. Chicago: Quintessence; 1999. p. 103–24.
[24] Marx RE. Platelet-rich plasma: a source of multiple autologous growth factors for bone grafts. In: Lynch S, Genco RJ, Marx RE, editors. Tissue engineering applications in maxillofacial surgery and periodontics. Chicago: Quintessence; 1999. p. 71–82.
[25] Grageda E, Lozada JL, Boyne PJ, et al. Bone formation in the maxillary sinus by using platelet-rich plasma: an experimental study in sheep. J Oral Implantol 2005;31(1):2–17.
[26] Jakse N, Tangl S, Gilli R, et al. Influence of PRP on autogenous sinus grafts. An experimental study on sheep. Clin Oral Implants Res 2003;14(5):578–83.