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Bone Substitutes for Sinus Lift

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Abstract:

Implant is the best alternative option nowadays for missing tooth replacement. Lack of bone height poses a significant difficulty for its placement. Bone augmentation is an option to counter this problem. In maxilla, to treat this local physiological as well as anatomical limitation, maxillary sinus floor elevation has become an important pre-placement procedure. Various methodologies have evolved to increase the thickness of maxillary sinus floor. One of the techniques involve simple and minimal elevation of maxillary sinus membrane, Schneiderian membrane, while other include placement of various type of grafts including allografts, autografts, bone morphogenetic proteins, and hydroxyapatite crystals. This review deals with the bone substitutes used in sinus lift.

Keywords: implant, Schneiderian membrane elevation, sinus lift, bone graft

INTRODUCTION:

It is frequently encountered in clinical situations where the bone volume is insufficient for an ideal dental implant placement and bone regeneration can provide the structural support necessary in these cases. Sinus lifting and alveolar ridge augmentation are procedures with high success rate and about 10-20% of the patients need them before the placement of implants. From 1980´s, bone substitutes have been used in this field.

Bone regeneration procedures are becoming an important as a result of the wide acceptance of dental implants as the "ideal" option for oral rehabilitation. These procedures are critical for the success of dental implant treatments in cases where there is a deficiency in bone width and/or height. The cornerstone in these treatments is the use of bone substitutes to create a bone mantle that covers the screw to enhance implant stability and treatment outcome. For this purpose, bone grafts are used which is osteogenic, osteoinductive, osteoconductive and is biodegradable. [1]

MAXILLA-ANATOMY:

The alveolar process of the maxilla has a compact cortical layer with high density and an inner porous cancellous bone filled with bone marrow. The bone has cylindrical channels called Haversian canals and contains blood vessels that supply the bone with nutrition and oxygen.

The bone cells are osteogenic cells and osteoclasts and they have different functions and structures. Osteogenic cells include osteoprogenitors, preosteoblasts, osteoblasts and osteocytes. Mesenchymal cells are first converted to osteoprogenitors and later to preosteoblast cells, which in turn are transformed to osteoblast cells.

The osteoblast cells produce osteoid; a noncalcified matrix which contains collagen and non-collagenous protein bone matrix. Osteoblasts also secrete several cytokines and bone morphologic proteins (BMP). The cytokines and hormones play a major part in bone healing and lead to increased bone regeneration. When osteoblasts stop producing matrix they convert into osteocytes and are buried in the calcified bone. [2]

SINUS LIFT:

The lack of bone volume can be treated with various bone grafting techniques before the implant placement. Boyne & James (1980) was the first to introduce maxillary sinus floor augmentation with autologous bone graft. This technique has been modified and improved by Tatum (1986) who introduced the lateral approach by fenestrating the buccal wall of maxillary sinus and lifting the Schneiderian membrane. This technique was modified by Wood and More in 1988.

The sinus floor augmentation procedure can be divided into two different techniques. The first of the two techniques is called the osteotomy technique and it is performed by the use of osteotomes to create a controlled fracture of the floor of the maxillary sinus. This method creates space by elevating the sinus membrane and provides room for the dental implant and bone grafting material. The advantage of this technique is that it is less invasive and thereby reduced surgical time and lower morbidity compared to other sinus lift techniques. This technique is suggested to be used when the vertical bone height is more than 4-6mm.

The second technique is the lateral window technique and is performed by surgical preparing of the bone, lateral to the maxillary sinus, and thereby exposing the Schneiderian membrane which will be elevated. The bone graft material is carefully packed and placed on the sinus floor. [3] This technique is more invasive than the osteotome technique due to the fenestration of the lateral sinus wall. The lateral window technique is preferred when there is less than 6 mm residual bone height. [4]

Direct Sinus Augmentation Technique (DSAT)

Those cases that has residual alveolar bone (RAB) height 5 mm or below was considered for the direct technique. Autogenous bone grafts was harvested by shaving the mandibular bone from external oblique ridge area or chin area. A bone mill was used to grind the bone shaving

into fine particles. After adequate local anesthesia and preparation, a surgical incision was placed on the crest of the RAB at most appropriate area, with vertical releasing curvilinear incisions flaring into the vestibule. Full-thickness, subperiosteal labial, and palatal flaps were raised, reflected. Care was taken to keep the base of flap broad as well as adequate buccal and palatal tissue for closure. After elevation, the anterolateral wall of maxillary sinus was visualized. Care was taken to identify and protect infraorbital nerve, if encountered. The dimension of osteotomy was determined based on clinical and radiographic examinations as well as the extent of edentulous span. A buccal bone window was made on exposed wall of maxillary sinus using a postage stamp method. The bony wall was gently manipulated with sinus membrane elevators without damaging Schneiderian membrane. The previously obtained graft material was then placed and packed. The implant was placed on same sitting with help of a stent which was positioned, then removed, and the site was checked for appropriate faciolingual and mesiodistal positioning . Any obvious abnormal crestal defects required slight modification of the position. [4]

Indirect Sinus Augmentation Technique (ISAT)

Indirect sinus augmentation is done for cases with RAB height of 6-8 mm . The RAB to receive the implant was given local anesthesia and perforated using a small rounded drill. A pilot drill was placed in marked implant site to establish the axis of implant recipient site. Following the pilot drill, subsequently increasing diameter of drills were used to enlarge implant recipient site till the desired diameter corresponding to implant diameter was reached. The height of drill was maintained 2 mm short of sinus floor. The indirect sinus lift was done by insertion of correct caliber osteotome and working up through successively greater instrument diameters, until the sinus floor was fractured and elevated up. The sinus floor was carefully fractured, separated from the Schneiderian membrane avoiding damage to membrane using a surgical mallet with controlled force. If required, autogenous graft material was inserted within the socket. The material was displaced apically with help of larger-diameter instruments, thereby lifting the membrane and condensing graft material between the latter and sinus floor. The implant was then placed immediately in the prepared site. 3-0 Vicryl sutures were used to close the surgical wound. Antibiotic coverage, pain killers, and nasal decongestants were prescribed for 5 days. The patients were monitored on a periodic basis both clinically and radiologically.[4]

BONE HEALING:

Bone healing after graft placement takes place in two phases: Repair with an inflammatory response and bone remodeling. In the first phase a blood clot is formed in the injured area where the outer area of the local bone becomes necrotic and the capillaries start to develop and further on migration of inflammatory cells e.g. lymphocytes, granulocytes and monocytes occur. This action restores blood flow and after 1-3 days an inflammatory response is active and granulation tissue is starting to form. The granulation tissue will mature to a collagen matrix and mesenchymal stem cells begin to differentiate into osteoblasts cells forming new bone.

During the second phase, the bone remodel, and is replaced by a more mature lamellar bone and a complete regeneration of a defect occurs when all bone is replaced with lamellar bone. [2]

BONE GRAFTS:

The ideal bone grafting material should have both osteoinductive and osteoconductive properties and be able to osseointegrate to the implant surface. These properties vary in different bone grafting materials .

Osteoinduction is defined as primitive, undifferentiated and pluripotent cells that are stimulated by an inductive means to become bone-forming cells and osteogenesis is induced.

Osteoconduction means that bone grows on a surface. An osteoconductive surface allows bone growth on the surface and down into the pits and pores .The grafting material used in maxillary sinus floor augmentation is expected to allow new natural bone formation with capillary infiltration and to provide the capacity for replacing the bone graft material and supporting the implants with adequate bone volume.

Various categories of bone graft materials can be placed in the maxillary sinus, such as autologous bone, allografts, xenografts and alloplasts.

Bone graft materials can be divided in four large groups: Autografts, Allografts, Xenografts and Synthetic biomaterials.

Autograft:

"Autograft" refers to bone tissue harvested from, and implanted in the same individual. Accordingly, autograft is a bone tissue that is separated from one site and implanted in other location in the same individual. The cellular component of trabecular bone graft includes few osteoblasts and a high number of precursor cells that survive the transplantation. These precursor cells explain the osteogenic potential of bone autograft. Autograft is considered the **"gold standard**" in bone regeneration due to its properties of osteoconduction, osteoinduction, osteogenicity and osteointegration. However there are major drawbacks to the use of this sort of ideal bone graft, namely the necessity of a second surgery to retrieve the bone graft at the donor site, with its associated morbidity; the increasing surgery time, the restrictions in quantity and shape of the bone graft, and the additional cost. [5,6]

Autografts are subdivided in two groups: cancellous autografts and cortical autografts. Cancellous autografts are retrieved mainly from cancellous bone, and upon transplantation, the majority of cells present in the grafts die as result of ischemia. However, the mesenchymal stem cells present in the bone marrow are resistant to ischemia and may survive the grafting procedure. The stem cells capacity of survival and proliferation after exposure to changes in the oxygen tension, pH and cytokine environment is the main reason behind the reliability of of cancellous bone autograft interventions. The incorporation of such type of autograft is speed, about 8 weeks. [7]

Cortical autografts are segments of cortical bone composed of necrotic bone that provides an osteoconductive support for bone formation, but does not supply significant amounts of living cells. For this reason, revascularization and integration of cortical autografts is slow. The main advantage of cortical autografts is the mechanical support that provides at the graft site [8], while its incorporation is slower than cancellous autografts. [1]

Allografts:

Freeze dried bone allograft (FDBA) and demineralized freeze dried bone allograft (DFDBA)

Allograft is defined as tissue that has been harvested from one individual and implanted into another individual of the same species.[9] The use of cadaver bone for grafting is known as bone allograft and it is considered by some the best available alternative to autografts due its similarly characteristics. Despite the superior properties of autografts, allografts are usually preferred by patients as bone grafting material because they the problems associated to donor site surgery in autografts. Allografts are obtained from cadaver tissue banks for mineralized freeze-dried (FDBA) or decalcified freeze-dried (DFDBA) bone. Both FDBA and DFDBA are obtained from cortical bone of long bones due to its high content of bone inductive proteins and less antigenic activity than cancellous bone. Bone allografts come in various configurations, including powder, cortical chips, cancellous cubes, and cortical granules among others.[9] The granulated form is obtained by milling the cortical bone under sterile conditions to obtain a particle size ranging from 250 to 750 μm. Moreover, allografts have been recently made available in different block forms; although their mechanical properties remain slightly lower than those of autograft cortical blocks.

Once the allograft is harvested they are processed through several methods including physical debridement to remove soft tissue and reduced cellular load, ultrasonic washing to remove remnant cells and blood, ethanol treatment in order to denaturalize proteins and viral deactivation, antibiotic wash to kill bacteria, and sterilization through gamma radiation and ethylene oxide for spore elimination. FDBA are washed in antibiotic twice for 1 hour, frozen at -70Co and dried up to 5% of water.

FDBA: Mineralized bone matrix has no active bone morphogenetic proteins (BMPs) and therefore it lacks osteoinductive properties, although it has osteoconductive properties. Graft incorporation is qualitatively similar to autograft, but occur more slowly. Cortical allografts will incorporate and eventually resemble their autograft counterpart although with more unremodeled necrotic bone present in allografts. [10] Milled forms present an open structure that facilitate invasion by blood cells, enhance graft incorporation and allows mixing with blood, platelet concentrates and other graft materials forming composites.

DFDBA: DFDBA forms are processed by acid demineralization in 0.5 to 0.6 molar hydrochloric acid as a result, 40% of the mineral content is removed leaving the organic matrix intact. This process preserves the BMPs present in bone, and therefore maintains some of the inherent osteoinductive properties. [11] Moreover, the collagen matrix present in DFDBA acts as a scaffold that provides osteoconductive properties alone side the osteoinductive behavior. Osteoinductivity of DFDBA was first described by Urist et al, after observing endochondral bone formation on DFDBA when placed in soft tissue. It has since been discovered that BMPs are the factors responsible for the novo bone formation.[12] BMPs are associated with the organic matrix of bone and embedded within mineral content, so demineralised process increases its bioavailability. BMPs attract mesenchymal stem cells and induce them to differentiate into chondrocytes leading into endochondral bone formation. Endochondral bone formation is attributed to a osteoinductivity response, while intra-membranous bone formation is indicative of an osteoconductive response. Nevertheless, osteoinductivity of DFDBA has been recently questioned, since it seems that this property is highly dependent on the manufacturing procedures.[13]

The main advantage of allografts include easy availability, avoiding the need of harvesting a patient donor site, reduced costs in terms of anesthesia (general anesthesia is not needed) and reduced surgical time. However, the use of cadaver bone for grafting is avoided by many clinicians due to its potential risk of infectious disease.

Allografts are available in the form of granules and blocks. Allograft granules' appearance is similar to other bone substitute granules, and they are ideal to fill bone cavities as alveolar bone defects and maxillary sinus. On the other hand, allograft blocks are especially useful in both vertical and horizontal bone augmentation procedures. [1]

Xenografts:

Anorganic bovine bone (ABB)

Bone xenograft is defined a bone tissue harvested from one species and implanted into a different species. One of the most commonly used xenografts is anorganic bovine bone (ABB).

ABB has an ultrastructural composition similar to human bone, it is composed of almost pure hydroxyapatite, and it is chemically treated to remove all organic components so it can be used as a graft material without causing host immune response. ABB is thermally and chemically treated in order to extract organic constituents and thereby eliminating its antigenicity and potential inflammatory response by the host bone. [14]The structure consists of a wide interconnective pore system with a particle size of 0.25 to 1 mm that can easily be invaded by blood vessels resulting in osteoblastic migration. . ABB is up to 75% porous and has a high specific surface area of almost 100 m2/g that results in increased angiogenesis, enhances new bone growth[15,16],and excellent osteoconduction properties. However, its highly porous consistency sometimes compromises its mechanical properties and its initial stability. ABB lacks osteoinductive properties, and its presentation in form of granules makes it difficult to hold on surgical sites. Moreover, it is non resorbable in vivo. Indeed, ABB might need several years (3-6 years) of implantation before showing some slow in vivo resorption through osteoclast activity, (Skoglung et al, reported that

granules were present even after 44 months [17]. The presence of unresorbed granules within the newly formed bone is undesired because it affects the quality of the newly formed bone by interfering with its remodelling, compromising its osteointegration capacity with dental implants. [1]

Although ABB is mostly used in form of granules, xenografts blocks design are also available. Xenogenic derived bone block have already been reported to achieve vertical bone augmentation in the mandible. However, these materials are quite brittle and fragile. This mechanical inconvenience not only complicates the surgical technique but it also hinders the bone graft healing process.[18,19] Other types of xenogenic (porcine) bone block seem to show better mechanical properties and low risk of fracture while screwing. Generally speaking, the use of xenogenic bone blocks is still under evaluation and at this moment there is not sufficient information regarding its invivo behavior.

Synthetic Calcium Phosphates:

Calcium phosphates constitute synthetic biomaterials that chemically resemble the bone mineral. Calcium phosphate biomaterials are widely selected to regenerate bone tissue due to their biocompatibility, osteointegration and osteoconductivity.

It contains high levels of Ca^{2+} ions have alkaline pH and therefore shows low resorption capability as hydroxyapatite (AP), while materials with low levels of Ca^{2+}ions have acid Ph and shows high resorption properties, as dicalcium phosphate forms.

According to their preparation, calcium phosphate could be divided into high temperature (ceramics of tricalcium phosphates, hydroxyapatite and biphasic calcium phosphate) and low temperature (cements) calcium phosphates. Such bone substitutes differ in the degradation rate in vivo, strength, alkalinity and acidity, and crystallographic structure. Generally, they are fragile materials and should be used in non-load bearing areas. Hydroxyapatite and beta-tricalcium phosphate (beta-TCP) are the ceramics mostly recruited clinically to treat bone defects and voids. Biological, stoichiometric hydroxyapatite of Ca/P ratio of 1.67 is highly stable and its very slow degradation is mediated by phagocytosis. Such handicap is managed by introducing impurities like carbonate ions, silicon ions and other ionic species present in the bone mineral. Structurally, porous hydroxyapatite was introduced to resemble native bone architecture, improve the degradability and enhance tissue reaction of angiogenesis and new bone in-growth. This resulted in engineering apatite and calcium carbonate of live species to produce a hydroxypatite conserving the macro and microporous architecture of the source . An example of such technology is the an organic bovine bone, coral apatite and algae apatite.

Biphasic calcium phosphate (BCP) is engineered to combine the advantages of both hydroxyapatite and beta-TCP. A relation of 60% hydroxyapatite and 40% beta-TCP is the most common among commercial biphasic calcium phosphate.

Calcium phosphate cements are classified according to the setting reaction end-product to hydroxyapatite and brushite cements. Hydroxyapatite cement is first developed by Brown and co-workers and since then various formulation have been developed and patented. Of such formulations are tetracalcium phosphate/dicalcium phosphate anhydrous (DCPA) system and beta-TCP based system. The setting reaction of hydroxyapatite cement occurs at neutral pH which is biologically favorable. The hydroxyapatite as setting product is low- crystalline and the stoichiometry can be varied to produce calcium deficient-hydroxyapatite (Ca/P ratio less than 1.67). These features and the development of carbonated apatite cement improve the degradability of hydroxyapatite cement.

Since their development by Mirtchi and co-workers, brushite cements are receiving much interest as bone substitute in the recent years. These cements are obtained by various combinations, such as beta-TCP + monocalcium phosphate monohydrate (MCPM) and beta-TCP + phosphoric acid. The setting reaction of these cements is a continuous dissolution/precipitation mechanism at low pH values as brushite precipitates at pH <6. The relatively short setting time of brushite cements compared with hydroxyapatite forming pastes depends on both the higher solubility of the cement raw materials and the higher rate of brushite crystal growth (3.32×10^{-4} mol min^{-1} m^{-2}) [compared with hydroxyapatite (2.7×10^{-7} mol min^{-1} m^{-2}). The main advantage of brushite is its higher degradability compared to hydroxypatite that stems from higher solubility at physiological conditions. However, in vivo brushite transformation to hydroxyapatite is kinetically favorable and additives are patented to inhibit such transformation. This fact has raised the attention to the anhydrous form of brushite, monetite that is prepared by drying brushite. Monetite is more stable than brushite due to its lower solubility and in vivo transformation to hydroxyapatite was not reported ensuring a predictable degradability.[20]

Bio glass:

Bioglass, also known as bioactive glass, is the commercial name for the first calcium substituted silicon oxide that was marketed as a bone regeneration material over 30 years ago. This material was developed by researchers working for the US army during the Vietnam War as a biomaterial for repairing bone loss in injured combat soldiers.[21] Bioglass has a large surface area that is alkaline and highly reactive to serum ions. This feature enables it to interact with serum, allowing a very fast precipitation of hydroxyapatite on its surface once implanted in vivo. This phenomenon is called bioactivity, and is one of the unique characteristics of Bioglass that allows a quick integration to bone tissue.

Bioglass is suitable for bone regeneration in dental implant surgery; moreover, it is purely synthetic therefore it does not present problems regarding transmission of infectious diseases. However, its granule format is difficult to handle due to the repulsive charges between the highly charged surfaces the granules. This renders its clinical handling more demanding than other biomaterials. [21]

The critical component of bioglass is SiO_2 which constitutes 45-60% of its weight. The first bioglass developed for bone regeneration was based on 4 components: SiO_2, Na_2O, CaO and P_2O_5.However, this composition tends to crystallize, and was modified to a more stable glass composed of: Na_2O-K_2O-MgO-CaO-B_2O_3-P_2O_5-SiO_2.

In vivo experiments have shown that implantation of bioglass in bone defects causes an inhibition in bone formation during the early healing stages, but it eventually doubles the amount of bone formed when no biomaterial is used.

Moreover, bioglass experiences sever resorption during the first 2 weeks after implantation. However, beyond this point its resorption rate is stabilizes.

Upon implantation, the smaller ions present in bioglass (i.e. Na^+ and K^+) tend to leach to the extracellular fluids. This results in a rich Si layer coating the biomaterial. Ca^{2+} and PO_4^{3-} ions from the body fluids then react and precipitate on the Si rich layer, forming a thin coat of hydroxyapatite. The calcium phosphate layer adsorbs proteins. [1] And these extracellular properties attract macrophages stem cells and osteoprogenitor cells.[21] Bioactive glass can be used in form of granules or as preformed cones designed for placement into fresh sockets to maintain the alveolar ridge.[22] It has shown clinical success in vertical bone augmentation procedures, in regeneration intra-bony defects and in the preservation of alveolar sockets.[23] However, even though it is resorbable and promotes bone formation, its bone regeneration capacity in maxillofacial surgery has been shown to be lower than Calcium phosphate biomaterials.

Other bone grafts:

Protein rich plasma: Protein rich plasma (PRP) is obtained when the blood is separated by centrifugation. PRP is mixed with calcium-chloride which gives its anticoagulant effect and the manageable gel mass, which give the increased stability when placed. PRP delivers a high concentration of angiogenic mitogenic growth factors which should accelerate the healing process of soft tissue. [2]

Combination of Bio-Oss and Autologous bone: Galindo et al. suggests that this composite graft could from a biological perspective give a better product with the use of both materials advantages in one graft material. [2]

CONCLUSION:

The techniques employed in this manuscript has facilitated implant placement in areas of limited bone height, improved primary stability, high implant success in posterior maxilla, simple, and minimally invasive surgery with increased success. [4]

Since the introduction of dental implants, bone grafting has become an important procedure required for the treatment of patients with limited bone availability. Bone autograft, alone or together with other bone substitutes, has been the biomaterial of choice for clinicians worldwide. However different xenogenic, allogenic and synthetic biomaterials have shown promising results in many bone augmentation procedures. [1] The major part of success with implant placement lies in the treatment planning. It is utmost importance that the preoperative evaluations are done perfectly and the most suitable technique is decided accordingly for that particular situation, to improve the prognosis of that treatment. [24] Thus the bone substitute needed for each bone regeneration procedure must be selected based on the individual´s characteristics, and the surgical procedure itself. Factors such as the osteogenic potential of the host residual bone, systemic health of patients, and morphology of the defects, will delimit the ideal bone substitute for each situation. [4]

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