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Various Ways to Enhance the Results of Maxillary Sinus Augmentation Procedures

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1. Introduction

The placement of dental implants in the distal edentulous maxillary region is challenging due to the significant resorption following tooth extraction and the pneumatization of the maxillary sinus (Tadjoedin et al., 2003). Maxillary sinus augmentation is a well-established procedure for functional rehabilitation of partially or completely edentulous patients, as demonstrated by Boyne and James (1980) (Boyne and James 1980) (Figures 1-4). The survival rate for implants placed in graft sinuses showed comparable results to those generally reported for implants placed in pristine bone in the non-grafted posterior maxilla (Wallace and Froum 2003).

Fig. 1. Preoperative clinical view.

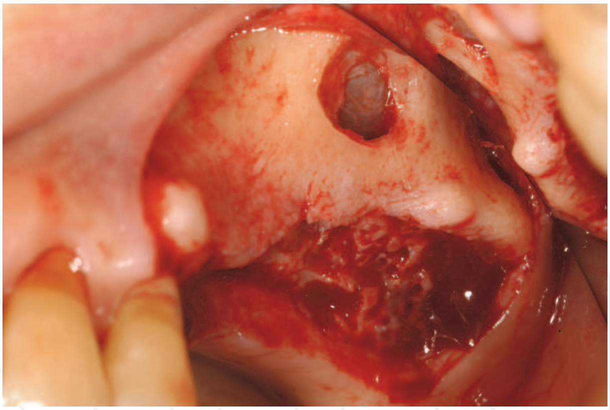

Fig. 2. Buccal view after elevation of sinus membrane.

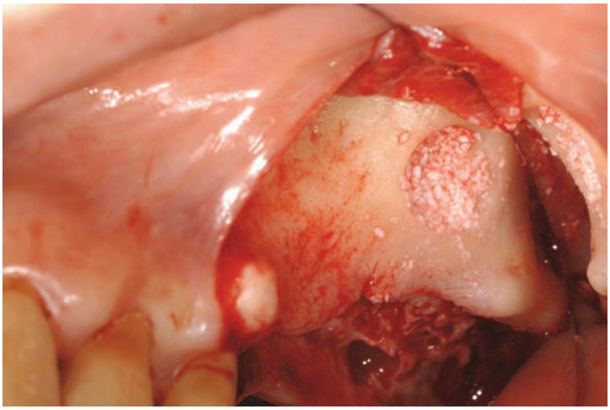

Fig. 3. Clinical view after application of graft material.

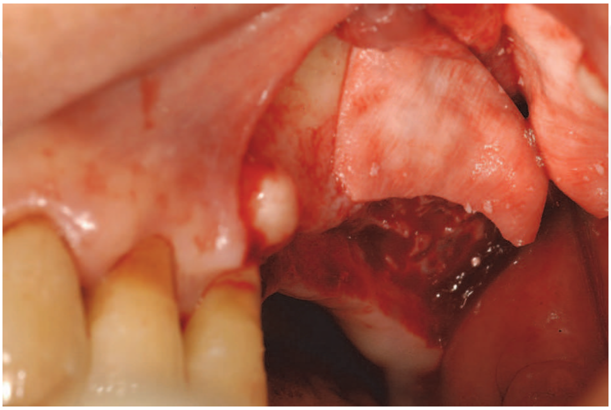

Fig. 4. The lateral wall is covered with a membrane.

Autogenous bone obtained from various donor sites from the patients performed with good results in bone regeneration and served as the gold standard (Tadjoedin et al., 2003). Various bone-grafting materials are being used in sinus augmentation including freeze-dried bone allograft (Avila et al., 2010), bovine xenograft (Chaushu et al., 2009), and alloplastic material (Bae et al., 2010) as an alternative or supplement to autogenous bone. Sinus augmentation procedures are highly predictable, with many studies reporting over 95% success (Del Fabbro et al., 2008). However, sinus augmentation may be influenced by the choice of graft material and implant surface micromorphology (Del Fabbro et al., 2008), and controversies still exist related to the most suitable way to perform sinus augmentation.

2. Type of graft

2.1 Autogenous graft

Although autogenous bone grafting is still the gold standard, according to the clinical results (Nkenke and Stelzle 2009), it is considered to have osteoinductive and osteoconductive properties, and it is known to contain growth factors (Turhani et al., 2005). Autogenous corticocancellous bone cores can be obtained intraorally or extraorally (Galindo-Moreno et al., 2007), however, this requires an additional second surgical donor site and additional morbidity (Park 2010).

A bone trap may be used to harvest bone debris during implant preparation, with additional bone collected by further drilling adjacent to the implant sites or by using a bone scraper to harvest cortical bone chips from the zygomatic buttress and from the lateral sinus wall before opening a bony window (Johansson et al., 2010). By using this approach, the autogenous bone can be achieved adjacent to the surgical site without the need for a remote second surgical donor site and additional morbidity (Park 2010). Furthermore, the amount of autogenous bone graft available for harvesting is limited and may be insufficient to fill large osseous defects (Mirzayan et al., 2001). Due to the complications associated with harvesting autogenous bone and its limited supply, many surgeons have sought bone-graft-substitute materials (Mirzayan et al., 2001).

2.2 Allograft

Allograft has been used for grafting in multiple intraoral applications such as periodontics (infrabony defects), oral surgery (extraction sites), and implant dentistry (ridge augmentation) (Froum et al., 2006). Allografts are bony tissue from a donor of the same species and they are known to contain no viable cells (Hallman and Thor 2008). This allograft may be prepared by demineralization of the bone in hydrochloric acid to expose bone morphogenetic protein and this demineralized freeze-dried bone allograft may be considered to have osteoconductivity and osteoinductivitiy (Kalish et al., 2008).

Atrophic maxillary floor augmentations were performed by mineralized human bone allograft in sinuses of different size, and the results showed that this material produced satisfactory bone formation (Maria Soardi et al., 2010). Histologic evaluation using mineralized freeze-dried bone allografts for sinus augmentation revealed a mean of 29.1% newly formed bone and graft particles were mainly in close contact with newly formed bone, primarily with features of mature bone with numerous osteocytes (Kolerman et al., 2008). Similar results were achieved with other reports that most of the specimens presented newly formed bone, and the interface areas between new and old bone were not discernible (Stacchi et al., 2008). There was no evidence of an acute inflammatory infiltrate in both studies (Kolerman et al., 2008; Stacchi et al., 2008).

However, histological evaluation revealed a chronic inflammatory reaction when demineralized freeze-dried bone was used in sinus augmentation, and the authors suggested that demineralized freeze-dried bone homografts may not be recommended to be used alone (Haas et al., 2002).

2.3 Xenograft

Deproteinized bovine bone is one of the most widely researched grafting materials and is used in the maxillofacial region because of its similarity to human (Hallman and Thor 2008). The complete absence of protein has been demonstrated, and its safety with respect to transmission of disease has been confirmed (Norton et al., 2003). Deproteinized cancellous bovine bone was placed as a grafting material for sinus floor elevation and histologic evaluation was performed after 6 months of healing (Valentini et al., 1998). Histologic evaluation showed that, in the grafted area and the previously existing area of the sinus floor, the bone was primarily of lamellar structure and intimate contact between newly formed bone and the particles of the graft was present (Valentini et al., 1998).

Dental implants installed in sinuses augmented with xenograft showed bone-to-implant contact of 27% to 63%, and xenograft was shown to be very slowly restored and seemed to behave as a semipermanent grafting material (Wallace and Froum 2003). If xenograft is used with autogenous bone, this may give additional advantages such as an increase in the volume of the graft and longer space-maintaining effects due to prolonged resorption (Galindo-Moreno et al., 2007).

2.4 Alloplastic materials

Alloplastic materials consist of a large group of chemically diverse synthetic calcium-based biomaterials, including calcium sulfate, calcium phosphate, bioactive glasses, and polymers (Hallman and Thor 2008), and these bone substitutes possess osteoconductive properties (Moore et al., 2001).

A study by Zijderveld, Zerbo, et al. showed that sinus augmentation using a limited volume of beta-tricalcium phosphate appeared to be a clinically reliable procedure, although autogenous bone grafting is still the gold standard (2005) (Zijderveld et al., 2005). This material is reported to act as an osteoconductive material and it allows osteoprogenitor cells to grow on its surface or into its porosity and differentiate into osteoblasts, thus bringing about bone deposition (Zerbo et al., 2005).

Calcium sulfate hemihydrate has been proposed as a grafting material for sinus augmentation, and this resulted in good, new tissue formation within the sinuses when clinically and radiographically evaluated. The histomorphometiric analysis revealed bone density of 34.3% to 55.54% (De Leonardis and Pecora 2000). Similar results were achieved by other investigators (Pecora et al., 1998), and the study done at two years revealed new irregular trabecular design was seen radiographically and revealed normal, vital trabecular bone with woven and lamellar structure in all the histollogically examined sections (Guarnieri et al., 2006).

2.5 Titanium granule

Resorption of grafting material may lead to unpredictable long-term results when rehabilitating the resorbed posterior maxilla. Nonresorbable, osteoconductive bone substitutes may therefore be an advantage over autogenous bone grafts. Titanium granules were used as bone substitute in patients scheduled to receive augmentation of the sinus floor prior to or in conjunction with placement of dental implants (Bystedt and Rasmusson 2009).

3. Growth factors and the cell-based approach

3.1 Platelet-rich plasma

The use of platelet-rich plasma to enhance bone regeneration has been documented in periodontal defects, in extraction sockets, during implant placement, and in guided bone regeneration procedures around implants, including sinus augmentation (Kim et al., 2002). The use of platelet-rich plasma in conjunction with autogenous bone graft materials has been advocated for use in sinus augmentation surgery as a means of enhancing both quantity and quality of newly forming bone (Danesh-Meyer et al., 2001). The use of platelet-rich plasma is based on the premise that autogenous plasma, rich in platelets, contributes large quantities of mitogenic polypeptides such as platelet-derived growth factor, transforming growth factor-beta and insulin-like growth factor-I, thereby enhancing osteogenesis, improving soft tissue healing, and reducing postoperative morbidity (Danesh-Meyer et al., 2001; Boyapati and Wang 2006; Browaeys et al., 2007). The handling of the particulate bone grafts is reported to be improved due to the adhesive capacity of platelet-rich plasma via its hemostatic capacity of fibrin (Galindo-Moreno et al., 2007; Arora et al., 2010).

In some reports, sinus augmentations were performed successfully with greater bone maturation when using a composite graft of cortical autogenous bone, bovine bone, and platelet-rich plasma (Galindo-Moreno et al., 2007). A randomized clinical trial was performed to test the efficacy of platelet-rich plasma in sinus augmentation procedures (Badr et al., 2010). No appreciable clinical effect could be observed when using platelet-rich plasma with autologous iliac crest bone graft in the maxilla. No statistically significant differences were observed for soft tissue healing indices (P=0.4) and mean graft resorption (P=0.5) between groups (autogenous bone only vs. bone + platelet-rich plasma). The findings suggest that the addition of platelet-rich plasma to bone derivative/substitute materials may not significantly enhance bone formation in the maxillary sinus area (Danesh-Meyer et al., 2001).

The results from the other study showed that the marginal bone level measurements showed no significant differences, although there was a tendency toward less resorption on platelet-rich plasma sides. Resonance frequency analysis measurements showed statistically significantly higher implant stability quotient values for platelet-rich plasma sites at abutment connectios in the anterior but not in the posterior regions (Thor et al., 2005).

Theoretically, it seems to have significant beneficial effects on the soft and hard tissue healing; however, the disparity in study design, surgical techniques, and different outcome assessment variables used makes it difficult to assess the practical benefit of its clinical use (Arora et al., 2010). Although platelet-rich plasma has been extensively studied for over a decade, there are no definitive reports proving the benefit of using platelet-rich plasma in sinus augmentation procedures (Arora et al., 2010). Therefore, the use of platelet-rich plasma may not be recommended as a standard method to support bone regeneration for maxillary sinus augmentation (Schaaf et al., 2008).

3.2 Platelet rich fibrin

Platelet-rich fibrin, a second-generation platelet concentrate, is a leucocyte- and platelet-rich fibrin biomaterial (Dohan Ehrenfest et al., 2009). Platelet-rich fibrin belongs to a new generation of platelet concentrates characterized by simplified processing and without biochemical blood handling (Dohan et al., 2006). Platelets are activated during platelet-rich fibrin processing by centrifugation, and massive degranulation allows the release of cytokine (Mazor et al., 2009). Platelet-rich fibrin is reported to release transforming growth factor-beta1, platelet-derived growth factor-AB and vascular endothelial growth factor up to the whole experimental time (Dohan Ehrenfest et al., 2009). Slow fibrin polymerization during platelet-rich fibrin processing leads to the intrinsic incorporation of platelet cytokines and glycanic chains in the fibrin meshes (Mazor et al., 2009). Thus, results showed that platelet-rich fibrin, unlike the other platelet concentrates, would be able to progressively release cytokines during fibrin matrix remodeling, leading enhanced healing properties in experimental and clinical situations (Dohan et al., 2006).

Platelet-rich fibrin was used in sinus augmentation procedures both in lateral and crestal approaches. In the lateral approach, platelet-rich fibrin was applied with or without the graft material, and the use of autogenous bone in combination with platelet-rich fibrin glue as a grafting material for maxillary sinus augmentation with simultaneous implant placement was tested in dogs (Lee et al., 2007). The results showed that the use of autogenous bone mixed with platelet-enriched fibrin glue can achieve results superior to those for grafts of autogenous bone alone in terms of enhanced osseointegration of dental implants (40.5±14.4% vs. 32.3±12.0%) and increased height of new bone (12.0±1.0% vs. 10.7±1.0%) (Lee et al., 2007).

Other studies used no bone substitutes, and the biopsies were taken in the center of the regenerated osteotomy window of the sinus lift. Therefore, all of the observed bone must be considered new bone built starting from the sole platelet-rich fibrin matrix (Mazor et al., 2009). All biopsies showed well-organized and vital bone, often with more than 30% bone matrix (33% ± 5%).

Osteotome-mediated sinus floor elevation was performed using only platelet-rich fibrin, and of the 138 implants that had been placed, 97 have been restored function for an average loading time of 5.2 months with a survival rate of 97.8% (Toffler et al., 2010). Early review of the osteotome-mediated sinus floor elevation with platelet-rich fibrin technique presented for localized sinus floor elevation and implant placement demonstrates a high degree of safety and success at sites with 5- to 8-mm residual subantral bone height (Toffler et al., 2010).

3.3 Bone morphogenetic protein

Growth factors are present at low concentrations in bone matrix and plasma, but they execute important biologic functions (Hallman and Thor 2008). The growth factors are believed to have an osseous regenerative effect on the mesenchymal stem cells and contribute to cellular proliferation, matrix formation, collagen synthesis, and osteoid production (Yamada et al., 2008). Bone morphogenetic proteins are multi-functional growth factors belonging to the transforming growth factor-beta superfamily, and bone morphogenetic proteins are reported to have a variety of functions (Wang et al., 1990; Xiao et al., 2007). Bone morphogenetic protein molecules not only induce the formation of both cartilage and bone but also play a role in a number of non-osteogenic developmental processes (Xiao et al., 2007), and they are capable of inducing ectopic cartilage and bone formation, a process that mimics embryonic endochondral bone formation (Xiao et al., 2007). Bone morphogenetic protein 2, 4 and 7, in particular, are reported to be the most effective growth factors in terms of osteogenesis and osseous defect repair (Schilephake 2002), and three bone morphogenetic proteins— bone morphogenetic protein 2, 7, and 14—have been applied in sinus augmentation procedures (Park 2009). The efficacy of Bone morphogenetic proteins for defect repair is strongly dependent on the type of carrier and has been subject to unknown factors in clinical feasibility trials resulting in ambiguous results.

Autogenous bone graft demonstrated greater increases in mineralization and probably angiogenesis of bone than the other bioimplants in rabbit sinus augmentation models when bone morphogenetic protein was delivered at the same time (Hu et al., 2010).

The effectiveness of recombinant human bone morphogenetic protein-2 on an absorbable collagen sponge was compared with an autogenous bone graft when used for two-stage maxillary sinus floor augmentation (Triplett et al., 2009). No marked differences were found in the histologic parameters evaluated between the two groups, but the induced bone in the recombinant human bone morphogenetic protein-2/absorbable collagen sponge group was significantly denser than that in the bone graft group (Triplett et al., 2009). Additionally, collagen sponge was shown to induce new bone equally as well as the other composite material when loaded with bone morphogenetic protein (Pekkarinen et al., 2005). The effects of mineralized bone replacement grafts (e.g., xenografts and allografts) on recombinant human bone morphogenetic protein-2/absorbable collagen sponge were tested, and bone graft densities tended to increase more with the xenograft than with the allograft (Tarnow et al., 2010). The increased density in allograft cases was likely the result of both compression of the mineralized bone replacement graft and vital bone formation, seen histologically (Tarnow, Wallace, et al., 2010). Loss of volume was greater with the four-sponge dose than the two-sponge dose because of compression, and resorption of the sponges and vital bone formation in the allograft cases ranged from 36% to 53% (Tarnow et al., 2010). Hydroxyapatite, biphasic tri-calcium phosphate-hydroxyapatite, and natural coral are reported to be equally good as framing material for bone morphogenetic protein (Pekkarinen et al., 2005).

Deproteinized bovine bone mineral is known to show excellent osteoconductive properties, and it has been used for sinus augmentation clinically (Terheyden et al., 1999). The bovine xenograft composite promotes formation of new bone in a similar fashion to autogenous bone when bone morphogenetic proteins were bound to the graft material, and could therefore be considered a biomaterial with potential applications as a bone substitute in maxillary sinus floor augmentation (Sicca et al., 2008).

It has been shown that beta-tricalcium phosphate is suitable as a biodegradable, highly biocompatible, and osteoconductive carrier for bone morphogenetic proteins in sinus augmentation procedures (Gruber et al., 2008). Both experimentally and clinically, recombinant human bone morphogenetic protein-14/beta-tricalcium phosphate was found to be effective and safe as the control treatment with autologous bone mixed with beta-tricalcium phosphate in sinus floor augmentation (Koch et al., 2010). Self-setting alpha-tricalcium phosphate was used in maxillary sinus augmentation, and it was shown to have bone-conductive activity and shown to maintain the rigidity of implanted bone screws (Marukawa et al., 2010).

Composite material has been used for bone morphogenetic protein-2 release in mandibular defect areas (Wen, Karl, et al., 2011). While in-vitro bone morphogenetic protein-2 release was highest for the polyethylene glycol hydrogel, the scaffold most successful in vivo was the collagen-hydroxyapatite composite infused with polyethylene glycol-hydrogel scaffold because it had the necessary mechanical strength to perform well in the mandibular bone environment (Wen et al., 2011). The in vitro release studies suggested a threshold dose of 5 µg that was confirmed by the in vivo dose response studies (Wen, Karl, et al., 2011). Many studies have demonstrated the potential for the bone morphogenetic proteins to increase bone formation in sinus augmentation procedures and further studies are warranted to find an appropriate carrier scaffold for the optimal release of bone morphogenetic proteins (Park 2009).

Bone morphogenetic protein-7 was loaded onto a poloxamer carrier or demineralized bone matrix in a poloxamer carrier (Ho et al., 2010). These bioimplants had more rapid initial bone production than all other materials, including autogenous bone, and these bone morphogenetic protein-containing bioimplants demonstrated promise as alternatives to autogenous bone grafts for sinus-augmentation procedures (Ho et al., 2010).

In the future, such biomaterials may enable earlier placement of dental implants into augmented maxillary sinuses.

3.4 Platelet-derived growth factor

Platelet-derived growth factor plays an important role in inducing proliferation of undifferentiated mesenchymal cells (Schilephake 2002); it is a stimulator of the proliferation and recruitment of both bone cells and periodontal ligaments (Nevins et al., 2003). It is an important mediator for bone healing and remodeling during trauma and infection, and it is reported to enhance bone regeneration in conjunction with other growth factors (Schilephake 2002).

Recombinant human platelet-derived growth factor-BB was used in simultaneous vertical guided bone regeneration and guided tissue regeneration in the posterior maxilla (Urban et al., 2009). The results demonstrated successful use of recombinant human platelet-derived growth factor-BB in conjunction with autogenous bone, anorganic bone mineral, and barrier membranes to reconstruct severe alveolar bone defects (Urban et al., 2009). A significant amount of periodontal bone gain was achieved in close apposition to a previously denuded root surface, giving the possibility of vertical periodontal regeneration (Urban et al., 2009). The use of purified recombinant human platelet-derived growth factor-BB mixed with bone allograft in humans is reported to result in periodontal regeneration in both Class II furcations and interproximal intrabony defects in human Class II furcation defects (Nevins et al., 2003).

The regenerative outcomes in maxillary sinus augmentation procedures were tested when recombinant human platelet-derived growth factor-BB was combined with particulate anorganic bovine bone mineral (Nevins et al., 2009). The surgical outcomes in all treated sites were uneventful at 6 to 8 months, with sufficient regenerated bone present. Large areas of dense, well-formed lamellar bone were seen throughout the intact core specimens, and a number of cores demonstrated efficient replacement of the normally slowly resorbing anorganic bovine bone mineral matrix particles with newly formed bone.

3.5 Mesenchymal stem cell

Long-term success of dental implants has been demonstrated when placed simultaneously with or after a sinus augmentation procedure (Gonshor et al., 2011). However, optimal bone formation can be from 6 to 9 months or longer with grafting materials other than autogenous bone (Pieri et al., 2008). Various osteoconductive materials have been applied to augment the sinus floor, but these materials are cell-free and may require more time for bone healing (Pieri et al., 2008).

Bone marrow contains a population of rare progenitor cells capable of differentiating into bone, cartilage, tendon, and other connective tissues, and these mesenchymal stem cells can be purified and culture-expanded from animals and humans and have been shown to regenerate functional tissue when delivered to the site of musculoskeletal defects in experimental animals (Bruder et al., 1998). Cells can be also be achieved intraorally from the maxillary tuberosity and the periosteum of the mandible (Turhani et al., 2005; Springer et al., 2006) The study was done to assess whether differences occur in bone formation after maxillary sinus floor elevation surgery with bovine bone mineral mixed with autogenous bone or autogenous stem cells (Rickert et al., 2010). Mesenchymal stem cellseeded on xenograft particles can induce the formation of a sufficient volume of new bone to enable the reliable placement of implants within a time frame comparable to that of applying either solely autogenous bone or a mixture of autogenous bone and xenograft; this technique could be an alternative to using autografts (Rickert et al., 2010).

Sinus augmentation procedures using either an allograft cellular bone matrix, containing native mesenchymal stem cells and osteoprogenitors, or conventional allograft showed similar results (Gonshor et al., 2011). Histomorphometric analysis of the allograft cellular bone matrix grafts revealed average vital bone content of 32.5% ± 6.8%, but results for the conventional allograft showed an average vital bone content of 18.3% ± 10.6% at an average healing period of 3.7 ± 0.6 months (Gonshor et al., 2011).

An ovine split-mouth study was applied to compare bovine bone mineral alone and in combination with mesenchymal stem cells regarding their potential in sinus augmentation (Sauerbier et al., 2010). The authors concluded that the high percentage of vital bone content, after a relatively short healing phase, may encourage a more rapid initiation of implant placement or restoration when a cellular grafting approach is considered (McAllister et al., 2009; Sauerbier et al., 2010).

4. Conclusion

Sinus augmentation procedures have been used clinically with very high success rates. Bone-substitute materials are reported to be as effective as autogenous bone when used alone or in combination with autogenous bone. It may be concluded that bone substitutes can be successfully used for sinus augmentation, reducing donor-site morbidity. Attempts have been made to accelerate bone formation with different scaffolds, growth factors, and mesencymal stem cells. Further studies are needed to find an optimal approach that can enhance bone formation in sinus augmentation procedures.

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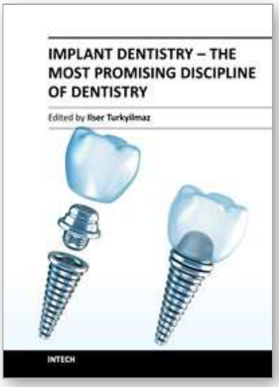

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