

Stability of Grafted Implant Placement Sites After Sinus Floor Elevation Using a Layering Technique: 10-Year Clinical and Radiographic Results

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Purpose: To evaluate long-term survival rates and radiographic stability of sinus floor elevations carried out using a two-layer grafting technique. **Materials and Methods:** Records were analyzed for patients treated with sinus floor elevations using a modified technique. Phycogenic hydroxyapatite (Algipore, Dentsply Sirona Implants) and autogenous bone particles harvested from intraoral sites were grafted in two distinct layers after elevation of the sinus mucosae. In this approach, the basal part of the sinus floor is grafted with autogenous bone, while the cranial part is grafted with the phycogenic hydroxyapatite. In some cases, implants were placed simultaneously, such that the entire surface of each implant was covered by autogenous bone particles. A titanium membrane was used to close the sinus window, and the implants were loaded 3 months later. In two-stage approaches, the implants were inserted 3 to 4 months after the grafting and loaded after 3 additional months. Panoramic radiographs were taken after the grafting procedure, after implant insertion, after the prosthetic restoration, and then annually for 10 years. These radiographs were used to measure the height between the implant shoulders and the top of the graft. **Results:** Of the 214 sinus floor elevations performed on 129 patients using the bilayering technique, 198 procedures in 118 patients were included in the study (136 one-stage and 62 two-stage). Membrane perforations during surgery occurred in 17.9% of the procedures and were sutured and sealed with fibrin glue. A total of 487 implants were placed in the grafted areas. No severe postoperative complications occurred, but three implants were lost throughout the 10-year follow-up period. A small decrease of vertical height was observed between the grafting surgery and the stage-two surgery (mean: 1.8 mm). After that, no bone height was lost over the 10 years. **Conclusion:** The layer grafting technique in combination with sinus floor elevation resulted in radiographically stable vertical bone height for 10 years. This technique enabled early placement and loading of implants in the grafted areas. The survival rate obtained with this procedure is similar to that expected for implants placed in nongrafted areas. *INT J ORAL MAXILLOFAC IMPLANTS* 2017;32:1086–1096. doi: 10.11607/jomi.5832

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One of the essential requirements for dental implant placement is the existence of sufficient bone to accommodate implants of an appropriate length and diameter.¹ However, after loss of the alveolar ridge due to trauma, periodontal disease, or failed endodontic treatment, it may

be difficult to place implants in the ideal position for esthetics and function. Loss of molar teeth in the maxilla also increases the size of the maxillary sinus.² The combination of a widened maxillary sinus and decreased residual bone height often requires bone augmentation before implant placement. Sinus floor elevation via lateral window ostotomy is one technique for increasing vertical bone height in the posterior maxilla that has been routinely performed for decades and has been accepted as a highly predictable and effective approach.^{3–5}

The use of autogenous bone for maxillary sinus floor grafting in advance of implant insertion is a safe treatment modality with good long-term outcomes.^{6–8} Nevertheless, when autogenous bone is applied alone as sinus grafting material, it has some limitations, eg, a rapid resorption rate.^{9–12} Therefore, the application of xenogenic or synthetic bone recently has been evaluated

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Table 1 Inclusion and Exclusion Criteria**Inclusion criteria**

Patients had to be older than 21 years of age at the time of surgery.

Patients had to be healthy enough to undergo oral surgical procedures (ASA [American Society of Anesthesiologists] classification 1 and 2).

Implant therapy was needed in the posterior maxilla to rehabilitate masticatory function.

Patients had to be partially edentulous with no teeth remaining distal to the planned implant placement sites, since any such teeth could have influenced graft resorption.

In periodontally compromised patients, appropriate and successful periodontal treatment was performed before implant surgery.

Patients could display no signs or symptoms of sinus or intraoral disease, as verified by clinical examination and radiographic assessment directly prior to the maxillary sinus floor augmentation.

Less than 7 mm of bone height had to remain in the posterior maxilla at baseline presentation.

Smokers, though not excluded, were warned about the elevated risk of surgical complications.

Exclusion criteria

Systemic disease (eg, rheumatoid arthritis, immunosuppressive chemotherapy, diabetes, or other autoimmune diseases)

ASA classification of 3 or higher

Drug and/or alcohol abuse

Pregnancy

History of aggressive sinus surgery (eg, Caldwell-Luc procedure) or chronic paranasal sinus inflammation

Fully edentulous maxilla

for its biocompatibility and volume-maintenance capacity.¹³⁻¹⁵ Beta-tricalcium phosphate (β -TCP: β -Ca₃(PO₄)₂) and hydroxyapatite (HA: Ca₁₀(PO₄)₆(OH)₂) have been applied for augmentation of the maxillary sinus floor,¹⁶⁻¹⁸ but both of these require a healing period ranging from 6 to 12 months. Due to its ability to maintain space, hydroxyapatite promotes osteoconduction and new bone formation, but it has low osteogenic potential.¹⁹ β -TCP, with its biocompatibility and higher degradation rate, has less compressive strength than hydroxyapatite^{20,21} and is therefore used as a substitute for autogenous bone.^{17,22} Therefore, using suitable ratios of hydroxyapatite or β -TCP and autogenous bone could enable better control over the resorption rate without altering the osteoconductive property of the bone.²³⁻²⁵

Pure hydroxyapatite has also been used for grafting the maxillary sinus floor.²⁶⁻²⁹ A phycogenic biomaterial with high porosity is derived from marine algae (Algipore, Dentsply Sirona Implants) by hydrothermally converting calcium carbonate in the presence of ammonium phosphate at approximately 700°C.³⁰ This process preserves the algae's porosity³¹ but completely removes the organic components and leaves pure inorganic calcium phosphate (CaP₃). While the granule size ranges between 0.3 and 2 mm with pores between 5 and 10 μ m,³¹ the surface of the granules is 32 to 50 m²/g, because of the 65% porosity.³² The pores have periodic septa with a mean length of 50 to 100 μ m that are connected by small perforations with a mean diameter of 1 to 3 μ m.²⁶ Fluorhydroxyapatite crystals,

ranging in size from 25 to 35 nm, line every pore.³² This porous material acts as a scaffold for bone regeneration, allowing vascularization and cell migration into the pores. The calcite skeleton of the algae is preserved throughout the entire processing procedure.²⁶

Pneumatic overpressure in the sinus leads to bone resorption in the edentulous posterior maxilla, which can cause a reduction of the grafting volume after sinus floor elevation.³³ This loss of graft volume might affect the long-term success of implants placed into the grafted maxilla. Of specific interest is whether the height and volume of the graft is preserved over the long term.

Besides a few short-term (< 1 year) studies,^{30,34,35} some studies with long-term results of radiographic changes in graft height following maxillary sinus floor elevation are available.^{1,9,36-39} However, these have used various radiographic methods, including tomographic Scanora,⁹ panoramic radiographs,^{9,34,37,38} and computed tomography (CT) scanning.^{34,40} Different grafting materials, including bone substitutes, autogenous bone, and their mixtures have been appraised. Hatano et al³⁸ applied a mixture of autogenous bone and bovine xenograft (2:1) for sinus floor elevation and simultaneous implant placement. The augmentation was followed by progressive pneumatization in the sinus, which decreased the graft height significantly throughout the first 2 to 3 years after surgery.

Sinus grafting using a layering technique has been suggested to reduce the healing period.³⁵ In this approach, pure autogenous bone chips are grafted close

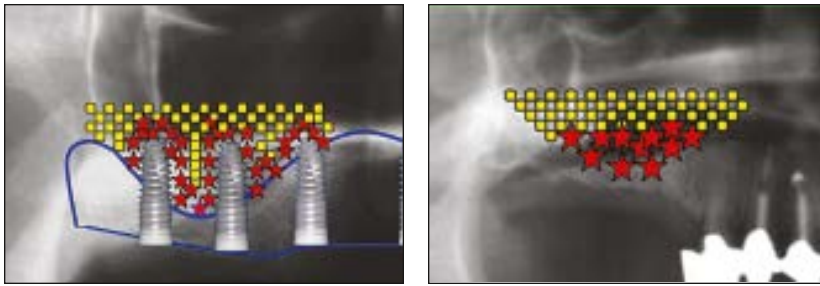


Fig 1 (Left) Schematic diagram of the layer technique at sinus floor elevation with simultaneous implantation. Biomaterial is used as a space maintainer (yellow), and the implant surface is surrounded by autogenous bone chips (red).

Fig 2 (Right) Schematic diagram of the layer technique at sinus floor elevation without simultaneous implantation: The cranial part of the elevated area is filled with the biomaterial (yellow) and basal part with pure autogenous bone chips (red).

to the alveolar crest, increasing the height of the pure bone area (remaining bone plus grafted bone) to at least 8 mm, while other biomaterial is placed cranially close to the elevated sinus membrane.

The aim of the present study was to analyze the 10-year results of patients treated with sinus floor elevation using a layer of autogenous bone and a layer of porous hydroxyapatite derived from algae. Of particular interest were any vertical dimensional changes.

This article was written following the STROBE guidelines (Strengthening the Reporting of Observational Studies in Epidemiology, <http://www.strobe-statement.org>).^{41,42}

MATERIALS AND METHODS

Patients

All patients included in the study were treated with a maxillary sinus floor augmentation procedure in 2004 to compensate for a lack of vertical alveolar crestal height. Table 1 shows the inclusion and exclusion criteria.

Surgical Technique

One surgeon performed all the procedures, using a standardized surgical protocol. Whenever the maxillary bone height was ≥ 5 mm, all of the maxillary sinus floor augmentations were performed in a one-stage procedure with simultaneous insertion of the implants (Fig 1). A two-stage procedure was employed when the remaining bone height in the posterior maxilla was less than 5 mm or when severe horizontal or vertical crestal bony defects were present (Fig 2). Amoxicillin 1.2 g or, in the case of allergy, clindamycin 600 mg was given intravenously 30 minutes before surgery, which was mostly performed under local anesthesia with conscious sedation, but also in some cases under general anesthesia, using the lateral approach.²

After a crestal incision of the soft tissue and reflection of a mucoperiosteal flap on the buccal site of the maxilla, bone chips were harvested from the sinus bone wall with a bone scraper (Safescraper). As soon as the

sinus bone wall became very thin, with some exposure of the sinus membrane, preparation was continued by using a small, round diamond bur to create a small window of approximately 8×6 mm. The "trap door" was not retracted inside the sinus cavity but rather removed for use as autogenous graft material. The sinus endothelium membrane was carefully reflected from the maxillary sinus floor, and partial septae were broken and removed. Any membrane perforations were closed by suturing (PGA 7-0, Resorba) and sealing with fibrin glue (Berioplast P Combi-Set, CSL Behring).³³

The area between the alveolar crest and the reflected membrane was filled using the following technique. The cranial part of the elevated sinus floor was grafted with a slow-resorbing porous fluorhydroxyapatite (Algipore, Dentsply Sirona Implants). The basal part of the sinus floor was grafted with pure autogenous bone chips harvested locally from the sinus bone wall, the implant bed (using a trephine bur), the palatal tubera area, or other intraoral sites. In the case of simultaneous implant placement, the entire surfaces of the implants were covered by autogenous bone particles (Fig 1). In two-stage procedures, autogenous bone augmentation was carried out to bring the native bone height to a minimum of 8 mm, and the layer thickness was controlled with a periodontal probe (XP23/UNC 15, Hu-Friedy) rounded off to the nearest millimeter (Fig 2). For additional lateral or vertical three-dimensional (3D) augmentation procedures, bone blocks were harvested from the mandibular retromolar area using the microsaw technique.⁴³ All grafting procedures were performed with the split bone block technique.^{33,43} The thin blocks were fixed at a distance from the crest using medical stainless steel screws (MicroScrews, Stoma),⁴⁴ and the space enclosed by the block and the recipient site was filled with autogenous bone particles.⁴⁵ Particles were well packed in the space to avoid fibroblast migration and obtain greater contact between the host bed and the graft (Figs 3a to 3c).

The sinus window was closed with the biomaterial and a nonresorbable titanium membrane (Frios BoneShield, Dentsply Sirona Implants). Tension-free



Fig 3a Preoperative radiograph with bilateral bone atrophy in the posterior maxilla including vertical bony defects in the left maxilla.



Fig 3b Three-dimensional bony reconstruction with autogenous mandibular bone blocks.



Fig 3c Postoperative radiograph after bilateral sinus floor elevation and vertical 3D bone reconstruction in the left maxilla.



Fig 3d Clinical view of the grafted area 3 months postoperative. The titanium membrane was used to close the sinus window.



Fig 3e Bone core harvested with a trephine from the grafted sinus demonstrates the layer technique. Biomaterial only is visible at the apical (left) part of the biopsy specimens.



Fig 3f Clinical view after removal of the membrane and the screws and insertion of the implants.

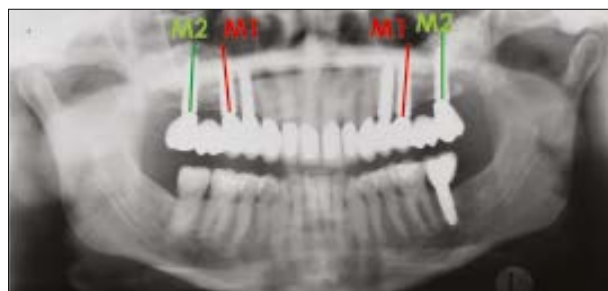


Fig 3g Panoramic radiograph after the oral rehabilitation with the measurement on the two posterior implants (left and right).



Fig 3h Panoramic radiograph 10 years postoperative demonstrating the stability of the grafted sinuses.

adaptation of the flap was managed by releasing the periosteum. The mucoperiosteal flap was replaced and sutured with resorbable sutures (Glycolon 6-0). Antibiotics were continued for a further 7 days (amoxicillin 2 × 1.2 g/day or clindamycin 2 × 600 mg/day). The postaugmentation regimen also included pain

medication (Ibuprofen AL 400, Aliud Pharma), topical nasal decongestants (Otriven 0.1% nose drops, Novartis Consumer Health), regular mouthrinses (chlorhexidine 0.2%, Chlorhexamed forte nonalcoholic 0.2%, GlaxoSmithKline Consumer Healthcare), and suture removal after 14 days.



Fig 4a Panoramic radiograph 10 years after oral rehabilitation with bilateral sinus floor elevation.

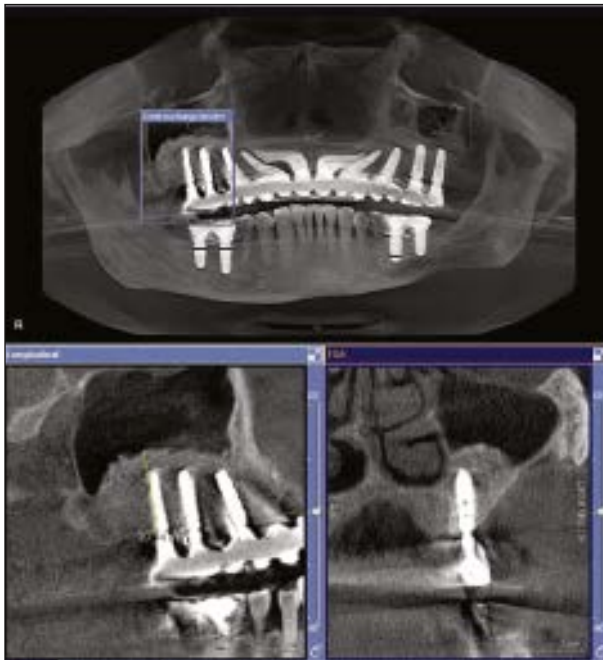


Fig 4b CBCT of the right grafted sinus confirming the stability of the augmented area without any pathology.

Implant Placement and Prosthetic Treatment

In cases with at least 5 mm of bone height, implants (Xive S, Dentsply Sirona Implants) were inserted at the time of the sinus augmentation. In two-stage procedures, implant placement followed 3 months after the augmentation procedure (Fig 3d). The titanium membrane was removed after 3 months either at implant exposure in one-stage approaches or at implant placement in two-stage approaches. The implant bed was prepared with a trephine bur. The bone cores that were removed showed two distinct layers: autogenous bone in the crestal portion and alloplast in the apical parts (Fig 3e). The biomaterial portion of the core was then removed, and the remaining autogenous portion was pushed again into the apical part of the osteotomy. Implant bed preparation was continued using osteotomes to push more autogenous bone from the crestal to the apical part (Fig 3f). Because the implant surfaces were mostly covered by autogenous bone, loading of the

implants with screw-retained fixed partial dentures on cast gold-alloy frameworks⁴⁶ was typically performed 4 months after implant placement and approximately 1 month after implant exposure and soft tissue management.⁴⁷ Maintenance care and continuous evaluation was performed on patients' individual supportive periodontal therapy (SPT) program. Recall intervals were chosen on the basis of the periodontal risk assessment.⁴⁸

Radiographic Examination

Panoramic radiographs were performed before surgery, after each surgical stage, after prosthetic restoration, and annually. Every panoramic radiograph was taken with the identical orthopantomograph (Orthophos, Dentsply Sirona Imaging). Morphometric measurements were performed using these radiographs. The implant body, the original and grafted sinus floor, and the original and grafted alveolar crest height after 3D reconstruction were traced manually with a soft pen on paper overlying the radiographs. That was done by one researcher who was not in contact with patient treatment (P.K.) and was intraexaminer calibrated.

Radiographs of the same patient were blinded according to time. The height between the implant shoulder and the apical extent of the graft was measured in areas of the two most posterior implants (M1, M2). The vertical heights were registered to evaluate the loss of graft. Measurements of graft height were always scaled using an adjusted conversion factor due to the magnification of the radiograph. The height was measured to the nearest 0.1 mm. The vertical bone height was measured from the implant shoulder to the most coronal dimension of the graft (Figs 3g and 3h).

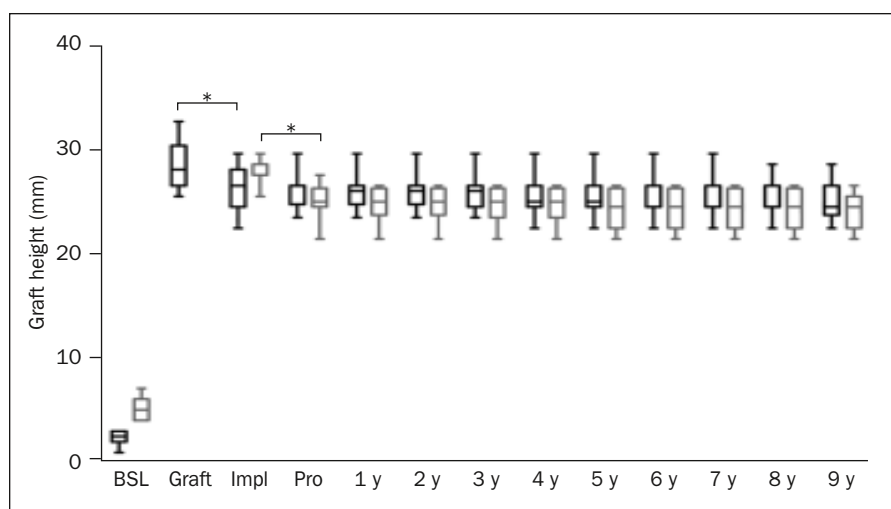
Some patients also received cone beam computed tomography (CBCT) scans (Galileos ComfortPlus, Dentsply Sirona Imaging) for diagnostics and treatment in other intraoral areas between the sixth and 10th year of follow-up after the sinus floor elevation. In such cases, the CBCT data were also compared with the panoramic radiographs from the same points in time (Figs 4a and 4b).

Statistical Analysis

The statistical analysis was done using a software program (SPSS, IBM). Each outcome (distance) was scored two times by the same evaluator. For statistical analysis, the mean of the two measures was obtained.

Data were expressed as mean \pm SD and median (interquartile range) or counts and percentages. The statistical distribution of all quantitative parameters was found to be non-Gaussian (tested by the Shapiro-Wilk test), and the significance of intragroup differences was assessed by paired *t* test and intergroup differences by one-way analysis of variance (ANOVA). The statistical significance level was set at .05.

Fig 5 Sinus graft height (in mm) in the region of the implant M1, separated for one-stage (*gray*) and two-stage (*black*) procedures over the 10-year follow-up.



Outcome Measures

Outcome measures for evaluating the long-term stability of the sinus floor augmentation using layers of autogenous bone and porous phycogenic hydroxyapatite derived from sea algae were as follows:

- Good healing of the surgical site: This was determined from the documentation of primary healing of the soft tissue over the grafted area without any tissue necrosis, suppuration, or bone exposure. The soft tissue had to show a normal color without any inflammation 2 weeks after suture removal, as well as at reentry.
- Good healing of the grafted area: This was determined clinically 3 months after the surgery by the presence of normal-colored soft tissue and no pathology such as a fistula, abscess, or exposed bone. Reentry had to show well-integrated implants without any mobility.
- Implant failure was determined by mobility or the need to remove stable implants because of infection or progressive marginal bone loss.
- Prosthetic failures were those in which the planned prosthetic restoration could not be performed due to implant failure (poor placement or angulation) or any other reason.
- Any biologic complication, for example, the presence of any symptoms of sinusitis or the presence/absence of chronic pain in the grafted site with or without involvement of the surrounding soft tissue.
- The height of the bone gained and its long-term stability: This was determined by radiographic examination, as previously explained.

Outcome assessment was not conducted by the operator but rather was independent.

RESULTS

In 2004, 214 sinus floor elevations were performed on 129 patients using the described layering technique. However, only 198 sinus floor elevations (138 one-stage procedures and 60 two-stage ones) for 118 patients (52 women and 66 men) with a mean age of 56.3 years (range: 32 to 69 years) were included in the study. Of the 11 patients who were not included in the study, two died, four moved abroad, and five did not adhere to SPT. The dropout rate was thus 7.47% (procedures) and 8.52% (patients).

Membrane perforations during surgery occurred in 17.9% of the procedures and were treated as described earlier. The width of the alveolar crest was adequate in 85 cases. In 77 cases, an additional lateral augmentation was needed, and in 36 cases, vertical 3D reconstructions had to be performed (Fig 5). In three patients, a minimal dehiscence was detected after 3D reconstruction. Two of the dehiscences were totally closed after nonsurgical local treatment (rinsing with 3% H₂O₂ and chlorhexidine gel). In the third case, a small surgical revision was necessary, consisting of removal of the exposed part of the graft and soft tissue augmentation.

All patients who had simultaneous implant placement healed uneventfully without any infection or major complications. In all the two-stage procedures, it was possible to insert all the planned implants in well-vascularized grafted sites. No severe postoperative complications were documented over the 10-year postoperative period, nor did any symptoms of sinusitis or chronic pain develop in any patients at any time.

Implants

A total of 578 implants (Xive S Dentsply Sirona Implants) were placed in the grafted areas: 423 with

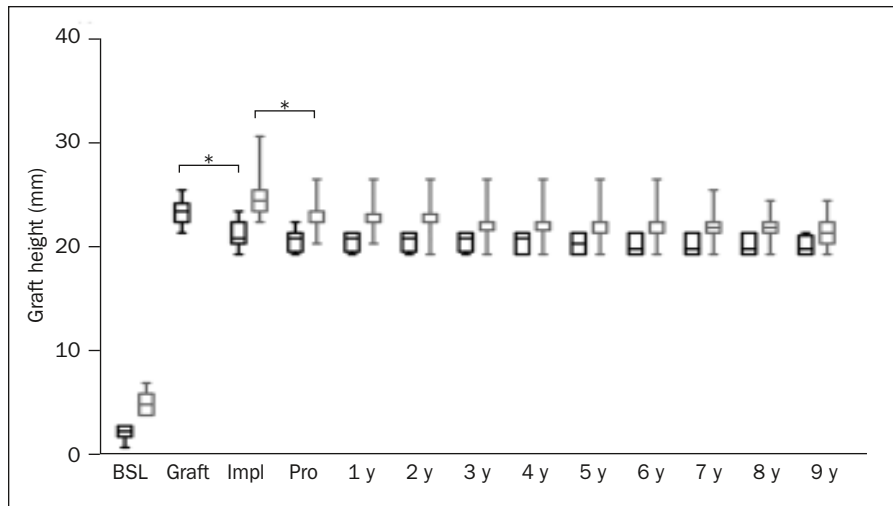


Fig 6 Sinus graft height (in mm) in the region of the implant M2, separated for one-stage (gray) and two-stage (black) procedures over the 10-year follow-up.

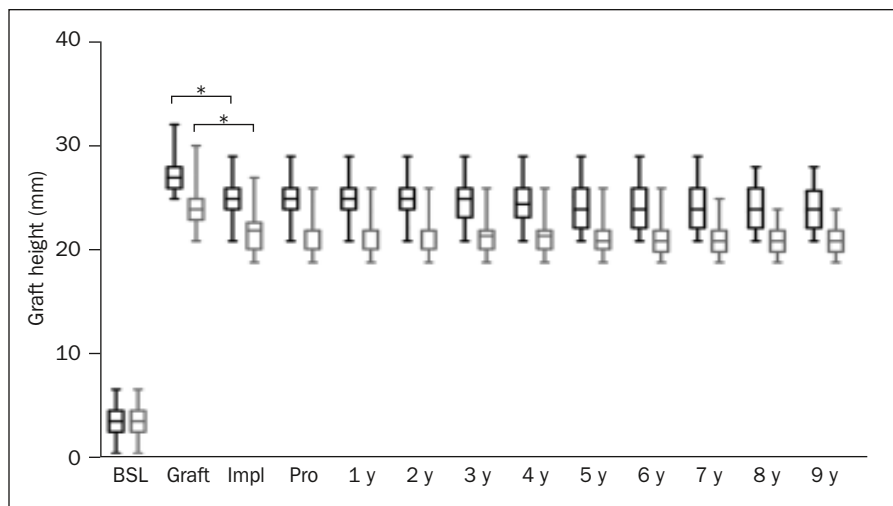


Fig 7 Comparison of development of sinus graft height (in mm) in the areas next to implant M1 (black) and implant M2 (gray).

3.8 mm diameter/15 mm length, 48 with the same diameter but 13 mm length, 12 with the same diameter but 11 mm length, 69 implants with 4.5 mm diameter/15 mm length, and 26 implants with the same diameter but 13 mm length.

Altogether, three implants were lost in three patients. One lost osseointegration 1 year after placement and was replaced by a new implant without any additional grafting. Another two implants had to be removed 7 and 9 years after the sinus grafting due to peri-implantitis. All patients who lost implants were smokers. All other implants were well osseointegrated and still functioning after 10 years (survival rate: 99.5%). All prosthetic restorations were still in place.

Radiologic Results

Similar results were found for the two most posterior implants (M1 and M2) at the same time points. For the M1 implants, there was a greater loss of graft height between sinus floor elevation and implant placement than between the other time periods. For the M2 implants,

similar results were found (Figs 5 and 6). The reduction in graft height that occurred during the first 3 months after sinus floor elevation was statistically significant ($P < .01$) (Figs 5 to 7). No statistically significant differences were found in cases with immediate or delayed implant placement (Figs 5 and 6). The mean graft height shrank by 1.87 ± 0.56 mm for M1 and 2.03 ± 1.47 mm for M2 in the initial phase after sinus floor grafting (Fig 7), regardless of whether implants were placed independently or later. For posterior areas (M2), the mean graft height contraction after augmentation was significantly higher than for anterior sinus areas (M1) ($P < .05$).

Three months after sinus floor grafting, no additional significant reduction in the M1 or M2 bone height occurred over the 10-year follow-up period. In addition, no statistical differences in the vertical stability of the anterior (M1) and posterior (M2) areas were found (Fig 7). The amount of native bone did not appear to significantly affect mean graft loss, although the standard deviation was more variable in patients with smaller initial amounts (Fig 8). No significant correlation was

detected between the original height of the alveolar crest and the resorption and quantity of grafted volume (Fig 8). There was also no statistical significance between cases in which the membrane was perforated and sutured and those that were not perforated.

Thirty-one patients (42 augmented sinuses) had CBCT scans taken between the 6th and 10th year of follow-up after sinus floor elevation for other reasons (Figs 4a and 4b). When these were compared with the panoramic radiographs taken at the same time, a magnification of $15.2\% \pm 3.7\%$ in the panoramic radiographs was found. The CBCT scans showed the implant lengths to be the same as those that were clinically placed. The same results of the sinus graft could be found and transferred to the panoramic radiographs without any statistical exceptions.

DISCUSSION

Rehabilitation of the maxillary alveolar crest by sinus floor elevation using different grafting materials has been extensively described.⁴⁹ The bilayer grafting technique used in the present study combines the advantages of autogenous bone and alloplasts. The latter promote volume stability of the grafts over time and therefore long-term implant survival, while the autogenous bone may promote osteogenesis and remodeling,³⁸ shortening the treatment time and making it possible to load the implants after just 4 months. Using the bilayer grafting technique may thus reduce treatment time by as much as 6 months.⁵⁰ Within 4 to 7 months, depending on whether the implants are placed immediately or in a delayed procedure, patients can receive a complete reconstruction of the atrophic posterior maxilla, including delivery of the definitive prosthesis. Although the bone quality tends to be soft 3 months after bone grafting, the bilayer grafting technique not only reduces treatment time, but also appears to result in high accuracy and success rates.

Predictable outcomes have been found with a variety of grafting materials, including autogenous bone, xenografts, allografts, alloplastic materials, and mixtures of these materials.⁴⁹ A consensus conference⁵¹ concerning sinus graft height showed the smallest changes (mean bone loss of 0.79 mm) in graft height by using a mixture of autograft (harvested intraorally) and alloplast (mostly porous hydroxyapatite) over 3 years. In one study, a long-term radiographic appraisal of graft height changes was performed for up to 10 years.³⁸ Maxillary sinuses were augmented with a 2:1 mixture of autogenous bone and a xenograft along with simultaneous implant placement. Following augmentation, the grafted sinus floor was constantly positioned above the implant apex. However, after 9 years,

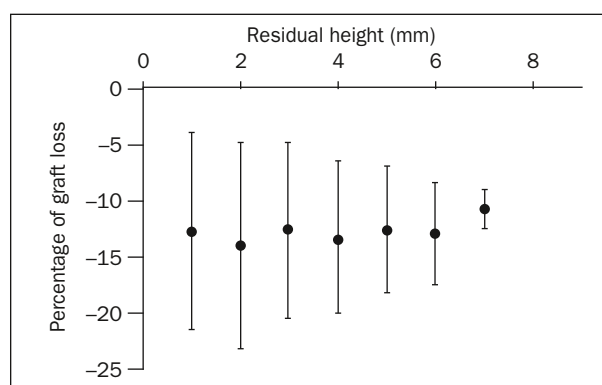


Fig 8 Percentage of graft loss (in mm) 10 years after grafting procedure according to the residual bone height before grafting procedure (in mm).

the vertical graft height in the sinus had narrowed significantly and was near the original sinus floor. Generally, reports have indicated that the graft resorption rate is affected by the type of graft material.⁵¹ The resorption rate around implants that were in function for at least 3 years has been reported to be 1.76 mm for autograft material, 2.09 mm for allograft (freeze-dried demineralized bone), and 0.96 mm for alloplast (hydroxyapatite).⁵¹ By using a nonresorbable or slowly resorbable grafting material, the loss of graft volume should be prevented. An alloplastic material, such as hydroxyapatite, is considered to limit bone resorption and sinus pneumatization.⁵² Similar to the results of the present study, Wanschitz et al²⁹ found that in humans, after sinus augmentation with a mixture of Aligpore and autogenous bone, the graft material showed a small volume loss over a 6-month period, providing a predictable volume for implant insertion.

In the present study, Aligpore, a phycogene hydroxyapatite, was used to maintain the space over the grafted bone, protecting it from the pressure of the sinus membrane. Patients need not provide additional consent for the use of this phycogenic biomaterial as compared to when xenogeneic bone substitutes are used. A histologic study of sinuses grafted with pure phycogenic hydroxyapatite showed that following a healing interval of 6 months, the percentage of newly formed bone was $35.2\% \pm 3.6\%$, of marrow spaces was $35.6\% \pm 2.3\%$, and of remaining residual grafted material was $37.1\% \pm 3.8\%$.³⁰ In animal studies, fluorhydroxyapatite was almost entirely resorbed, and at the same time, replaced by bone. In one of these histomorphometric studies, newly formed bone in rabbit tibia defects was shown inside almost all the highly osteoconductive biomaterial particles (approximately $35.3\% \pm 4.8\%$ in each particle). The percentage of contact between newly formed bone and biomaterial particles was $71.2\% \pm 9.8\%$.⁵³ After 26 weeks, Thorwarth

et al found only 20% of pure residual grafted material left in minipig sinuses.³¹ Resorbed Aligpore particles are gradually substituted by newly formed bone during the bone-remodeling process.^{27,28,53}

The resorption of Aligpore particles may be influenced by the small size of fluorhydroxyapatite crystallites and enzymes secreted by multinucleated giant cells, which are found in close proximity to the granules.³² The particles also serve as an osteoconductive scaffold for osteoblastic cells and stimulate deposition of bone matrix.

Almost all earlier studies of graft volume preservation after sinus floor elevation were carried out with a combination of autogenous bone and a deproteinized bovine bone xenograft (Bio-Oss). Deproteinized bovine bone xenograft seems to be slowly or not at all resorbed,⁵⁴ as confirmed for up to 6 years by clinical biopsy specimens.⁵⁵ Bovine bone has been reported to have a very slow resorption rate, which gives it long-lasting and space-maintaining characteristics.⁵⁶ Non-resorbable grafting material will neither remodel nor functionally attach to the native bone and could be a negative mechanical factor. A mixture of grafting materials (autogenous bone with alloplast) may promote both osteogenesis and remodeling.³⁸ Another study described a loss in graft height in the first 2 to 3 years after grafting, but subsequent changes were minimal.³⁸ Using a 80:20 mixture of bovine hydroxyapatite and autogenous bone for maxillary sinus augmentation, a prospective 1-year radiographic study showed small (< 10%) and significant dimensional change of the grafted material ($P < .01$).⁹ After using a modified bilayer grafting technique with autogenous bone and phycogenic hydroxyapatite, this amount of dimensional change could only be found in the first months with subsequent stable long-term results. In agreement with another systematic review, a small loss of augmentation volume during the early healing period was found.^{1,57} With the bilayer grafting technique, the range of volume reduction in the first months was small, and long-term results regarding reduction of augmentation volume over time were similar to those for pure bone substitutes or composite grafts.⁵⁷ In accordance with the findings of Tosta et al, the amount of newly formed bone in pure autogenous grafts was significantly larger than in pure bone substitute groups ($P < .05$).⁵⁸ The advantages of autogenous bone could be preserved without reported substantial graft loss of approximately 45% to 60% after 6 months to 2 years.^{12,57,59}

The volume of the graft possibly also influences the amount of graft resorption. That is why three groups depending on the residual native vertical bone height (< 4 mm, 4 to 8 mm, > 8 mm) were evaluated concerning different grafting materials and graft height maintenance over 3 years in a retrospective quantitative radiographic analysis. The original alveolar crest

height has not significantly affected alterations of graft height, even though the smallest vertical graft loss was seen in sites with the highest extent of residual alveolar crest.³⁶ The present results confirm this, as do those of another study about grafting with autogenous bone, in which no significant correlation was observed between native bone height, amount of augmented bone height, and resorption.⁶⁰

In accordance with other studies,^{12,57,61} maximum resorption was found during the initial healing interval. However, implants were often inserted at the time of sinus grafting. One study alone examined the height loss of grafted bone throughout the first 6 to 8 months after immediate and delayed implant placement. The reduction of vertical grafting height between the two groups (1.21 vs 1.22 mm, respectively) was not statistically significant.³⁴ This confirms the present results, which showed no statistically significant difference in graft volume loss when immediate and delayed implant placement were compared.

In the present study, lateral windows were closed with barrier membranes in all patients. A randomized controlled trial involving 12 patients found that the application of nonresorbable titanium membranes (Frios BoneShield) tends to increase vital bone formation in the grafting area.⁶² In a comparison of either nonresorbable or resorbable membranes to no membranes, vital bone formation in sinus grafts was not shown to be significantly superior for the membrane groups (16.9% and 17.6%, respectively, vs 12.1%).⁶³ The beneficial impact of membranes upon formation of vital bone is thus now questionable. A recent systematic review showed similar vital bone formation in membrane and nonmembrane groups.⁶⁴

Within the limitations of the present study, the bilayer grafting technique showed vertically stable long-term results and offered the advantage of early implant loading. Panoramic radiographs can be used to study the grafted sinus floor and its relationship to dental implants.¹ However, the maxillary sinus floor may be difficult to assess on two-dimensional radiographs, due to poor visualization.⁶⁵ Therefore, computed tomography was randomly used in almost 20% of the cases to compare the results for height measurements with those found using panoramic measurements.

Survival of implants placed combined with sinus floor elevation using a lateral window has been reported to range between 90.1% (95% CI: 86.4% to 92.8%) and 93.7% over a 3-year period after functional loading.⁴ The best results in this systematic review (98.3% implant survival after 3 years) were achieved by rough-surfaced implants with membrane coverage of the lateral access.⁴ It is important to consider the fact that 80% of implant failures happened during the first year.⁶⁶ Recent systematic reviews have shown

survival rates ranging from 75.57% to 99.5% using a lateral approach and longer implants, after a minimum follow-up of 16 months.^{50,61,67,68} In a 10-year clinical and radiographic study, the survival rate of implants placed after sinus floor elevation was 86%.⁶⁹ In comparison, using the bilayer technique in the present study resulted in a 99.5% survival rate after 10 years. This technique seems to be superior compared with other published survival rates of implants placed after sinus floor elevation with the lateral approach.^{3,4,66,69} The survival rate of implants placed in sinuses grafted using a bilayer technique is similar to those of implants placed in native, nonreconstructed bone.^{3,70,71}

CONCLUSIONS

The results of this study demonstrate that maxillary sinus floor elevation and grafting using a lateral approach and a bilayer grafting technique is a safe, effective, and predictable procedure that enables both implant placement in extremely resorbed posterior maxillae and long-term vertical stability of the graft. Within the limits of this descriptive and analytic study, radiographic stability of the vertical height appeared to be maintained over the 10-year study period. The implant survival rate was superior to others reported after sinus floor elevation using a lateral approach. Furthermore, it enabled effective early placement of implants and early loading with reduced treatment time. The survival rate obtained with this procedure is similar to that expected for implants placed in nongrafted areas.

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