Measurement of Volume Changes After Sinus Floor Augmentation with a Phycogenic Hydroxyapatite

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Purpose: *The purpose of this study was the determination of time-dependent volumetric changes of particulate sinus inlay grafts. A mixture of phycogenic hydroxyapatite (Algipore/C-Graft) and autologous bone collected from the surgical access area was used as the grafting material.* ***Materials and Methods:*** *Thirty-three sinus floor augmentations using phycogenic hydroxyapatite combined with autologous bone collected at the augmentation site and venous blood were performed on 18 patients aged 57.4 ± 12.5 years (mean ± SD) with severe atrophy of the posterior maxilla. Graft volume was measured 1 to 14 days postoperatively and before the placement of dental implants 6.1 ± 2.1 months later (mean ± SD; range, 4 to 11 months) to evaluate the amount of time-dependent resorption of the implanted material on computerized tomographic (CT) images of the augmented region. The images were put into Digital Imaging and Communications in Medicine (DICOM) format and evaluated using the software library Analyze. The implanted bone replacement material was plotted manually on each CT slice, and the volume of the implanted material was calculated.* ***Results:*** *The average volume loss of the bone replacement material during the observation period was 13.9% ± 1.9% (mean ± SEM). All sinus floor augmentations healed without complications except for delayed membrane exposure in 2 cases.* ***Discussion:*** *The results indicate that the graft material, a mixture of Algipore, bone chips from the access area, and venous blood, exhibited a small volume loss over a period of approximately 6 months, thus providing predictable height for second-stage implant surgery.* ***Conclusion:*** *Further investigations are needed to evaluate long-term stability and implant success.* Int J Oral Maxillofac Implants 2006;21:433–438

Key words: *augmentation, bone graft volume, dental implant stability, maxillary sinus*

Osseointegrated dental implants have greatly improved the possibilities for restoring jaw function and oral esthetics in partially or completely edentulous persons with severe atrophy of the alveolar crest.[1,2] The key factors in achieving long-term implant stability are bone quantity and quality.[3–6] In patients with extremely resorbed alveolar ridges, implant treatment is often not possible without bone augmentation. To provide adequate bone volume for stability of dental implants in the atrophic edentulous maxilla, various grafting techniques[7,8] and materials[9,10] have been described. The results of these procedures have only partially fulfilled expectations because considerable graft resorption occurs.[11,12]

Computerized tomographic (CT) imaging can provide detailed information about the anatomy of the alveolar crest and maxillary sinus and therefore greatly facilitates treatment planning and postoperative evaluation of the augmented site. In contrast to conventional radiographic imaging, CT imaging also allows the calculation of the volume of depicted structures, since pixel size and table progression are known parameters. CT scans have been used in cross-sectional studies to evaluate the dimensions of maxillary sinus grafts,[13,14] the volume of bone grafts in cleft patients,[15] and bone dimensions after distraction osteogenesis.[16] It has been shown that this technique is an accurate and precise tool for volume determination.

The aim of this study was to determine time-dependent volumetric changes of particulate sinus inlay grafts. A mixture of the phycogenic hydroxyapatite Algipore[17] and autologous bone collected from the surgical access area was used as the grafting material.

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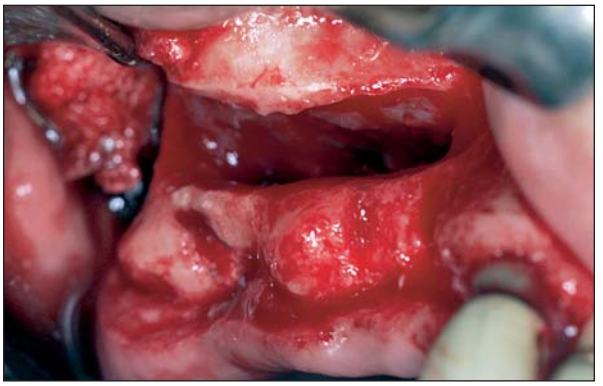

Fig 1 Surgical access to the right maxillary sinus.

Fig 2 Bone grafting material for the maxillary sinus lift, a mixture of Algipore, a phycogenic hydroxyapatite gained from calcifying algae; collected autologous bone chips from the surgical access area; and peripheral venous blood.

MATERIALS AND METHODS

The study sample comprised consecutive patients referred for sinus floor augmentation from December 2001 to December 2002. Thirty-three maxillary sinus augmentation procedures were performed in 18 patients, 15 women and 3 men, aged 57.4 ± 12.5 years (range, 37 to 77 years). Fifteen patients underwent bilateral maxillary sinus floor elevation, 2 patients underwent unilateral sinus floor elevation on the right side, and 1 patient underwent unilateral sinus floor elevation on the left side. In all patients the posterior maxillary atrophy was class 5 or 6 according to Cawood and Howell.[18] Consecutive patients were included in the study if they had posterior maxillary bone height less than 5 mm, had not been diagnosed with a bone disease, and were not on any medication known to affect bone metabolism. Each patient signed an informed consent, which was required according to the guidelines of the ethical commission of the Medical University of Vienna.

The preoperative clinical and radiographic examination (panoramic radiographs and axial CT scans) revealed no maxillary sinus pathology, such as inflammation, cysts, tumors, or fractures, and none of the patients had had previous maxillary sinus surgery. Known factors that might influence the healing process of the bone graft, such as general health, current medication, and tobacco use were documented. Five patients stated they smoked between 1 and 20 cigarettes a day. Patients who smoked were informed about the risks, and those smoking more than 10 cigarettes per day were requested to stop smoking before surgery.

Surgical Procedure

After infiltration with a local anesthetic agent containing adrenalin for vasoconstriction, a crestal incision was made, and the mucoperiosteum was elevated for exposure of the buccal wall of the maxillary sinus. A portion of the buccal wall (6 × 20 mm) slightly superior to the sinus floor was removed with a bur (Fig 1), and bone chips collected with the Frios BoneCollector (Dentsply Friadent Ceramed, Lakewood, CO). The exposed schneiderian membrane was elevated with great care to prevent perforations. If perforations occurred, they were closed with thin resorbable sutures. A mixture of Algipore (Dentsply-Friadent, Mannheim, Germany; in the United States: C-Graft, The Clinician's Preference, Golden, CO), a phycogenic hydroxyapatite gained from calcifying algae, collected autologous bone chips, and peripheral venous blood (Fig 2) was applied to the sinus floor. Venous blood (1 mL) was added to 1 mL of hydroxyapatite. Approximately 0.5 cm^3 of bone was collected per side. The defect in the buccal wall was covered with titanium membranes (Frios BoneShield; Dentsply Friadent Ceramed).[19,20]

Antibiotic therapy with amoxicillin/clavulanic acid (1 g twice a day) or clindamycin (300 mg 3 times a day) was started 1 day prior to surgery and continued for 9 days after the augmentation procedure.

To evaluate volume changes, axial CT scans of the maxillary sinus region were performed within 2 weeks after surgery and a mean (± SD) of 6.1 ± 2.1 months later (range, 4 to 11 months). The imaging was performed on a Tomoscan 7000 (Philips Medical Systems, Andover, MA/Best, The Netherlands) with a table progression of 1 mm. Before measurement, all CT vol-

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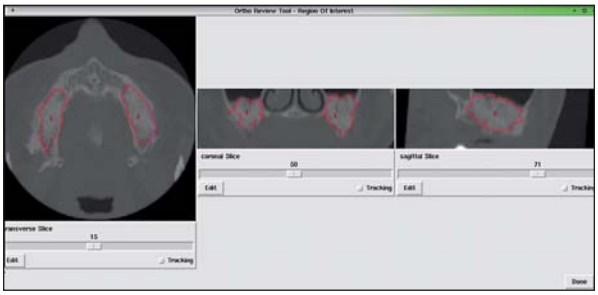

Fig 3a *(Above)* Before measurement, all CT slices were transformed into isotropic voxel size using the software program Analyse. The area of the graft material was manually plotted on transversal, coronal, and sagittal slices.

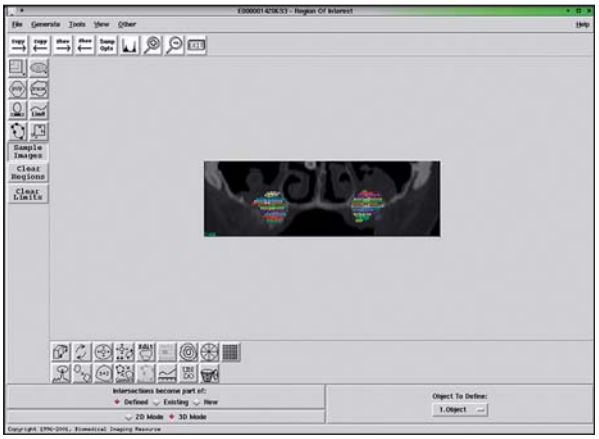

Fig 3b *(Right)* Automatic calculation of the graft volume with Analyse was accomplished by multiplying the sum of all marked areas with the known thickness of the CT slices (1 mm).

umes were transformed into isotropic voxel size using the software program Analyze (version 4; Biomedical Imaging Resource, Mayo Clinic, Rochester, MN). The grafted area was marked manually in each CT slice (Fig 3a). Care was taken not to include local bone, swelling of the mucous membrane, or free fluid in the remaining maxillary sinus in the marked region. Analyze then calculated the volume automatically by multiplying the sum of all marked areas with the known thickness of the CT slices (ie, 1 mm) (Fig 3b).

Statistical Analysis

The median volume of the bone graft ± SEM was calculated. Graft volume changes from the point of the augmentation procedure (1 to 14 days postoperatively) to radiographic examination 6.1 ± 2.1 months later were analyzed using 2-way ANOVA. Linear regression was used to analyze the different volume changes compared with initial levels. In all calculations statistical significance was set at $P \leq .05$.

RESULTS

The volumes of the sinus inlay grafts immediately postoperatively and 6.1 ± 2.1 months later are shown in Table 1.

The largest graft measured 6.15 cm^3; the smallest, 1.71 cm^3; and the median volume was 3.67 ± 0.2 cm^3. In all cases, bone graft volume was smaller at the second CT investigation. Overall, volume decrease was statistically significant ($P < .001$). The median decrease in graft volume was 13.9% ± 1.9% (range, 1.2% to 43.4%).

Table 1 Graft Volumes Measured Using CT Images Obtained 1 to 14 Days Postoperatively and 6.1 ± 2.1 Months Later

	Graft Volume (cm^3)			
	Left		Right	
Patient	Time 1	Time 2	Time 1	Time 2
1	4.143	3.367	2.516	2.250
2	2.682	2.649	3.000	2.690
3	4.937	4.752	3.109	2.974
4	3.936	3.440	3.936	3.635
5	2.563	2.219	2.845	1.976
6	5.018	2.839	4.428	2.899
7	5.867	5.530	5.654	5.251
8	1.878	1.796	1.712	1.626
9	3.150	2.647	4.250	2.638
10	2.615	2.494	2.997	2.783
11	3.997	2.889	2.887	2.303
12	6.147	5.427	N/A	N/A
13	N/A	N/A	2.789	2.531
14	3.867	3.561	3.553	3.439
15	N/A	N/A	3.357	3.225
16	4.935	4.093	4.859	3.872
17	3.467	2.852	2.906	2.255
18	3.619	3.494	3.493	2.964

Volumes in the Time 1 column were obtained 1 to 14 days postoperatively. Volumes in the Time 2 column were obtained 6.1 ± 2.1 months later. Three patients had only 1 side augmented; therefore, no data was available for the contralateral side.

For the 17 right maxillary sinus lifts, the mean volume of the grafted material (± SD) was 3.43 ± 0.22 cm^3 at the first examination; the median decrease over the evaluated time interval was 14.7% ± 2.6%. For the 16 left maxillary sinus lifts, mean volume was 3.9 ± 0.3 cm^3, and median decrease was 13.1% ± 2.6%.

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Eight patients with 15 augmented maxillary sinuses evaluated after 4.4 ± 0.5 months (the "early" group) were compared with 10 patients with 18 augmented sinuses evaluated at 7.6 ± 1.7 months (the "late" group). In the early group, graft volume was reduced by 16.2% ± 2.9% (range, 4.4% to 43.4%), whereas the late group had a reduction in volume of 12.0% ± 2.5% (range, 1.2% to 37.9%).

In 31 sinus lifts the graft site healed without complications. In 2 sinus lifts delayed membrane exposure occurred. Local inflammation was prevented with antiseptic care, resulting in good healing at the grafted site. Early removal of the membrane was not necessary in either case. All membranes were removed at dental implant placement.

DISCUSSION

Maxillary sinus grafting and subsequent placement of dental implants is a well-established and documented technique for functional and esthetic dental rehabilitation of partially or completely edentulous patients with severe maxillary atrophy. This technique enables the surgeon to place dental implants of sufficient length in the desired positions. When bone grafting is performed for dental implant treatment, biologic properties such as revascularization and resistance to resorption are essential for future implant stability. Remodeling and resorption rates of grafted autologous material are significantly higher than in local bone.[21] This could lead to increased implant loss in 1-stage procedures or could affect the positioning of implants in 2-stage procedures in cases where an insufficient amount of augmented bone remains.

The subject of this study was the resorption rate of Algipore, a phycogenic hydroxyapatite. Schopper and associates[22] have shown that this biomaterial is suitable for sinus lift procedures and that it acts as a scaffold for bone growth. In their study, after a mean healing time of 7 months, specimens removed with a trephine during the placement of dental implants were processed undecalcified and histomorphologically and histomorphometrically examined. New bone formation (mean ± SD) of 23% ± 8.3% was found around the Algipore/C-Graft particles. Bone formation was also evident within the pores of the particles. Resorption by osteoclasts and replacement with newly formed bone was also observed.

When grafting is performed with autologous bone from the iliac crest, resorption is reported to be highest in the first months until stabilization a year after grafting.[14] However, no significant difference in volume change was found between the early group and the late group in the present study.

Autologous bone collected at the access site added osteoinductive properties to the graft material. This technique makes additional harvesting of autologous bone unnecessary, thus preventing undesired morbidity at the donor site.

The resorption of bone grafts was first studied using 2-dimensional techniques. Graft loss was measured on successive radiographs and expressed as loss of height or width.[23] The measurement of graft loss in 1 dimension is insufficient to describe the behavior of 3-dimensional grafts. Volumetric analyses based on CT[24] or magnetic resonance imaging (MRI)[25] are better tools for volume determination. Several authors have shown that CT and MRI allow the determination of the volume of grafts or anatomic structures with up to 97% accuracy.[12,26]

Uchida and associates[26] measured maxillary sinus volume as an aid in determining the volume of graft bone needed before grafting autogenous bone to the maxillary sinus floor. Maxillary sinus volumes were measured from CT images of 38 sinuses using a 3-dimensional reconstruction system. They stated that at least 5.46 cm^3 of graft material was required for a 15-mm lift and at least 7.96 cm^3 for a 20-mm lift.

Johansson and associates[12] evaluated the resorption behavior of autologous bone in a sample of 10 edentulous patients with severely atrophic maxillae. Buccal onlay grafts were applied to the maxilla, and particulate bone grafts were applied to the maxillary sinus. The grafted area was manually plotted on successive 2-mm-thick axial CT slices according to the formula $V_{graft} = \Sigma$ area of each section $\times$ thickness of each section. The CT scans were obtained in the first 2 weeks postoperatively and after 6 to 7 months. In this time interval the volumes of the inlay and onlay grafts were reduced by an average of 49.5% and 47.0% of the initial volume, respectively.

A similar approach was used to measure the volume of the particulate graft material in the present study. After an observation period of 6.1 ± 2.1 (mean ± SD) months, the volume of the inserted mixture of phycogenic hydroxyapatite, autologous bone from the access area, and venous blood collected intraoperatively had decreased by only 13.9% ± 1.9% (mean ± SEM; range, 1.2% to 43.4%). There was no statistically significant difference between the mean graft volume placed in the right maxillary sinuses (3.43 ± 0.22 cm^3) compared with the left maxillary sinuses (3.93 ± 0.29 cm^3). No significant correlation between initial graft volume and amount of resorption was found; percentage volume decrease in smaller grafts was comparable with that observed in larger ones (Fig 4).

Although autologous bone has certain benefits as a graft material, including immunologic benefits and osteoinductive properties, it is well documented that

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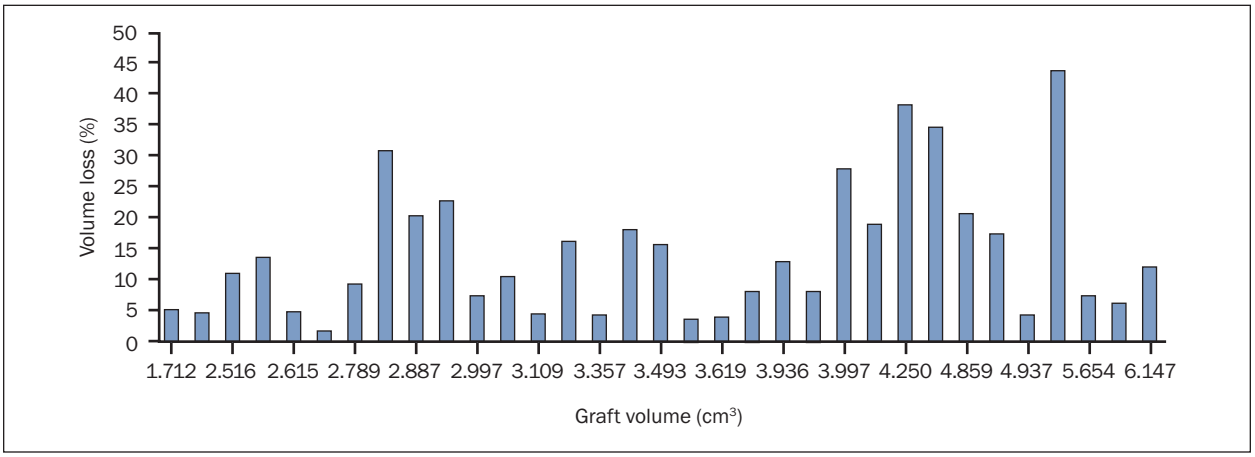

Fig 4 Graft volume at the first measurement 1 to 14 days postoperatively for each sinus lift is shown in relation to the amount of volume loss measured.

it also has limitations and complications. These include limited quantity of bone available from some donor sites and the necessity for a second surgical access site and associated donor site morbidity in some cases.[27] Usually the pain is more intense from the donor site than from the maxillary sinus, and patients with grafts taken from the iliac crest can be partially disabled for 1 to 2 months.[28,29]

The method described does not require an additional donor site and has a proven safety record and unlimited availability.[30] It contains no organic components, is well tolerated, and has an architecture similar to bone. Regarding parameters such as porosity, inner surface area, crystallite size, and calcium-to-phosphorus ratio, phycogenic hydroxyapatite closely resembles human bone.[22]

For bone ingrowth from the surrounding implant bed into a porous grafting material, the microchambers of the graft material must have a certain volume range. For connective tissue ingrowth the necessary microchamber diameter is between 5 and 15 µm.[31] For Algipore the specific inner surface is 30 to 50 m^2/g and the median pore size 10 µm,[32,33] which may suggest that Algipore has good osteoconductive properties. Osteoinductive elements can be added to the graft by combining it with autologous bone from the access area and venous blood.

A particulate graft has its total surface exposed to an environment for vascular ingrowth. This could help particulate grafts regain normal biologic properties faster than cortical grafts.[34]

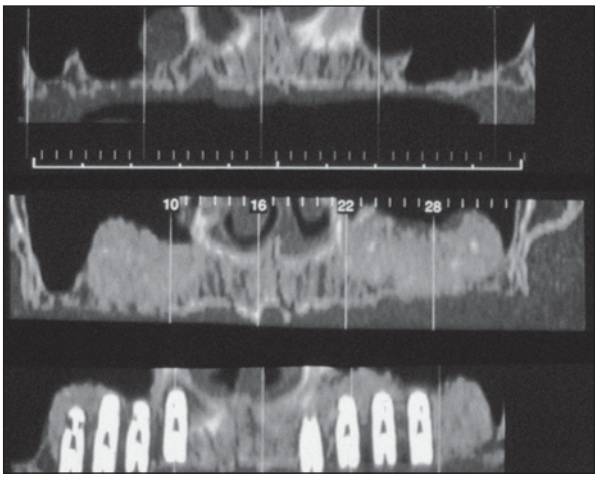

Fig 5 CT slices of a reconstructed area of the maxilla before surgery, after bilateral sinus augmentation, and at implant placement in the same patient.

SUMMARY

This study was based on measurements made on CT images at 2 different time points. The results indicate that a small loss in graft material was observed over a period of 6 months when the sinus floor was augmented with a mixture of phycogenic hydroxyapatite, bone chips from the access area, and venous blood (Fig 5). Thus, this material can be used to provide predictable height for second-stage implant surgery. Further investigations are needed to evaluate the use of this grafting material after dental implant loading.

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