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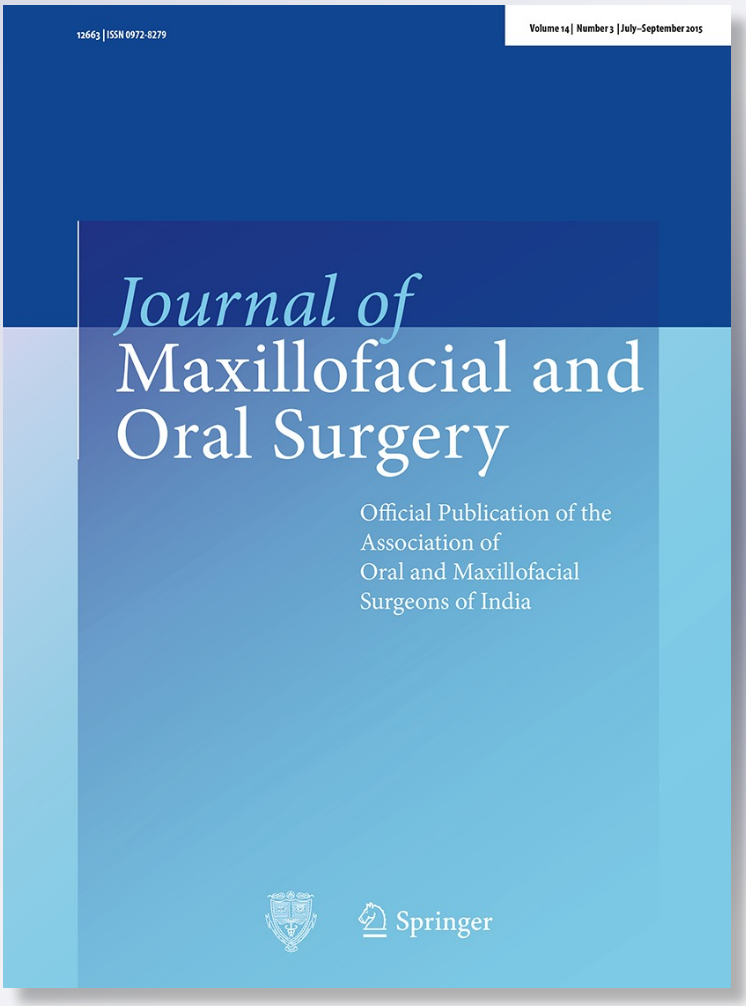

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RESEARCH PAPER

Evaluation of Three-Dimensional Volumetric Changes After Sinus Floor Augmentation with Mineralized Cortical Bone Allograft

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Abstract

Aim The aim of this retrospective study was to quantify three-dimensional (3D) volumetric bone changes over a two-year period in maxillary sinuses augmented with a mineralized cortical bone allograft material (MCBA) material.

Patients and Methods Eleven patients (6 males and 5 females) with mean of age of 51.6 (range: 46–61) years were treated to increase the vertical dimension of the alveolar crest by maxillary sinus floor augmentation procedure. Study data were collected from patient records and by analyzing preoperative radiographs and cone beam computed tomography (CBCT) scans taken within the first two weeks after maxillary sinus lift (T0), immediately before implant placement four months after grafting (T1), and after one year of implant loading (T2). All DICOM-formatted images were rendered into volumetric images using software that automatically calculated the volume of the grafted material in cubic centimeters.

Results Mean graft volume was 16.24 ± 1.54 cm^3 at T0, 14.48 ± 1.48 cm^3 at T1 and 13.06 ± 1.39 cm^3 at T2. Mean volume retraction resulted in 1.76 ± 0.34 cm^3 $\Delta V1$ (T0–T1) and 1.42 ± 0.4 cm^3 $\Delta V2$ (T1–T2) and was 10.83 % of the initial total volume at (T0–T1) and 9.8 % of the total volume (T1–T2).

Conclusion The present retrospective investigation demonstrated a 20.63 % decrease in graft volume. Volumetric 3D assessment of CBCT scans with the selected software appeared to be a promising approach to quantifying long-term changes in the grafted area.

Keywords Sinus graft · Allograft · Augmentation · Volume

Disclaimer: The authors do not have any financial interests, either directly or indirectly, in the products or information listed in this paper.

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Introduction

Sinus lift or Schneiderian membrane elevation is a common surgical procedure used to increase the height of residual bone between the crest and sinus floor in the posterior edentulous maxilla for dental implant placement [1]. In the lateral approach, an osteotomy of the buccal wall is performed to create a window into maxillary sinus in order to access the sinus cavity. Once the sinus has been accessed, the Schneiderian membrane is carefully elevated away from the sinus floor. Bone graft material is then placed between local host bone and elevated membrane to enable simultaneous or delayed placement of dental implants [1–3]. The sinus lift augmentation procedure was introduced to increase bone volume for implant placement, and clinical success has been documented with autogenous, allogenic, alloplastic and xenogenic materials used alone or in combination with other substances [4–6]. The various augmentation materials have exhibited different remodeling and volume contraction rates when used to graft the maxillary sinus [7]. Among the choices of augmentation materials, autologous bone grafts are still considered the gold standard [8, 9]. Nevertheless, resorption and remodeling of an autologous bone graft still remains a concern, as an imbalance between these processes may lead to insufficient bone volume and thereby frustrate implant placement [10]. Volumetric reduction of grafting material has been observed with autogenous bone grafts as well as synthetic bone substitute materials [11–16].

The success of sinus lift augmentation procedures may be evaluated by various criteria, such as whether the quality and density of newly formed bone maintains three-dimensional stability and achieves a high percentage of vital bone-to- implant contact [11]. Grafted sinuses may adapt considerably in shape and volume due to repneumatization of maxillary sinuses [12].

Radiographic evaluations of vertical graft height after maxillary sinus floor elevation are well documented [8, 9, 17–34]. However, these studies differ in radiographic methods, using panoramic radiographs [18, 22–24, 29, 33], computed tomography (CT) [9, 21, 23, 26] or cone beam computed tomography (CBCT) [8, 22, 32, 34].

Conventional dental or panoramic radiographs are unsuitable for volumetric analysis, as their two-dimensional nature can only provide an approximation of sinus graft vertical dimensions [20, 25, 33]. For this reason, alternative methods and quantification techniques have been introduced to three-dimensionally assess the volume of maxillary sinus grafts, such as magnetic resonance imaging (MRI), CBCT or CT with or without the use of adapted software [17, 20, 27, 30, 32].

The purpose of this retrospective study was to three-dimensionally quantify volumetric changes in maxillary sinuses augmented with mineralized cortical bone allograft (MCBA) over a 2-year period.

Materials and Methods

A retrospective review of patient charts was conducted to identify all maxillary sinus augmentation surgeries that took place between 2011 and 2013 in the department of ENT section of oral surgery, at Sacre-Coeur Hospital, Beirut, Lebanon. A total of eleven patients (6 males and 5 females) with mean of age of 51.6 (range 46–61) years were identified. Data from the patients' records were entered into a spreadsheet (Microsoft Excel, Microsoft Corporation, Redmond, WA) on a password-protected personal computer. In addition, diagnostic and post-treatment radiographs and CBCT scans were thoroughly evaluated. In all cases, preoperative images showed severe atrophy of the alveolar process in the posterior maxilla, and indicated that sinus floor augmentation would be necessary prior to implant placement.

Sinus Lift Procedure

All surgical procedures were performed under local analgesia using a technique described in a previous study [35] by the authors. Briefly, the lateral maxillary wall was surgically exposed via full-thickness flap, and a window was surgically prepared through the lateral maxillary using an ultrasonic piezoelectric device (EMS, Nyon, Switzerland) and surgery tip (Tip SC, EMS, Nyon, Switzerland). The precise surgical sites were determined by the planned location(s) of the implant(s) and the anatomy of the maxillary sinus [35]. After gaining entrance into the sinus cavity, curettes and elevator instruments were used to carefully free and elevate the Schneiderian membrane away from the sinus floor. A solvent-dehydrated, mineralized cortical bone allograft (MCBA) (Puros® Cortical, Zimmer Dental Inc., Carlsbad, CA) (0.25–1.0 mm particulate) was hydrated in sterile saline according to its instructions for use and carefully packed into the cavity between the residual sinus floor and the elevated Schneiderian membrane. The lateral window was covered with a collagen wound dressing (CollaTape®, Zimmer Dental Carlsbad). All patients were treated with a unilateral sinus graft. After 4 months of healing, two or three dental implants (Tapered Screw-Vent®, Zimmer Dental), (ranging from 11.5 to 13 mm in length and 4.1 to 4.7 mm in diameter, were placed in the grafted area using a 2-stage protocol. All patients were rehabilitated with fixed, implant-supported restorations.

Radiological Follow-Up

Panoramic radiographs and CBCT (Kodak 9500 Cone Beam 3D System, Carestream Health, Inc., Rochester, NY) scans were taken before sinus augmentation, within 2 weeks after grafting (T0), immediately prior to implant placement 4 months after grafting (T1) and after 1 year of functional implant loading (T2). Subsequent CBCT scans were taken with a 0.300 mm slice thickness, at 2–15 mAs, with a 18.4 × 20.6 cm field of view, a focal point at 0.7 mm, frequency of 140 kHz and at 60–90 kV.

Volumetric Analysis

All DICOM-formatted CBCT images were rendered into volumetric images using Imaging software (AMIRA® Software, Mercury Computer Systems, Berlin, Germany) to render all DICOM-formatted CBCT images into volumetric 3D reconstructions and sagittal, axial, and coronal volumetric slices with a threshold set at 200 and a minimum and maximum data window set at 4,000.

Axial slices of 300 µm were analyzed. The segmentation procedure for sinus was performed using interactive segmentation tools and starting with axial slices. When all axial slices were traced, modifications were made on all sagittal and coronal slices. The same operator performed all manipulations to obtain adequate and precise results. The volume of the sinus is the reconstruction of the axial, coronal and sagittal segmentation. It is the summation of all slices, which is automatically calculated by the software in cubic centimeters (Fig. 1A–F). Measurements were calculated for the volume of grafted material at the T0, T1 and T2 time intervals.

Statistical Analysis

The Kolmogorov–Smirnov test revealed that the data was normally distributed at each time point. Accordingly, the one-way repeated-measures analysis of variance (rANOVA) was used to test the working hypothesis of difference in the sinus volume between T0, T1 and T2. A confidence level of 0.01 was considered statistically significant. Data were analyzed using the Statistical Package for Social Sciences (SPSS), Version 21.0 (SPSS V7.0, IBM, Armonk, NY).

Results

Data from the patient charts indicated that all augmented sinuses and dental implants successfully healed, and that the restored implants were successfully in function after 1 year without any complications. These clinical findings were affirmed by the radiographic and CBCT data. For the analysis, 33 CBCT images with a total of 11 augmented sinuses in 11 patients were analyzed. Volumetric measurements are presented in Table 1. Results showed a mean volume of grafted material 16.24 ± 1.54 cm^3 at T0, 14.48 ± 1.48 cm^3 at T1 and 13.06 ± 1.39 cm^3 at T2. The mean volume retraction resulted in 1.76 ± 0.34 cm^3 ΔV1 (T0–T1) and 1.42 ± 0.4 cm^3 ΔV2 (T1–T2) and was 10.83 % of the initial total volume at (T0–T1) and 9.8 % of the total volume (T1–T2) (Table 2). The sinus volume difference was significant across the three time points, $F(2, 20) = 395.84$, $p < 0.0001$. Pairwise post hoc comparisons of the sinus volume indicated that the volume decreased significantly from T0 till T1 (mean difference = 1.76 ± 0.104 cm^3) and from T1 till T2 (mean difference = 1.422 ± 0.123 cm^3). The total decrease in volume was 3.182 ± 0.112 cm^3 (Table 3).

Discussion

This retrospective analysis aimed to evaluate volumetric changes of grafted areas after maxillary sinus augmentation. Stability of the grafted volume represents an important factor for implant success. Previous reports have clearly indicated that resorption of transplanted bone resulted in an increased implant loss in one-stage procedures, or adversely

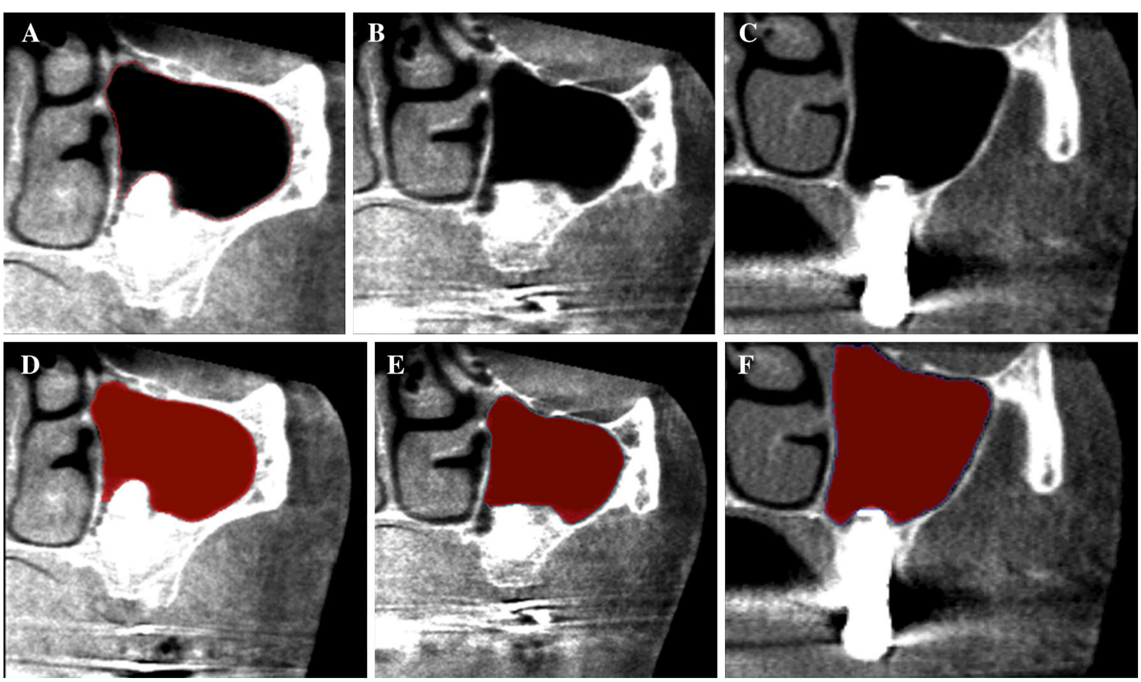

Fig. 1 The grafted area as shown by the CBCT: **A** T0, **B** T1 and **C** T2. The coronal volumetric slices as shown with AMIRA: **D** T0, **E** T1 and **F** T2

affected implant positioning in two-stage procedures in cases where an insufficient amount of transplanted bone remained [10, 13, 26, 36]. Although the number of cases was limited in the present study, but a significant 3D radiographic volumetric reduction was measured in all augmented area with a mean resorption rate of 20.63 % over a 2-year period from grafting to implant placement, restoration and 1 year of clinical function. The mean volume reduction was 10.84 % during the 4-month sinus graft healing period, and 9.8 % after 1 year of implant loading.

Table 1 Summary of gender, age and volumetric data at T0, T1 and T2

Name	Sinus	Gender	Age	T0 (cm3)	T1 (cm3)	T2 (cm3)
P1	Left	F	48	15.1	13.3	12.7
P2	Right	M	46	16.25	14.3	13.05
P3	Left	F	52	14.56	12.82	11.3
P4	Right	M	54	13.37	11.97	10.22
P5	Right	M	58	16.82	14.35	13.15
P6	Left	F	47	16.55	14.65	13.68
P7	Right	M	49	18.14	16.85	14.75
P8	Left	F	59	15.23	13.82	12.25
P9	Right	F	61	16.75	15.15	13.75
P10	Left	M	48	17.53	15.85	14.15
P11	Right	M	46	18.38	16.26	14.68

Table 2 Volumetric data of patient: volume changes ΔV and percentage of change % ΔV at T0–T1 and T1–T2

Patients	ΔV1 (T0–T1) cm^3	ΔV2 (T1–T2) cm^3	% ΔV1	% ΔV2
P1	1.8	0.6	11.92	4.5
P2	1.95	1.25	12	8.7
P3	1.74	1.52	12	11.8
P4	1.4	1.75	10.5	14.6
P5	2.47	1.2	14.6	8.3
P6	1.9	0.97	11.4	6.6
P7	1.29	2.1	7.1	12.4
P8	1.41	1.57	9.2	11.3
P9	1.6	1.4	9.5	9.2
P10	1.68	1.7	9.5	10.7
P11	2.12	1.58	11.5	9.7
Mean	1.76	1.42	10.83	9.8
SD	0.34	0.4	1.97	2.81

Our results are in accordance with previous reports of grafted sinuses [4, 12, 21, 22, 26, 34, 37, 38]. Dellavia et al. [34] reported a total bone volume change of 19 % in 6 months following sinus augmentation when using a mixture of autogenous bone (30 %) and bovine bone matrix (BioOss®, Geistlich Pharma AG, Wolhusen, Switzerland) (70 %). Kirmeier et al. [12] mainly used Bio-Oss (Geistlich Pharma AG) and found an overall volume reduction in the order of 25 %. Wanschitz et al. [26] observed an average volume loss of 13.9 % about 6 months postoperatively using autogenous bone in combination with fluorohydroxyapatite (Frios® Algipore®, Dentsply Implants, Waltham, MA). Smolka et al. [37] found that augmentation with calvarial bone resulted in a mean volumetric reduction of 16 % after an observation period of 6 months and 19 % after 1 year. Hatano et al. [4] treated patients with a mixture of a bovine xenograft (Bio-Oss®, Geistlich Pharma AG) and autogenous bone (1:2) in a one-phase procedure with simultaneous sinus floor elevation and implant placement. Progressive pneumatization of the sinus occurred after augmentation and graft height significantly decreased during the first 2–3 years after augmentation, but subsequent changes were minimal [4]. Kirmeir et al. [12] reported on 30 consecutive patients treated with autogenous inlay and onlay bone grafts from the iliac crest. After a mean vertical bone loss of 1.3 mm during the first year after bone grafting, only minimal resorption was observed during the second and the third years [12]. In a comparable study [22], patients augmented with a mixture of Bio-Oss (Geistlich Pharma AG) and autogenous bone (4:1) exhibited small (10 %) but statistically significant changes in the graft site after 1 year of loading. Johansson et al. [21] evaluated volume change in autogenous bone grafts, and found an average volume loss of approximately 49.5 %. In composite grafts consisting of autologous bone mixed with different bone graft substitutes, maintenance of bone graft height was significantly better in a combination of intraoral autogenous grafts and allograft versus allografts alone [38].

We can only speculate that these differences in volumetric reductions with different materials may be related to complex factors likely to influence the resorption rate of

Table 3 Sinus volume measurements, mean and SD and normal distribution of the data

	Time points					Pairwise comparisons		
	T_0	T_1	T_2	F	p	T_0–T_1	T_1–T_2	T_0–T_3
Sinus volume (cm^3)	16.24 ± 1.55	14.48 ± 1.48	13.06 ± 1.39	395.8	<0.0001	1.76*	1.42*	3.18*

* Statistically significant ($p < 0.001$)

the grafting materials, such as preoperative bone quality and quantity, surgical technique, condensation, stability, physicochemical characteristics of the used materials, as well as pneumatization of the sinuses. Volumetric analysis of CBCT slices with the software used in the present study has been described as a highly accurate method of analyzing volumetric changes [32]. The 3D acquisition scanners and software of the system facilitated calculating volumes while eliminating the risk of error-inherent distortions and expansions of radiological images.

One common and well-studied approach is manual perimeter tracing with three-dimensional imaging (CT/CBCT) to display the region of interest [19, 21, 26, 30, 39, 40]. After tracing this region slice by slice to obtain multiple surface areas, these areas are then multiplied by the thickness of each slice to calculate the three-dimensional volume. As a major constraint, this technique proved to be rather time-consuming and distinctly technique-sensitive [30].

Another measurement technique called "Region Growing Segmentation Thresholding" (RGST), as described by Park et al. [41], is based on digitally selecting an appropriate seed point with a defined Hounsfield unit (HU) value, a mouse click in the region of interest to visualize CT or CBCT dimensionally in 3D. All neighboring contacting voxels located within a defined range (threshold) of similar HU values are conflated (region growing) for semi automated volumetric assessment. However, due to the similar HU values of the grafting material and the surrounding bone, this approach cannot normally be used to assess graft volumes in the maxillary sinus [42].

Platzer et al. [11] used a non-commercial measurement technique based on the novel concept of an Interactive Rigid Registration Algorithm (IRRA). Parameters analyzed included the reproducibility of IRRA measurements and their reliability in comparison with the established measurement technique of RGST. They found that the IRRA measurement technique could be recommended as a non-invasive tool to evaluate graft volumes in human maxillary sinuses [12].

Dellavia et al. [34] showed that the calculation of the augmented sinus volume throughout standardized and automatic masks-based method on CBCT data allowed repeatable measurements to be obtained. The proposed computation procedure turned out easy and quick for both an expert and non-expert operator [34]. The volume of bone formation was calculated using a software (Somariss® Sienet Magic View Software, Siemens AG Medical Solutions, Health Care, Henkersh, 127, D-91052, Erlargen, Germany). The use of adapted software reduces the error margin of freehand drawings for analysis that could be sensitive to analysis bias.

Conclusion

Within the limits of a retrospective evaluation, the present investigation demonstrated a decrease in graft volume of 20.63 %. Three-dimensional CBCT volumetric assessment with the selected software appeared to be a promising approach to quantifying long-term changes in the grafted area. To improve long-term material stability, further prospective studies are needed to investigate volume changes of other graft materials in sinus augmentation procedures, and the factors that influence repneunatization of the maxillary sinus.

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Conflict of interest None.

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