CLINICAL ORAL IMPLANTS RESEARCH

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Implant success remains high despite grafting voids in the maxillary sinus

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Abstract

Objectives: Given that the nature and presence of voids present within grafted sinuses following maxillary sinus elevation procedures were not known, nor was the contribution of these factors to implant success, the purpose of this study was to investigate these parameters and their relationship to implant success.

Materials and Methods: This study evaluated data from 25 subjects who had a lateral window maxillary sinus augmentation procedure. Cone-beam computed tomography (CBCT) was performed at baseline and 4 months after surgery. CBCT images were used to evaluate grafted sites prior to implant placement. Using CBCT images, three examiners independently measured bone-grafted areas (BG), void areas (V), and percentage of void areas (V%) from six different sections within grafted sites. The six sections were defined as a cross-sectional (CS) midpoint, CS mesial point, CS distal point, horizontal section (HS) low point, HS midpoint, and HS high point. Implant success was also determined.

Results: The calculated V% (V/BG) for the CS midpoint, CS mesial point, CS distal point, HS low point, HS midpoint, and HS high point were 5.30 ± 6.67%, 5.79 ± 8.51%, 6.67 ± 7.12%, 2.07 ± 2.56%, 5.30 ± 6.62%, and 4.92 ± 5.17% respectively. Implant success after 6 months of follow-up approximated 100%.

Conclusions: Although voids within grafts varied in terms of distribution and size, the V% within the HS low point were significantly smaller compared to those within the CS midpoint and CS distal point, which had the most intra-subject V%. Thus, more attention should be given to the distal aspect of the sinus when compacting graft materials in the lateral wall sinus augmentation procedure. Implant success was not influenced by the existence of voids as implant success remained high.

When restoring the edentulous posterior maxilla, insufficient bone volume becomes an obstacle to providing implant-supported prostheses. The placement of the implant may be limited by the location of the maxillary sinus floor and loss of alveolar bone height. To address these limitations, bone volume can be increased by augmentation of the maxillary sinus cavity with autogenous, allograft, alloplast, or xenograft materials.

There are several anatomical features to consider when evaluating the maxillary sinus using Cone-beam computed tomography (CBCT) prior to the maxillary sinus augmentation procedure. The maxillary sinus is the largest of the paranasal sinuses. It has been described as pyramidal in shape, wherein the apex points laterally to the zygoma and the base points toward the nasal wall. The dimensions of the sinus are approximately 3 cm in mesio-distal width, 4 cm in vertical height, and 4.1 cm in antero-posterior depth. The volume of the sinus averages 15 cm^3 (Ogle et al. 2012).

According to a CBCT study of edentulous patients, bone height decreases from the premolar to molar areas, with a high percentage of first and second molar sites exhibiting a bone height of less than 5 mm (54.12% and 44.65%, respectively) (Nunes et al. 2013). Furthermore, with age, pneumatization of the maxillary sinus leads to an extension of its dimensions and potentially impacts dental treatment (Scuderi 1952; Scuderi et al. 1993).

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In addition, the alveolar antral artery represents a critical anatomical structure within the sinus cavity that needs to be considered. The average height of the artery from the alveolar crest is 16 mm (±3.5 mm) (Elian et al. 2005). The vertical distance from the lowest point of alveolar antral artery to the alveolar crest, in the area of the first molar, averaged 11.25 ± 2.99 mm (Rosano et al. 2012). Locating the alveolar antral artery is important in the surgical management of the sinus augmentation procedure as its violation may lead to surgical complications (Rodella et al. 2010; Rosano et al. 2011).

The lateral maxillary sinus augmentation procedure was first introduced by Boyne & James (1980). This technique was designed to increase maxillary alveolar bone height for optimal dental implant placement. The volume of bone graft needed for this procedure is determined by the dimensions of the dental implants planned for the site and the anatomical characteristics of the maxillary sinus. The procedure is initiated by creating a buccal opening or lateral window in the maxillary bone opposite the maxillary sinus, followed by careful elevation of the Schneiderian membrane. The space created after the elevation of the Schneiderian membrane is filled with grafting material to facilitate bone regeneration. The healing period ranges from 4 months (Small et al. 1993) to 12 months (Tarnow et al. 2000). Histological studies have shown that maxillary sinus-grafted sites exhibit between 11.9% and 27% vital bone formation (Froum et al. 1998; Tarnow et al. 2000).

Implants placed in maxillary sinus-augmented areas exhibit high survival and success rates (Pjetursson et al. 2008; Cha et al. 2012). Several risk factors for implant failure in the atrophied maxilla have been identified, including the patient's health history, smoking, the number of surgical interventions, and bone-to-implant contact (Testori et al. 2012; Chambrone et al. 2013). However, further investigation is needed to understand the reasons behind the failure of implants in the maxillary sinus-augmented sites.

The use of CBCT is considered the gold standard for diagnosis of sinus pathology and treatment planning of sinus procedures in the craniofacial complex (Lund et al. 2000; Stewart et al. 2000). CBCT allows for a clear, three-dimensional evaluation of the imaged anatomical structures and spaces and is free of the superimposition of surrounding structures seen on two-dimensional imaging such as in periapical and panoramic radiographs. Pre-surgical CBCT analysis of the maxillary sinus provides information about anatomical considerations, including the presence and location of antral septae (Neugebauer et al. 2010), the angulation of the palatal nasal recess (Chan et al. 2013), pathology within the sinus (Chan & Wang 2011; Pette et al. 2012), and the distance to vital structures, such as arteries (Elian et al. 2005). To date, no radiographic investigation of the void-to-graft ratio of grafted maxillary sinuses post-augmentation has been reported. We hypothesize that voids within grafted maxillary sinuses could impact implant success. Therefore, the aim of this study was to evaluate the internal structure of maxillary sinus bone grafts 4 months after the augmentation procedure using CBCT as a non-invasive tool to determine the presence, size, and distribution of voids within the grafts and to relate this to implant success.

Material and methods

Patient and procedure characteristics

Approval for this study was obtained from the University of Michigan Institutional Review Board for human subjects. Patients were excluded from the study if they exhibited systemic diseases, sinus pathology, or smoking. A reasonable sample size of 30 was selected. A total of 30 patients, ages 26–66, were evaluated for this study (Table 1). Residual radiographic bone height ranged from 2.4 mm to 6.0 mm. The mean volume of a β-TCP graft material (Cerasorb ®, Frankfurt, Germany) applied to the sinuses ranged from 1.25 cc to 5.0 cc. The sinus augmentation surgery and the subsequent implant placement were performed by two experienced

Table 1. **Patient demographics**

Patient characteristics and demographics	
Number of patients enrolled	30
Mean age (range)	26–66
Ethnicity	Caucasian 26 Asian 2 African American 2
Right/left maxilla	16/14
Female/male	20/10
Drop out	4
Residual bone height (radiographic)	2.4–6.0 mm
Residual bone height (clinical)	1.6–6.0 mm
Mean graft volume	1.25–5 cc
Number of membrane perforations	8
Post-surgical complications	1 sinusitis

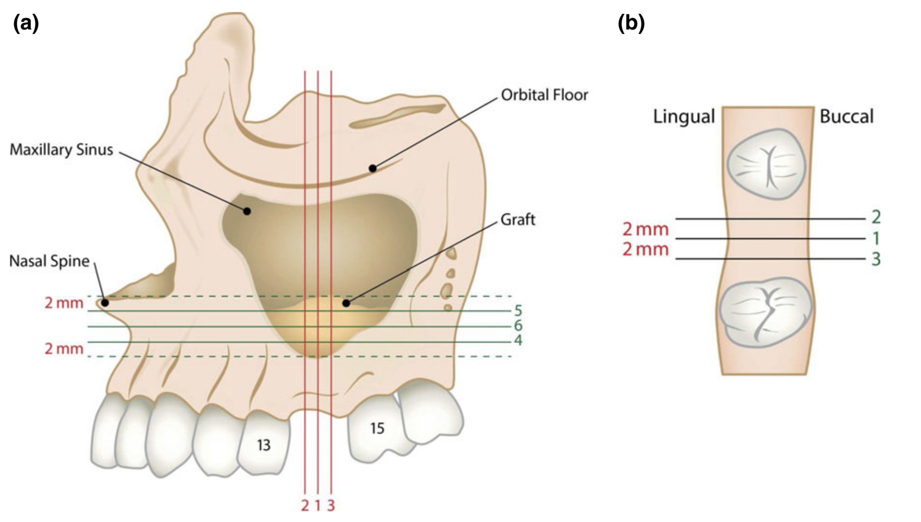

Fig. 1. Diagrams of the maxillary and alveolar views used for orientation and measurements. (a) Diagram of a sagittal view of the maxillary dentition and sinus anatomy indicating a missing maxillary first molar (#14). The diagram illustrates the reference lines used for obtaining standardized measurements of the grafted sinus areas. Line 1 (Section 1) defines the cross-sectional (CS) Midpoint, which was drawn at the center of the mesio-distal distance between teeth #13 and #15. Line 2 (Section 2) defines the CS Mesial point, which was designated as 2-mm mesial to Line 1 (Section 1), whereas Line 3 (Section 3), the CS Distal point, was 2-mm distal to Line 1 (Section 1). The two green, horizontal, dashed lines indicate the upper and the lower extent of the graft. Line 4 (Section 4) represents the horizontal section (HS) Low point, which is 2 mm superior to the lower border of the grafted area, whereas Line 5 (Section 5), the HS High point, is 2 mm inferior to the upper border of the grafted area. Line 6 (Section 6) represents the HS Midpoint, which is the midpoint between Lines 4 (Section 4) and 5 (Section 5). (b) Diagram of the occlusal/axial view of a partially edentulous alveolar ridge. Line 1 (Section 1), 2 (Section 2), and 3 (Section 3) represent the CS Midpoint, the CS Mesial point, and the CS Distal point, respectively. Line 1 defines the cross-sectional (CS) Midpoint, which was drawn at the center of the mesio-distal distance between the two teeth.

surgeons. Prosthodontic restoration and follow-up were performed by one experienced prosthodontist. Buser's criteria were utilized to assess the implant success rate (Buser et al. 1990).

One CBCT was taken of each patient before sinus augmentation surgery. The second CBCT was taken 4 months after surgery.

One examiner (CG) screened the CBCT scans of all subjects to determine agreement with inclusion criteria noted below. Images were projected on a 28-inch desktop monitor with a 1024 × 768 pixel resolution and visualized using ambient room lighting. The distance between the examiner and the monitor was approximately 30 cm. The CBCT images selected for this study had to fulfill the following inclusion criteria:

1. No scattering artifacts from nearby metal restorations
2. Visualization of the entire grafted site and native bone

Images were excluded if:

They were unclear or incomplete due to scattering or other reasons.

Image orientation and measurements

All measurements were obtained by three calibrated examiners (CG, CT, and KM). A calibration session preceded the individual image analysis session until complete agreement was established between all three examiners. The sampling method used in this study was based on the concept of stratified randomized sampling (Lohr 2010). Three repeated measurements were acquired from each of six different image planes or strata. These six different image planes were obtained for each subject.

The CBCT scans that qualified and met the inclusion criteria were realigned and reoriented so that the maxilla was positioned bilaterally symmetrical, and the maxillary plane, defined as the line connecting the anterior and posterior nasal spine (ANS and PNS), was parallel to the floor (Figs 1 and 2). Reconstructed panoramic views and corresponding cross-sectional images were obtained by tracing a line through the center of the maxillary alveolar ridge at the level of the alveolar crest (Figs 1–3).

In the sagittal plane, cross sections of the edentulous ridge were standardized at 2 mm mesial to the center of the ridge and 2 mm distal to the center of the ridge (Fig. 1a). In addition, the axial/horizontal plane images used were set 2 mm above the sinus floor, 2 mm below the highest point of the graft, and an axial plane image at the center between these two sections (Fig. 1b). The following measurements were performed:

Bone graft–void relationship

1. Bone-grafted Area (BG): The total area of bone graft inside the sinus cavity
2. Void Area (V): The area of the voids within the bone graft in the sinus cross sections
3. Void Percentage (V% = V/BG): Percentage of void areas with respect to the total area of the bone graft

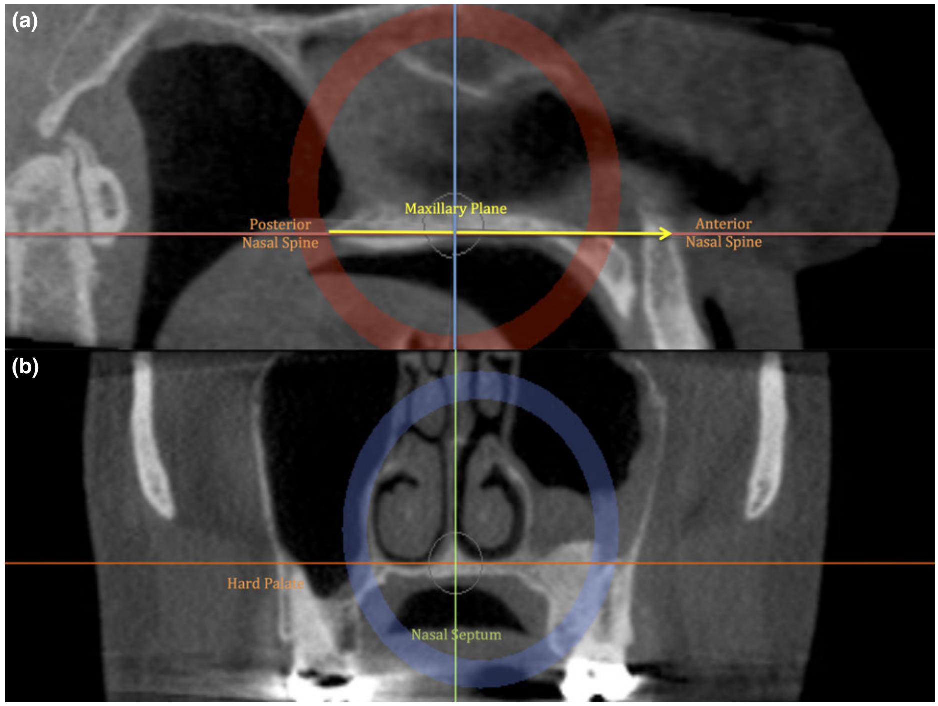

Fig. 2. (a) Cone-beam computed tomography (CBCT) image in the sagittal plane at the level of the midline. (b) CBCT image in the coronal plane at the level of the first molar. These images were used for calibration. The calibration was performed with reference to anatomical landmarks. In the mid-sagittal section (a), the image was rotated until the anterior and posterior nasal spines were aligned with the reference line in the maxillary plane. In the coronal section (b), the image was rotated until the hard palate was aligned with the reference line. The axial plane orientation, which represents the occlusal view (not shown), was automatically aligned once the sagittal and coronal planes were correctly oriented.

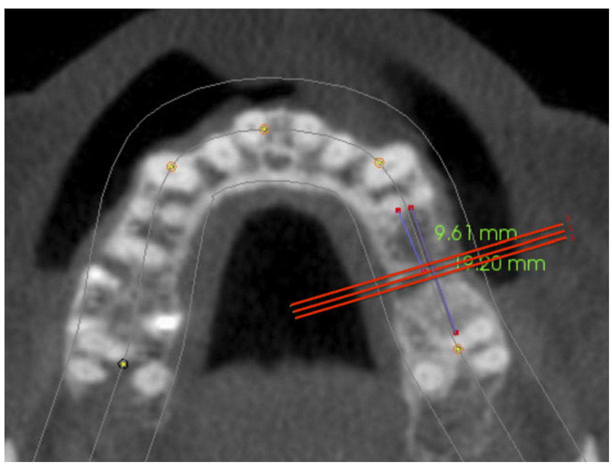

Fig. 3. Cone-beam computed tomography (CBCT) image in the axial plane at the level of the roots of the maxillary teeth showing the maxillary alveolar anatomy. Line 1 (Section 1) was identified in the axial plane at the level of the alveolar crest. The distance between adjacent teeth was measured and used to define the midpoint of the edentulous space. The middle red line was defined as Line 1 (Section 1). The other two red lines were additional reference lines not used in this study.

Table 2. **Measurements of void percentages (V%) for all defined sections in subjects**

	V%								
	CS midpoint			CS mesial point			CS distal point		
	Examiners								
Subjects	CT	CG	KM	CT	CG	KM	CT	CG	KM
#1	9.11	0.00	0.00	14.23	0.0	23.0	25.54	20.16	0.00
#2	1.49	3.06	2.25	12.15	0.0	6.4	3.86	5.21	6.37
#3	1.66	0.75	0.00	1.19	2.3	3.7	1.71	1.26	1.93
#4	0.00	22.10	0.00	0.63	0.0	0.0	0.00	0.00	0.00
#5	0.00	0.00	0.00	1.53	0.0	0.0	0.00	0.00	1.48
#6	13.05	5.98	5.29	2.39	12.6	7.9	14.43	11.22	7.09
#7	0.00	7.15	0.00	8.59	0.0	0.0	4.64	4.07	0.00
#8	0.00	3.10	4.34	3.40	0.0	7.3	0.00	7.29	0.00
#9	19.65	29.72	18.71	17.61	52.6	21.9	17.39	28.42	20.44
#10	0.00	4.85	0.00	0.00	4.6	0.0	0.00	5.01	22.75
#11	7.17	0.00	0.00	15.54	12.4	0.0	0.00	15.67	0.00
#12	5.79	35.33	5.69	2.69	0.0	5.8	3.39	20.83	2.21
#13	2.48	0.00	0.00	3.32	0.0	0.0	0.00	0.00	0.00
#14	7.41	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.00
#15	0.00	0.00	0.00	2.22	0.0	0.0	0.00	0.00	0.00
#16	0.00	0.00	3.70	2.79	0.0	4.6	0.00	2.18	4.86
#17	1.22	2.95	0.00	2.74	2.0	1.5	2.90	2.24	5.96
#18	2.09	10.40	2.33	1.77	9.1	3.5	4.71	2.34	4.67
#19	N/A	0.00	0.00	N/A	0.0	0.0	N/A	13.86	0.00
#20	N/A	63.94	65.19	0.00	55.6	43.9	0.00	49.80	38.03
#21	3.05	0.00	0.00	0.00	0.0	0.0	5.61	0.00	0.00
#22	14.79	29.17	4.02	0.00	27.5	2.9	12.48	17.62	0.00
#23	18.28	22.96	0.00	8.49	10.4	2.6	19.75	27.74	23.11
#24	N/A	0.00	0.00	N/A	0.0	0.0	N/A	33.74	23.57
#25	5.38	0.00	0.00	9.92	44.6	0.0	0.00	51.52	0.00

	V%								
	HS midpoint			HS low point			HS high point		
	Examiners								
Subjects	CT	CG	KM	CT	CG	KM	CT	CG	KM
#1	10.03	0.00	10.51	14.23	8.00	8.65	0.00	15.06	0.00
#2	3.84	0.00	1.31	12.15	27.18	7.54	36.18	0.00	27.86
#3	0.00	0.00	0.00	1.19	4.09	0.00	4.83	7.24	0.00
#4	1.92	0.00	2.87	0.63	0.98	0.00	1.99	6.44	1.79
#5	3.60	0.00	0.00	1.53	0.66	2.56	4.50	0.00	3.55
#6	7.45	0.00	0.00	2.39	1.19	3.81	8.72	0.00	0.00
#7	15.67	24.90	0.00	8.59	6.95	0.00	0.00	0.00	0.00
#8	0.00	0.00	0.00	3.40	17.78	8.61	8.10	0.00	18.41
#9	15.22	0.00	0.00	17.61	48.89	8.79	8.93	0.00	7.08
#10	0.00	13.22	0.00	0.00	0.00	0.00	5.97	0.00	0.00
#11	0.00	0.00	0.00	15.54	1.81	5.11	6.54	0.00	2.19
#12	25.37	0.00	0.00	2.69	0.00	3.11	3.67	0.00	2.49
#13	0.00	0.66	0.00	3.32	0.00	0.00	0.00	0.00	0.00
#14	0.00	0.00	0.00	0.00	0.00	0.00	7.35	0.00	0.00
#15	0.00	1.71	0.00	2.22	0.00	3.12	0.00	0.00	4.20
#16	0.00	0.00	7.43	2.79	0.00	0.00	2.46	0.00	2.18
#17	5.46	3.85	2.93	2.74	2.75	3.69	5.13	8.14	5.16
#18	3.55	0.00	0.00	1.77	12.26	2.68	7.97	3.77	0.00
#19	N/A	4.16	0.00	N/A	24.23	0.00	N/A	11.86	0.00
#20	0.00	0.00	57.34	0.00	0.00	45.56	0.00	0.00	0.00
#21	0.00	0.00	0.00	0.00	0.00	0.00	5.31	8.40	0.00
#22	1.70	0.00	0.00	0.00	2.13	0.00	14.49	26.97	2.95
#23	0.00	0.00	0.00	8.49	15.04	10.05	0.00	0.00	4.77
#24	N/A	0.00	16.76	N/A	0.00	8.59	N/A	0.00	11.06
#25	9.01	0.00	15.62	9.92	25.17	34.29	0.00	0.00	13.42

Not available (N/A) designation assigned to unclear images. Those patients with N/A were excluded from the data analysis.

Image acquisition

All images were acquired with an i-CAT CBCT scanner (Imaging Sciences International, Hatfield, PA, USA) in the Department of Periodontics and Oral Medicine at the University of Michigan School of Dentistry by board certified Oral and Maxillofacial radiologists (EB and SB) between 2005 and 2013. The imaging parameters were set at 120 kVp, 18.66 mAs, scan time 20 s, resolution 0.4 mm, and a field of view (FOV), which varied based on the scanned region. The scans used in the present study were selected from the CBCT database. The CBCT scans of each individual were transferred to a desktop computer equipped with an implant planning software program (InVivoDental, Anatomage, San Jose, CA, USA). Data were saved in the Digital Imaging and Communications in Medicine (DICOM) format.

Statistical analysis

A repeated measures ANOVA with Greenhouse Geisser correction was used to compare the contribution from six sections to the total void areas within subjects (Lohr 2010). The difference between means of every two sections was examined in a post hoc test. A P-value of less than 0.05 was accepted as statistically and significantly different. All the data were analyzed using the IBM Statistical Product and Service Solutions (SPSS) software (IBM North America, New York, NY, USA).

Results

Four of the 30 subjects did not complete the study, and one of the 26 CBCT data files was eliminated because it did not meet the inclusion criteria. Thus, data from 25 subjects were collected based on the inclusion criteria for our study. Measurements were obtained from CBCT images for all 25 subjects (Tables 2 and 3). The undefined V values were listed as not available (N/A). There were a total of six patients containing N/A values in any one of six sections. Data from these six subjects were omitted from statistical analysis due to inability and/or difficulty in determining the void areas and their corresponding measurements using the software. The P-value was 0.12 among mean measurements from six sections within each subject.

In pairwise comparisons, the P-value was 0.035 when comparing section 1 (CS midpoint) with 4 (HS low point). The P-value was 0.006 when comparing section 3 (CS distal point) with 4 (HS low point). The P-value was 0.047 comparing section 5 (HS high point) with 4 (HS low point). However, the differences for pairwise comparisons among all other measurements were not significantly different. The P-values for pairwise comparisons of marginal means are listed in Table 4.

The data were treated as repeated measurements. The means for all data groups are listed in Table 3. The range of void percent-

Table 3. **Estimated marginal means of measurements for all sections in subjects**

Section V%	CS mid Avg.	CS mesial Avg.	CS distal Avg.	HS low Avg.	HS mid Avg.	HS high Avg.
#1	3.04	9.16	15.23	13.56	10.29	5.02
#2	2.26	3.13	5.14	3.45	15.62	21.35
#3	0.80	2.80	1.63	0.42	1.76	4.02
#4	7.37	0.00	0.00	1 60	0.54	3.40
#5	0.00	1.30	0.49	1.20	1.58	2.68
#6	8.11	9.78	10.91	6.22	2.47	2.91
#7	2.38	2.77	2.90	6.58	5.18	0.00
#8	2.48	2.45	2.43	2.43	9.93	8.83
#9	22.69	37.33	22.08	14.55	25.10	5.34
#10	1.62	1.76	9.25	1.67	0.00	1.99
#11	2.39	7.74	5.22	5.22	7.49	2.91
#12	15.60	5.12	8.81	15.40	1.93	2.05
#13	0.83	0.00	0.00	0.00	1.11	0.00
#14	2.47	0.00	0.00	0.00	0.00	2.45
#15	0.00	0.00	0.00	0.00	1.78	1.40
#16	1.23	1.54	2.35	3.21	0.93	1.55
#17	1.39	1.51	3.70	3.55	3.06	6.14
#18	4.94	5.44	3.91	1.96	5.57	3.91
#19	0.00	0.00	6.93	6.93	12.12	5.93
#20	64.57	33.16	29.28	35.72	15.19	0.00
#21	1.02	0.88	1.87	0.00	0.00	4.57
#22	16.00	12.90	10.04	6.44	0.71	14.80
#23	13.75	7.13	23.54	9.25	11.19	1.59
#24	0.00	0.00	28.65	25.25	4.29	5.53
#25	1.79	22.29	17.17	25.38	23.13	4.47
Total	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
N = 19	5.30 ± 6.67	5.79 ± 8.51	6.67 ± 7.12	2.07 ± 2.56	5.30 ± 6.62	4.92 ± 5.17

Table 4. **Pairwise comparisons of estimated marginal means**

Section	Section	*P*-value
1	2	0.674
	3	0.216
	4	0.035
	5	0.997
	6	0.839
2	3	0.526
	4	0.058
	5	0.711
	6	0.690
3	4	0.006
	5	0.324
	6	0.390
4	5	0.047
	6	0.050
5	6	0.814

Section 1 = CS midpoint; Section 2 = CS mesial point; Section 3 = CS distal point; Section 4 = HS low point; Section 5 = HS high point; Section 6 = HS midpoint.

ages (V%) for the CS midpoint, CS mesial point, CS distal point, HS low point, HS midpoint, and HS high point were 5.30 ± 6.67%, 5.79 ± 8.51%, 6.67 ± 7.12%, 2.07 ± 2.56%, 5.30 ± 6.62%, and 4.92 ± 5.17% respectively (Fig. 4).

Table 3 demonstrates that for the mean V% for all 25 subjects, at least two of six measurements were larger than 0. Therefore, in each of 25 grafted sinuses, void areas could be found in more than one section, respectively. The void prevalence in our study was 100%.

Thirty-nine implants were placed 4 months after the sinus lift surgery. One out of all the implants was removed due to failure of osseointegration at 2 months. Thirty eight implants were restored 2 months after placement with implant-supporting prostheses. No complication was reported in the 6-month follow-up period after prosthetic treatment.

Discussion

Overall, the *P*-value of the within-subject effect was greater than 0.05 ($0.12 > 0.05$). This indicates that the voids within the same subject were randomly distributed. In other words, there was no predictability in terms of where the voids would be located and how big the voids would be in certain locations. However, this seeming randomness for the presence, and location of voids was reasonable, given differences in individual patient's health status, healing ability, anatomical differences, and variations in the surgical technique on different patients. However, in the pairwise comparison analysis, there were significant differences between the CS midpoint and HS low point, and between the CS distal point and HS low point. We could conclude that the V% for bone grafts between the CS midpoint and HS low point, CS distal point and HS low point, HS midpoint and HS low point were significantly different. The mean V% for HS low point was 2.07 ± 2.56%. In contrast, the percentage mean V% of CS distal point, CS midpoint and HS midpoint were 6.67 ± 7.12%, 5.29 ± 6.67%, and 5.30 ± 6.62%, respectively. In other words, the HS low point section had the smallest V % compared to the CS midpoint, CS distal point, and HS midpoint. Given these data, it could be concluded that more attention should be given to the distal aspect of the sinus when compacting graft materials.

Limitations in the surgical field may lead to difficulty in condensation of graft material. Retraction of the cheek is limited by the tension of facial muscles, such that the distal and posterior maxilla are harder to access. Additionally, the high prevalence of sinus septae in first and second molar areas potentially limits the ability to condense the graft material in certain angles (Neugebauer et al. 2010). Furthermore, the nature of the distal space under the elevated sinus membrane can be open-ended and thus less controllable compared to the mesial space where anterior teeth can provide a definite anterior stop for compaction of graft material.

In terms of implant failure, only one implant failed within the 4-month post-operative period for patient #12. The failed implant was removed. An implant-supporting bridge was fabricated and delivered for this patient on the other two successful implants. Another patient (#20) experienced a failed sinus grafting procedure. The patient underwent a second sinus lift surgery and subsequent implant placement with successful restoration. In patient #12, the V% within the graft ranged from 0% to 35.33%. Within the limitations of the study, this suggests a possible association between inconsistent distribution of grafting material and future implant failure. All implants, except one, were restored. There were no complications reported after functional loading of the implants after 6 months of follow-up. The success rate in our study was 98% (38/39) (Buser et al. 1990). In aggregate, these data indicate that small V% of the maxillary sinus do not have an impact on implant failure. Larger V% may negatively impact outcomes. However, longer-term follow-up would help confirm the concept that V % in the range of 2.07 ± 2.56% to 6.67 ± 7;12% do not impact implant success.

There are several possible reasons why implant success rate remains high despite the presence of voids within grafts. Graft voids have the potential to transform into new bone. Lundgren et al. (2000) discussed the possibility of new bone formation by elevating the Schneiderian membrane. Space maintenance

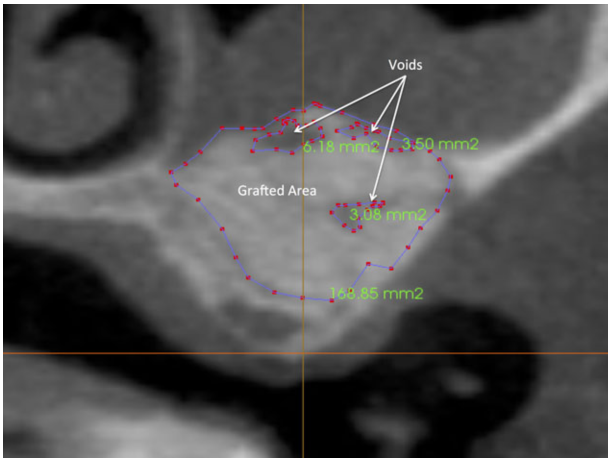

Fig. 4. Cone-beam computed tomography (CBCT) image of the maxillary sinus anatomy in the coronal plane. This image also represents Section 1. After outlining the grafted area and void areas, all areas were measured with an implant planning software program (InVivoDental, Anatomage, San Jose, CA, USA). Grafted areas and void areas were measured and recorded.

can be achieved by using implants as tent poles, allowing a coagulum and graft material to fill in the voids within the space that then remodels as new bone. Other studies also discussed the possibility of performing sinus lift procedures without the use of graft materials. The amount of bone gain obtained when not employing graft material was not significantly different from that obtained when performing sinus lift procedures that did include graft materials. (Lundgren et al. 2000; Nedir et al. 2006; Hatano et al. 2007; Thor et al. 2007; Sohn et al. 2008; Gabbert et al. 2009). Similarly, an animal study that used a split-mouth design on primates found that Schneiderian membrane elevation without a graft compared to elevation with a graft material exhibited no differences in bone formation (Palma et al. 2006). However, the exact mechanism involved in bone formation when employing membrane elevation alone without graft material is not fully understood and needs to be further investigated.

Our data indicate that implant success remains high despite the presence of random, small V% within maxillary sinus grafts. This may relate to bone-to-implant contact (BIC), as BIC influences osseointegration (Novaes et al. 2010). A mean BIC value of 60% was achieved for successful implants in a biological engineering study (Lian et al. 2010). Average BIC in an SEM study was reported to be 35% (Manresa et al. 2013). A histometric evaluation indicated that the mean BIC% ranged from 45.2% to 34.10% (Shibli et al. 2013). In addition, the void areas identified in CBCT images might be uncalcified tissues when examined histologically; however, this remains to be determined. In our study, mean V% ranging from 6.67% to 2.07% were likely not significant enough to potentially influence or compromise the average BIC for successful implant outcomes (Lian et al. 2010). Reducing the V% in sinus lift grafting may be important, but the contribution of V/BG ratio (albeit in a small range) was not considered critical to implant success.

The optimal time for acquiring a post-sinus augmentation CBCT scan and if one is indicated is unclear. Bone maturation following sinus augmentation progresses continuously up to 40 weeks (Schulze-Spate et al. 2012). Other studies show that combinations of grafts and growth factors can accelerate bone formation (Bettega et al. 2009; Mazor et al. 2009). Therefore, the optimal time for obtaining a post-operative CBCT scan, if indicated, must be carefully assessed. To better investigate the relationships between V% in sinus grafts and implant success, and the change of V with time, longer follow-up may be beneficial.

Our results indicate that grafting material within augmented maxillary sinuses concentrates inferiorly and anteriorly over time. In addition, voids were found within the grafted sites, albeit generally in small percentages relative to the grafted volume. Previous quantitative sinus studies took advantage of histological and radiological methods. Volumetric dimensions in bone grafts changed significantly 1 year post-operatively. Software combined CBCT analyses of grafted maxillary sinuses demonstrated a volumetric loss of 28.0% at 6 months and 39.6% at 1 year post-operatively (Kim et al. 2013), whereas other studies (Dellavia et al. 2013) showed a volumetric loss of 19% at 6 months post-operatively. Using a two-dimensional radiographic image analysis, the 4-year study by Riachi reported a volumetric loss of 23.4% and 33.4% using Cerabone and Bio-Oss, respectively (Riachi et al. 2012). In contrast, Pal and coworkers reported linear changes of approximately 8.5 mm of bone gain at 3 months (Pal et al. 2012). Compared to earlier studies, the current study provides tomographic mapping information of grafted sinuses. It may be beneficial to use both conventional radiographs and CBCT to accurately assess the quantity, quality, and distribution of graft voids within augmented maxillary sinuses.

Our study is the first quantitative radiographic study to investigate the internal structure of bone grafts (i.e., presence, size, and distribution of graft voids) following maxillary sinus augmentation and its contribution to implant success. Post-operative CBCT analysis is not considered routine practice. Due to the high success rate of implants placed in the area of maxillary sinus augmented sites, and given the findings of the current study, taking CBCTs post-operatively can be helpful in understanding the characteristics of grafts within the maxillary sinus. CBCT allows for a more comprehensive analysis of grafted maxillary sites.

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