The Influence of the Bucco-Palatal Distance on Sinus Augmentation Outcomes

Gustavo Avila,* Hom-Lay Wang,* Pablo Galindo-Moreno,† Carl E. Misch,‡ Robert A. Bagramian,* Ivan Rudek,* Erika Benavides,* Ildefonso Moreno-Riestra,* Thomas Braun,§ and Rodrigo Neiva*

Background: Maxillary sinus augmentation is one of the most reliable implant site development options to increase vertical bone height. However, graft consolidation requires adequate angiogenesis and migration of cells involved in osteogenesis and bone remodeling. It is speculated that these biologic events are greatly determined by the dimensions of the maxillary sinus cavity. Hence, the purpose of this study is to assess the influence of the distance from the lateral to the medial wall of the maxillary sinus on the outcomes of sinus augmentation procedures.

Methods: A total of 25 patients in need of sinus augmentation were recruited for the study. After initial examination, customized radiographic and surgical guides were fabricated and a cone-beam computerized tomography scan was obtained per patient. The bucco-palatal distance (BPD) was measured at 8, 10, and 12 mm from the alveolar crest. Sinus grafting was performed by a lateral window approach using a particulated allograft material. Patients were followed-up for 6 months. At the time of implant placement, bone core biopsies were harvested using the radiographic-surgical guide. Sections of the bone cores at 8, 10, and 12 mm from the alveolar crest were histomorphometrically analyzed. The proportion of vital bone (%VB) was correlated with the BPD using a statistical model.

Results: Twenty-one patients underwent sinus augmentation for a total of 24 sinuses; however, the data analyzed contained only one sinus per patient. One sinus developed an infection after grafting, resulting in a 96% success rate for the sinus grafting procedure. Twenty sinuses were used in the final statistical analysis. Histomorphometric analysis revealed that mean %VB was 22.71 ± 19.08, mean percent of remaining allograft was 23.39 ± 20.85, and average percent of non-mineralized connective tissue was 53.90 ± 13.23. Analysis of the correlation between %VB and BPD by linear regression, using the actual values of BPD showed a strong negative association ($R^2 = 0.141$; $P < 0.001$).

Conclusion: The findings suggest that the %VB formation after maxillary sinus augmentation is inversely proportional to the sinus BPD. *J Periodontol 2010;81:1041-1050.*

KEY WORDS

Bone transplantation; dental implants; maxillary sinus; models, anatomic.

Placement of implants in the posterior maxilla frequently poses a challenge due to the abundance of cases presenting with limited residual bone and reduced osseous density.[1] Natural resorption of the alveolar process[2] following tooth loss and pneumatization of the maxillary sinus[3] often leads to limited bone availability for proper implant placement. Limited alveolar bone height in this area happens from two fronts, making the need for augmentation even more critical. Compromised implant primary stability due to the presence of very trabecular (D4) bone in the posterior segments of the maxilla may lead to early implant survival.[4] Likewise, the use of shorter implants to avoid bone grafting may negatively impact long-term clinical outcomes since the strong occlusal forces typically exerted in this area may conduce to a mechanical complication and excessive peri-implant bone stress.[5] Over the years,

* Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, MI.
† Department of Oral Surgery and Implant Dentistry, University of Granada School of Dentistry, Granada, Spain.
‡ Private practice, Beverly Hills, MI.
§ Department of Biostatistics, University of Michigan School of Public Health, Ann Arbor, MI.
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several implant site development modalities, such as guided bone regeneration, onlay block grafts, distraction osteogenesis, ridge splitting and expansion, and sinus grafting have been described to overcome limited bone width and height.[6-8] In the 1980s, Boyne and James[9] introduced the concept of sinus augmentation in dentistry, derived from surgical otorhinolaryngologic techniques. Originally, sinus augmentation was aimed at obtaining enough bone volume to allow proper implant placement in posterior areas of edentulous maxillae. Since then, modifications of the technique and the use of different materials have been proposed, seeking higher predictability and minimal complications.[10-13]

Researchers have aimed at identifying and understanding the factors that may have a critical impact on the outcomes of sinus augmentation. These factors include untreated systemic disease, smoking status, implant surface features, grafting material used, and surgical technique applied. Several authors have pointed out the importance of anatomic variables. Fenner et al.[14] conducted an animal study (minipigs) to evaluate the influence of remaining alveolar bone height (RBH) on stability and osseointegration of dental implants placed in maxillary posterior segments. Three months after tooth extraction, animals underwent sinus augmentation with simultaneous implant placement and were assigned to four different groups of RBH: 2, 4, 6, and 8 mm. Desired RBH was surgically created. It was found that implant stability measured by resonance frequency analysis at implant placement and 6 months after placement was influenced by RBH. Higher resonance frequency analysis values were associated with higher RBH, although it did not seem to influence implant survival. Therefore, the paradigm of the need for a minimum of 5 mm to ensure stability and subsequent implant survival was challenged. The authors also observed that osseointegration could be influenced by RBH. Two implant failures were recorded belonging to the 2-mm RBH group.[15]

Rios et al. [16] performed a review aimed at evaluating the correlation between remaining alveolar bone crest and implant survival after sinus augmentation, including human studies. The data reviewed from the literature suggest that higher implant survival can be expected as available residual bone increases.

In a human study, Artzi et al.[17] evaluated the osteoconductive properties of two different grafting materials. Twelve patients underwent bilateral sinus floor elevation. After a period of 12 months of healing, bone core biopsies were harvested from the lateral wall. It was observed that the proportion of vital bone (VB) increased significantly from superficial to internal sections regardless of the grafting material. These findings possibly indicate that the lack of a bony wall may hinder VB formation.

Successful graft consolidation relies on the progressive apposition of newly formed VB, followed by functional remodeling and progressive replacement of the grafting material by vital tissue.[18] This process requires the presence of a stable scaffold, adequate angiogenesis (blood supply), and the migration of osteogenic cells. These events could be hindered in situations where the dimensions of the maxillary sinus cavity or the lateral window are excessive. Delayed or insufficient bone maturation may occur in cases where the sinus cavity presents larger dimensions, or in cases where limited alveolar bone remains after tooth loss. The influence of these factors on sinus augmentation outcomes remains unclear. We hypothesize that the distance from the buccal (lateral) to the palatal (medial) wall of the sinus cavity may influence bone maturation after sinus augmentation. This study assesses the influence of the distance from the lateral to the medial wall of the maxillary sinus (bucco-palatal distance [BPD]) on the outcomes of sinus augmentation procedures.

MATERIALS AND METHODS

Subject Screening and Recruitment

Patients from the University of Michigan School of Dentistry, Ann Arbor, MI, patient pool in need of either unilateral or bilateral sinus augmentation were screened. The experimental protocol was approved by the University of Michigan Institutional Review Board (HUM00017520). The study was also registered in the database of the National Institutes of Health for clinical trials code CT00868777. Patients were included in the study according to the following criteria: 1) adult patients 18 to 85 years of age in need of sinus augmentation, 2) classification of physical status according to the American Society of Anesthesiologists of I or II, 3) RBH ≤6 mm assessed in periapical radiographs using the paralleling technique, 4) O'Leary plaque score ≤20%.[19] Exclusion criteria included long-term (>2 weeks) use of antibiotics in the past 3 months; use of medications known to affect bone metabolism; smoking >10 cigarettes per day;[20] alcoholism or recreational drug abuse; uncontrolled conditions known to alter bone metabolism; pregnant or attempting to get pregnant; presence of mucocutaneous diseases; severe acute or chronic sinus pathology (i.e., sarcoidosis, osteomas, or carcinomas); history of cancer; radiation to the head and neck in the last 18 months; and chemotherapy in the last 12 months or postoperative complications related to these therapies. Patients who met the criteria and agreed to participate in the study were required to read, understand, and sign an informed consent. The study was conducted from January 2008 to April 2009.

Preoperative Sequence

Upper and lower arch impressions were obtained from each patient for planning and to fabricate customized radiographic and surgical guides that indicate the ideal path of insertion of the implants as determined by a restoring dentist (IR), using a clear acrylic material.‖ Gutta-percha was included in these guides to correlate planned implant prosthetic position with anatomic structures. In a second visit the customized guide was tested. A cone-beam computed tomography (CBCT) scan was made with a cone-beam machine.¶ The patients wore the radiographic guide during the scan. The position of the gutta-percha markers was verified (Fig. 1) using a tridimensional software-based reconstruction (see supplementary video in online *Journal of Periodontology*.)# Proprietary software** was used to make linear measurements of the BPD using the guide as a reference. Starting at the center of the apical end of the gutta-percha marker, a line parallel to the major axis of the marker was drawn and prolonged into the sinus cavity. The distance was recorded drawing perpendicular lines at three different heights (8, 10, and 12 mm from the alveolar crest) from the lateral to the medial wall, as illustrated in Figure 1. Two calibrated, masked examiners (GA and IM-R) specifically trained for this project, performed the anatomic measurements twice within a 2-week interval. RBH was also recorded. In cases where abnormal thickening of the membrane was noticed or cystic and tumoral pathology was suspected, patients were referred for an otorhinolaryngologic consultation. All patients were requested to take an antibiotic (amoxicillin, 500 mg three times a day for 10 days, starting 2 days before the surgery; or clindamycin, 300 mg three times a day for 10 days, starting 2 days before the surgery, in case of allergy to penicillins) and oral corticosteroids to minimize the risk of infection, postoperative swelling, and discomfort.

Surgical Procedure

All patients were offered intravenous sedation to undergo the surgical procedure. Surgeries were performed under local anesthesia with a vasoconstrictor.†† A supracrestal incision was made slightly toward the palatal aspect of the edentulous alveolar crest. The incision extended between the remaining teeth or from the remaining teeth to the tuberosity in cases of edentulous distal extension. A mesial or distal vertical releasing incision was drawn when necessary to gain appropriate access. A full-thickness mucoperiosteal flap was elevated for visualization of the lateral wall of the maxillary sinus. Then, a window was delineated with a round diamond bur, using the CBCT images as a reference. Once exposed, careful elevation of the Schneiderian membrane was performed using sinus membrane elevators.‡‡ Sinus membrane was never lifted beyond the sinusal ostium to avoid occlusion of the meatus,[21] but at the same time it was not elevated <14 mm from the crest, to allow sufficient implant length. The membrane was protected after its elevation with a flat, blunt-edged metal instrument. In cases of Schneiderian membrane perforation, an absorbable collagen membrane§§ was placed over the perforation to minimize the risk of complications. An allograft,‖‖ with a particle size ranging from 600 to 1,250 μm, was used as single grafting material to fill the sinus cavity. As much grafting material as necessary was placed to obtain a minimum height of 14 to 16 mm from the alveolar crest, and to fill up completely to the borders of the lateral window. An antibiotic liquid suspension (clindamycin, 150 mg/ml) was added to the bone graft to hydrate it and minimize the risk of infection. The proportion followed was 1 ml of antibiotic per 2 cc of grafting material. In all cases, an absorbable collagen material¶¶ was placed over the surgically created window as a dressing and hemostatic material. Soft tissues were sutured to achieve primary closure using 4-0 polyglactin for the supracrestal incision and 5-0 chromic gut to suture the vertical incision, if present.

Postoperative Care and Follow-Up

All patients were provided written and verbal postoperative instructions for oral surgical procedures. Patients continued the antibiotic regimen for 7 days and were instructed to take 6 mg of dexamethasone the same day of the surgery, 4 mg the day after, and then 2 mg 2 days after the sinus augmentation. A prescription for analgesic and anti-inflammatory medication (hydrocodone, 5 mg/acetaminophen, 500 mg per tablet) was given to all patients. Patients were seen approximately 2 weeks after the surgery for suture removal and evaluation. Thereafter, all patients returned for monthly follow-up visits at 1, 2, 3, 4, and 5 months.

Implant Placement and Bone Core Biopsy Harvesting

At the 5-month follow-up visit a second CBCT scan using the radiographic guide was obtained. An analysis of the grafted area was conducted to assess total bone height achieved and to identify unfavorable outcomes that could contraindicate implant placement. The radiographic guide was then transformed into a surgical guide designed to orient a 3.75-mm-diameter

‖ Ortho-Jet, Lang Dental Mfg, Wheeling, IL.
¶ i-CAT, Imaging Sciences International, Hatfield, PA.
# OsiriX Imaging software, Geneva, Switzerland.
** i-CAT, Xoran Technologies, Ann Arbor, MI.
†† Xylocaine 2%, Astra Zeneca USA Pharmaceuticals, Westborough, MA.
‡‡ Salvin Dental Specialties, Charlotte, NC.
§§ BioMend, Zimmer Dental, Carlsbad, CA.
‖‖ MinerOss, BioHorizons, Birmingham, AL.
¶¶ CollaTape, Zimmer Dental.

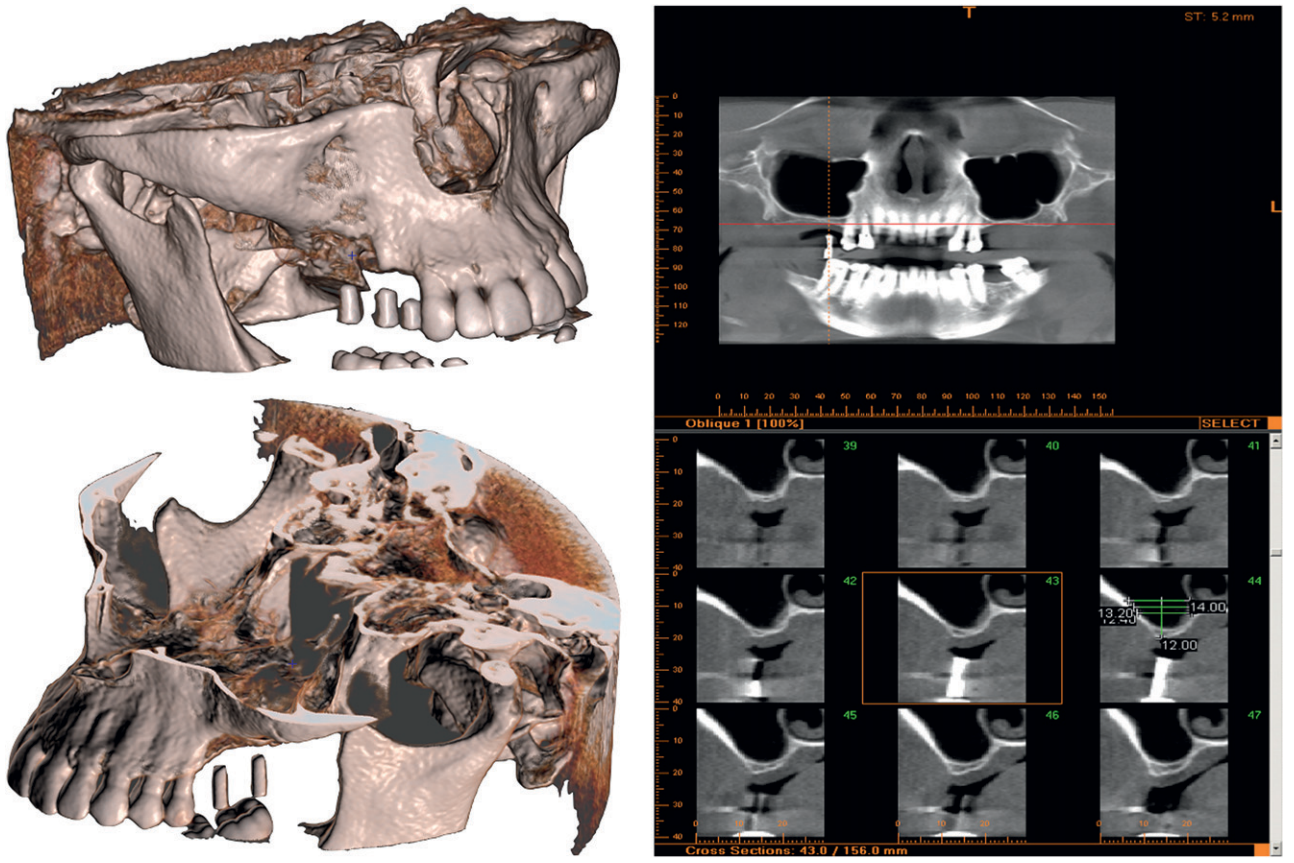

Figure 1.
Tridimensional reconstruction of the maxilla and other adjacent orofacial structures using imaging software to verify the position of the radiographic guides in relation to the maxillary sinus (left), and illustration of how the presurgical measurements were obtained using a specialized software (right).

trephine. Implant placement was performed at least 6 months after bone augmentation, and never after 7 months. Harvesting of a bone core biopsy (minimum height of 13 mm) was attempted for each implant location using the customized stent and a trephine as starting drill. This guide was used to obtain samples from the same locations where the radiographic measurements were made. The drilling sequence continued to the planned implant length and diameter. Implant diameter was ≥4 mm in every case; therefore, in some cases no other drill was used beyond the trephine. Implants[##] were placed in a two-stage approach with a minimum insertion torque of 30 N/cm^2 to ensure primary stability.

Histologic Preparation

Immediately after harvesting, each biopsy was marked on the crestal aspect and submerged in a 10% neutral buffered formalin solution for fixation. Following demineralization, cores were dehydrated and embedded in paraffin. Specimens were sectioned following a protocol accurately to obtain circular sections at 8, 10, and 12 mm from the crestal portion of the sample. Samples were stained with a conventional hematoxylin-eosin (H & E) technique and coverslipped for histologic and histomorphometric analysis.

Histomorphometric Analysis

All the samples were analyzed using a bright-field optical microscope with a digital camera.*** At least two slides of each height level per bone core specimen were analyzed. Images of the samples were captured at the same magnification (×4). A quantification of the %VB, remaining allograft particle (RA), and non-mineralized connective tissue (NMCT) was performed using specialized software.††† Vital bone was defined by the identification of osteocytes in the lacunae.

Statistical Analysis

Sample-size calculation. A power analysis using specific software‡‡‡ was performed after introducing the effect size and standard deviation obtained from the

BioHorizons Internal Implants, BioHorizons.
*** Nikon E800 Light microscope with Diagnostics Spot-RT cooled CCD digital camera, Nikon, Tokyo, Japan.
††† Image-Pro Plus 5.0, Media Cybernetics, Bethesda, MD.
‡‡‡ G*Power 3, Institute for Experimental Psychology, Heinrich Heine University, Düsseldorf, Germany.

Table 1.

BPD Values Stratified by the Three Different Analyzed Levels: 8, 10, and 12 mm From the Alveolar Crest

Patient Code	8 mm	10 mm	12 mm
	BPD (in mm)	BPD (in mm)	BPD (in mm)
1002	16.8	17.6	X
1003	5.4	7.6	X
1004	12.3	12.1	12
1005	12.7	14.6	16.9
1006	X	13.4	14.2
1007	9.4	14.6	17.6
1008	11.9	14.5	16.6
1009	12.9	15.3	16.9
1010	8.2	9.2	10.4
1011	X	12.4	13
1013	10.6	13.9	17.6
1015	10.9	13.4	14.8
1016	10.4	12	14.2
1017	7.9	10.3	11.6
1018	16.9	21	22.7
1019	6.3	7.8	X
1020	11.2	12.6	14.3
1022	7	9.9	11.9
1024	8	11.5	12.7
1025	5.7	9.8	10.6
Total Mean	10.2 (SD = 3.4)	12.7 (SD = 3.2)	14.6 (SD = 3.2)

X = sample was excluded from the analysis because the histologic section was not analyzable.

data collected in a previous pilot study. In that pilot study, multiple measurements of the BPD of the sinus walls were analyzed from the CBCT database of the University of Michigan School of Dentistry. Statistical analysis showed that 22 samples would provide 85% power, assuming a Type I error rate of 5%, to detect a true difference in the BPD of the maxillary sinus. The number of patients recruited was based on this sample-size calculation after inflation for an expected 10% dropout rate. Although this sample size was motivated by BPD and not %VB, this sample size also has 80% power to detect any correlation between BPD and %VB of 0.50 or higher in magnitude.

Data analyses. The unit of analysis is the patient. One sinus from each patient was randomly chosen for analysis. Normality of data was assessed informally by visual inspection of histograms, because the sample size is insufficient to power formal tests of normality. No serious deviations from normality were seen. The association of %VB with the BPD was quantified as a correlation coefficient. Linear regression was used to estimate the correlation of %VB and BPD to adjust for the age and gender of each patient. Furthermore, given that the data consisted of three cores drawn from each implant site, the standard error of the correlation coefficient was generated from the robust standard errors produced from the method of generalized estimating equations. All analyses were repeated with a categorized version of BPD, in which there were three categories: <10, 10 to 14, and ≥15 mm. The statistical significance of the correlation was assessed with a Wald test; a P value <0.05 was considered statistically significant. Data analyses were performed using statistical software.§§§

RESULTS

Study Population

A total of 25 patients enrolled in the study. Four patients dropped out before undergoing sinus augmentation surgery; 21 individuals (9 males and 12 females) with a mean age of 57.6 years (range, 23 to 69) were included in this study. Four patients were smokers (<10 cigarettes/day) at the beginning of the study. Four patients were referred for otorhinolaryngologic consultation, and all of them received medical clearance for the maxillary sinus augmentation procedure. All but one patient received intravenous sedation.

Clinical Findings

A total of 21 sinus augmentation procedures were performed. Three patients received bilateral sinus augmentation. The incidence of Schneiderian membrane perforation was 20.83% (5 of 24 sinuses). One patient developed an infection after sinus augmentation, not related to membrane perforation. The infection was successfully controlled with antibiotics and removal of the bone graft plus debridement in a second surgical approach. This patient was excluded from final measurements. The remaining 20 patients analyzed followed-up regularly and completed the study. Soft tissue invasion, at the level of the lateral window into the grafted area at the time of implant placement (6 months after grafting) was noticed in only one case. The depth of the invasion was <3 mm, as measured horizontally with a periodontal probe, and implant placement was performed

§§§ R statistical software package, Free Software Foundation, Boston, MA.

uneventfully. A total of 39 implants were placed. Primary stability (determined by insertion torque >30N/cm^2) was achieved in all cases.

Radiographic Findings

Twenty sinuses (one per patient) were analyzed. Radiographic measurements obtained by the two examiners (I-MR, GA) were averaged to obtain the final value (intraexaminer and interexaminer error was <0.5 mm). The BPD ranged from 5.4 to 22.7 mm, with a mean value of 12.5 ± 3.7 mm. It was observed that BPD increased in an apical direction in most of the patients analyzed. Stratified data regarding BPD are shown in Table 1. Mean radiographic RBH was 3.3 ± 1.4 mm, ranging from 1 to 5.5 mm. Mean ridge height achieved after sinus augmentation was 15.9 ± 2.9 mm, ranging from 12 to 21.6 mm.

Histologic and Histomorphometric Analyses

A total of 23 biopsies were harvested. Three of them could not be processed because of excessive deterioration during biopsy harvesting or at the time of extracting the specimen from the trephine. The study protocol dictated that three levels per area per core be analyzed (8, 10, and 12 mm from the alveolar crest), which means that a total of 60 areas were cut to obtain analyzable sections. Four of the 60 levels were too deteriorated for a proper histomorphometric analysis after laboratory processing and were discarded. Circular sections with a thickness of approximately 5 μm were obtained and analyzed (Fig. 2A). Newly formed VB presented a well-organized, lamellar structure. It was a common finding to observe VB in intimate contact with RA particles, in absence of inflammatory infiltrate (Fig. 2B). Histomorphometric analysis revealed that mean %VB was 22.71 ± 19.08, mean %RA was 23.39 ± 20.85, and average %NMCT was 53.90 ± 13.23 (Table 2). Interestingly, when BPD was subdivided into three different categories (<10, 10 to 15, and >15 mm), it was observed that as BPD increases, the total %VB decreases (Fig. 3). Histomorphometric data are reported in Table 2.

Analysis of Correlation

Analysis of the correlation between %VB and BPD by linear regression, using the actual values of BPD, showed a strong negative association (r = –0.376; P <0.001). This finding strongly suggests that as BPD decreases, %VB increases. In the same sense, the analysis using categorical BPD demonstrated a negative association between %VB and BPD (r = –0.301; P = 0.014), reaching statistical significance. Because of the limited sample size in each category, it was not possible to establish a cutoff value indicating a significant drop in VB presence depending on a particular BPD.

DISCUSSION

This project was conducted to determine the influence of BPD on the outcomes of sinus augmentation procedures using an allograft. Analysis of the proportion of newly formed VB in human histologic samples, by histomorphometric analysis, is generally accepted as the gold standard to assess the consolidation of a bone substitute.[22] Other authors have previously used this method to evaluate the outcomes of a sinus augmentation technique using a freeze-dried allograft material.[23,24] Data from our study show that mean %VB obtained was 22.71 ± 19.08, mean %RA was 23.39 ± 20.85, and average %NMCT was 53.90 ± 13.23. These findings are in agreement with studies that evaluated sinus augmentation outcomes using a particulate allograft as a sole material. Kolerman et al.[25] reported a mean %VB of 29.1%, Froum et al.[26] showed a proportion of 25.2%, whereas a group from the University of Loma Linda reported a value of 20.7%. Timing of bone core harvesting was 9 months in the Froum et al.[26] study and 12 months in the Hanisch et al.[27] study, which significantly differs from the protocol followed in our study. Mean %VB of 30.8% was observed after 6 months of healing in a recently published study, using the same material used in this project.[28] However, Cammack et al.[29] reported a percentage of approximately 41% of newly formed bone in samples harvested between 6 and 36 months postgrafting, using an allograft. Differences in %VB between studies could be explained by the variability in

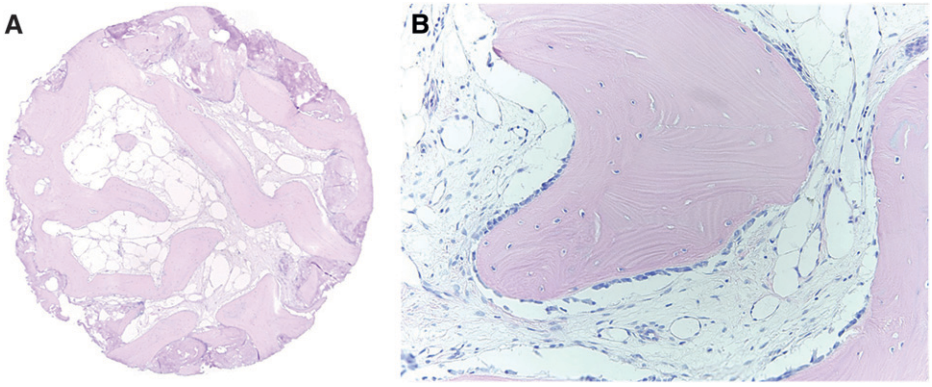

Figure 2.
A) *Sample section obtained for histologic–histomorphometric analysis (H&E; original magnification ×4).*
B) *Detail of a histologic sample showing vital bone in intimate contact with remaining allograft (H&E; original magnification ×20).*

Table 2.

Presentation of Values Obtained After Histomorphometric Analyses of Tissue Samples

	8 mm			10 mm			12 mm		
Patient Code	Vital Bone (%)	Allograft (%)	Non-Mineralized Tissue (%)	Vital Bone (%)	Allograft (%)	Non-Mineralized Tissue (%)	Vital Bone (%)	Allograft (%)	Non-Mineralized Tissue (%)
1002	40.29	2.26	57.45	4.30	70.18	25.52	X	X	X
1003	46.34	2.25	51.41	63.17	7.85	28.98	X	X	X
1004	0.00	21.33	78.67	0.00	51.56	48.44	0.00	45.83	54.17
1005	41.68	4.34	53.98	29.21	7.83	62.96	28.96	6.55	64.49
1006	X	X	X	37.16	5.55	57.29	30.94	13.96	55.10
1007	44.90	9.81	45.29	13.85	44.97	41.18	14.11	32.74	53.15
1008	5.71	54.75	39.54	2.21	55.67	42.12	11.13	39.08	49.79
1009	36.41	11.54	52.05	7.20	56.55	36.25	0.00	41.87	58.13
1010	23.60	6.26	70.14	29.74	1.76	68.50	76.32	0.00	23.68
1011	X	X	X	13.33	25.82	60.85	20.99	14.27	64.74
1013	46.94	21.43	31.63	22.23	13.99	63.78	30.10	0.51	69.39
1015	12.68	38.24	49.08	0.77	63.34	35.89	0.37	35.15	64.48
1016	25.33	0.00	74.67	36.89	0.00	63.11	6.82	37.42	55.76
1017	31.35	0.00	68.65	28.16	7.36	64.48	18.96	31.39	49.65
1018	0.00	26.69	73.31	1.52	45.84	52.64	0.00	63.80	36.20
1019	47.06	14.36	38.58	41.71	0.86	57.43	X	X	X
1020	45.72	5.88	48.40	47.58	2.86	49.56	52.23	2.52	45.25
1022	9.36	20.92	69.72	5.17	60.41	34.42	3.36	44.97	51.67
1024	20.86	6.15	72.99	3.62	40.00	56.38	2.42	29.64	67.94
1025	16.08	16.78	67.14	21.72	18.49	59.79	48.38	3.09	48.53
Total Mean	27.46 (SD = 17.05)	14.61 (SD = 14.43)	57.93 (SD = 14.32)	20.48 (SD = 18.26)	29.04 (SD = 24.94)	50.48 (SD = 13.1)	20.30 (SD = 22.05)	26.05 (SD = 19.32)	53.65 (SD = 11.65)

X = section not analyzable after processing.

the waiting time to harvest the samples after sinus augmentation. Our results should have been similar to the report by Gapski et al;[28] however, there is almost a 10% discrepancy (31% versus 23%). Hence, assuming that patients participating in these studies are healthy, other local factors, such as the size of the sinus cavity, may be involved.

When BPD was stratified, results showed that as BPD increases, total %VB decreases. In the group with the lowest BPD (<10 mm), %VB was 31%, whereas %RA was 13%. In samples where the BPD was >15 mm, mean %VB and %RA were 13% and 35%, respectively. Statistical analysis of the correlation between BPD and %VB showed that as BPD increases, the proportion of VB decreases. Taken together, these results support the hypothesis that more time may be needed for proper VB formation in large sinus cavities. However, it is important to consider that samples were obtained at a single time point (6 months). Furthermore, correlation coefficients indicated that BPD explains to a certain extent (5% to 10%) the variability of %VB after sinus floor elevation procedures. A variety of significant factors, such as RBH, the incidence of Schneiderian membrane perforation, the size of the lateral window, and the total volume of the sinus, may also influence these results. Therefore, future clinical

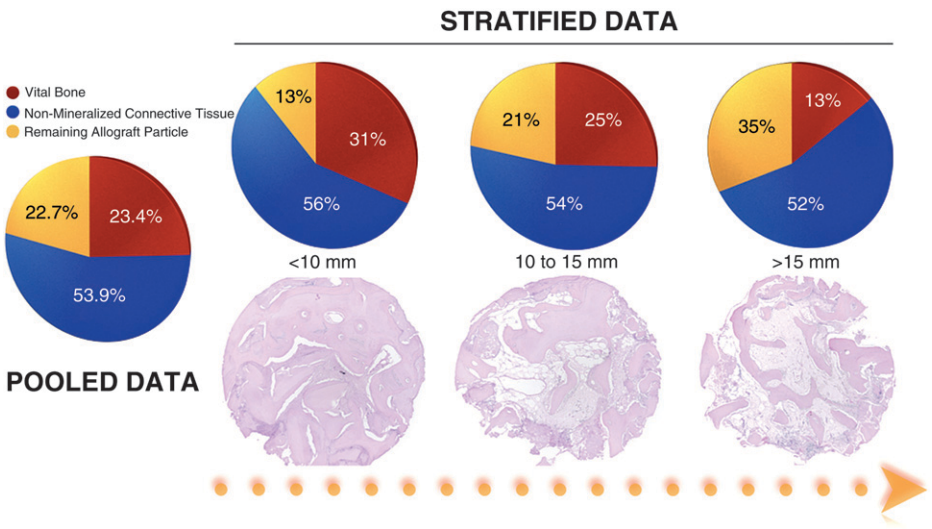

Figure 3.
Diagrams showing the total mean values of each element analyzed in the histologic samples, including vital bone, remaining allograft particle, and non-mineralized connective tissue (left, pooled data), and the variation in percentage of vital bone, percentage of remaining allograft particle, and percentage of remaining non-mineralized connective tissue expressed in function of three categories of bucco-palatal distance (right, stratified data). Categories are matched with representative histologic samples (bottom).

trials are needed to confirm the hypothesis whether homogeneous mature bone formation will eventually occur in larger cavities after a longer period of time (>6 months), or if larger sinuses are prone to less favorable bone formation, such as in critical size defects. Until additional data become available, clinicians may consider allowing sinus cavities presenting large BPD (>15 mm) to heal for extended periods of time.

An interesting aspect of this research project was the use of an absorbable collagen dressing instead of a slowly resorbable or non-resorbable barrier membrane over the lateral window. This collagen dressing was primarily used to promote hemostasis and prevent graft disruption at the time of suturing. It has been suggested that placing a barrier membrane over the lateral wall may prevent soft tissue invasion into the sinus and enhance VB formation.[30] The use of barrier membrane has been widely promoted since an association with higher implant survival rates has been reported in several studies.[31-33] However, it is important to keep in mind that, besides the limited number of clinical trials addressing this specific topic, a small sample size, short-term follow-up, and lack of control in harvesting biopsies may be important limitations of these studies. The rationale to use a rapidly degradable material in our study was to resemble as much as possible the conditions of healing in a critical size defect.[34] The application of a barrier membrane could have affected the healing, limiting the possibility of assessing the true impact of anatomic features. In a human split-mouth clinical trial, Choi et al.[35] evaluated the importance of using an absorbable membrane in terms of new bone formation in sinus augmentation when anorganic bovine bone was applied. Interestingly, they observed a significantly greater invasion of soft tissue in the side where no membrane was used; however, no differences in new bone formation were noticed between groups. In the present study, buccal soft tissue invasion was noticed only in one case. In that particular patient a premature wound opening of approximately 4 mm in a bucco-lingual dimension was recorded in the first postoperative visit, at 2 weeks. No signs of infection or graft extravasation were noticed; on the contrary, granulation tissue formed between the edges of the wound. This patient was followed-up for the rest of the healing period. No adverse events or symptoms were recorded. At the time of implant placement, the depth of the invasion was approximately 3 mm, which did not prevent implant placement. We speculate that the soft tissue invasion may be explained by an alteration of the initial healing caused by the reported premature wound opening, which may have elicited the migration of cells of epithelial origin, a too rapid resorption of the collagen material, or a combination of both. Hence, the need to use a slowly absorbable collagen membrane is questioned based on the findings from this study. Future studies in this area are needed.

One of the most remarkable aspects of this research project is the validation of a new methodology to assess the outcomes of sinus augmentation at different levels (clinical and histologic). This method relies on the combination of conventional bone histomorphometric techniques with advanced imaging modalities, such as CBCT scans and computer-generated images. This study was designed to obtain analyzable samples corresponding with a known height, enabling us to evaluate bone graft consolidation and remodeling patterns in function of anatomic (bucco-palatal dimension of the maxillary sinus cavity) and clinical variables. The successful development of this project opens the door to perform well-controlled analyses of different sinus augmentation materials in function of anatomic conditions.

CONCLUSIONS

Based on the results of this study it can be concluded that the proportion of VB formation after sinus augmentation is inversely proportional to the BPD of the maxillary sinus. This information may be considered for the clinical decision of when to intervene for implant placement.

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Correspondence: Dr. Gustavo Avila, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, 1101 N. University Ave., Room 1324A, Ann Arbor, MI 48109–1078. Fax: 734/936-0374; e-mail: avila@umich.edu.

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