Volume Changes of Grafted Autogenous Bone in Sinus Augmentation Procedure

Carolina Sbordone, MD, Ludovico Sbordone, MD, DDS,† Paolo Toti, BSc, DDS,‡ Ranieri Martuscelli, MD, DDS,§ Luigi Califano, MD,‖ and Franco Guidetti, MD¶*

Purpose: To evaluate associations between the osseous remodeling and the 3-dimensional features of both the grafted bone and the recipient site, as well as the density of the grafted bone, and to assess the relation between the degree of bone resorption and the type of autogenous bone-grafting procedure or the source (block or particulate bone from iliac crest or block bone from chin).

Patients and Methods: A retrospective chart review of patients receiving sinus lifting and grafting procedures for implant positioning was conducted: radiographic analysis of the volume and area of both sinuses and autogenous bone grafts was performed, as per Smolka et al and Krennmair et al. The volumetric remodeling—measured at 1 year after implant positioning as the percentage of residual bone (%R)—was correlated, with Spearman analysis, to 3-dimensional features of both graft and recipient sites. All quantities correlated with %R at a statistically significant level were used for 2-dimensional and multidimensional visualizations with scattergrams.

Results: Twenty-five iliac crest or chin grafts were inlay positioned in the maxillary sinuses of patients. Computed tomography scans, taken before implant positioning and after 1 year, showed a 1-year negligible volume remodeling for block graft from chin (97.9%) but slightly greater resorption values (%R) for particulate and block grafts from iliac crest (93.8% and 83.3%, respectively). Three- and four-dimensional scattergrams of significant data resulting from Spearman correlation tests (particulate and block grafts both from iliac crest) showed a variation of the remodeling pattern dependent on 3-dimensional features, namely inlay graft thickness, surface area of the graft in contact with basal bone, volume of the recipient site, and surface area of the graft projecting into the sinus cavity.

Conclusions: Retrospective data analysis shows that iliac crest grafts positioned on a small basal bone volume ($\leq$2.5 mL) may point to a very favorable remodeling of the volume when the particulate graft is molded to a thickness of less than 4 mm, with a reduced surface area protruding into the sinus ($\leq$5 cm^2). Bone blocks with a reduced contact surface and with basal bone ($\leq$4 cm^2) also display minimal resorption.

J Oral Maxillofac Surg 69:1633-1641, 2011

Fully and partially edentulous patients have been increasingly treated by implant-supported oral rehabilitation, even in those with an insufficient bone volume that requires the use of elaborate osseous reconstructive surgical techniques. Severe atrophy of the posterior maxilla coupled with sinus pneumatization has been successfully treated by several investigators via different techniques of "sinus lift."[1-3] Allogeneic, xenogeneic, or synthetic grafts have been used with a highly predictable outcome,[4-6] but still many studies

*Postdoctoral Fellow, Department of Maxillo-Facial Surgery, School of Medicine, University of Naples "Federico II," Naples, Italy.

†Full Professor and Chairman, Department of Surgery, University of Pisa, Pisa, Italy; and Director, Complex Operating Unit of Odontostomatology and Implantology, Azienda Ospedaliero-Universitaria Pisana, Pisa, Italy.

‡Postdoctoral Fellow, Department of Surgery, University of Pisa, Pisa, Italy; and Complex Operating Unit of Odontostomatology and Implantology, Azienda Ospedaliero-Universitaria Pisana, Pisa, Italy.

§Aggregate Professor, Department of Odontostomatological Sciences and Maxillo-Facial Surgery, School of Medicine, University of Naples "Federico II," Naples, Italy.

‖Chairman and Professor, Department of Maxillo-Facial Surgery, School of Medicine, University of Naples "Federico II," Naples, Italy.

¶Director (ad interim), Complex Operating Unit of Maxillo-Facial Surgery, Azienda Ospedaliero-Universitaria Pisana, Pisa, Italy.

Supported in part through Ministero dell'Istruzione Università e Ricerca Scientifica (MIUR Italian Department of Education, University and Scientific Research) PRIN 2008 grants 2008K4XXF8_02 (CUP G51J10000030001) to Ludovico Sbordone and 2008K4XXF8_03 (CUP E61J100000200001) to Ranieri Martuscelli.

Address correspondence and reprint requests to Dr Sbordone: Department of Surgery, University of Pisa, Via Roma 67, 56126 Pisa, Italy; e-mail: lsbordon@med.unipi.it

0278-2391/11/6906-0029$36.00/0
doi:10.1016/j.joms.2010.12.004

report autogenous bone as the grafting material of choice because of its osteoconductive, osteoinductive, and osteogenic properties.[7,8]

The degree of remodeling over time that has been reported differs depending on the type of material used, ranging from 13.9% to 26% for alloplastic material[9,10] and from 16% to 49.5% for autologous bone.[11,12]

Nevertheless, Chiapasco et al[13] recommended autogenous bone as the material of choice in cases of combined intra-sinus and onlay reconstructive procedures, and they focused on the lack of information regarding the use of non-autogenous materials in such techniques.

The purpose of this retrospective chart review was to assess potential factors associated with the osseous remodeling phenomenon for sinus inlay grafts, positioned in patients with severe maxillomandibular atrophy coupled with sinus pneumatization, for rehabilitation by implant-supported restoration.

The primary aim was to evaluate the associations between the osseous remodeling and the 3-dimensional features of both the grafted bone and of the recipient site, as well as the density of the grafted bone. A secondary aim was to assess whether the degree of bone resorption was related to the type of autogenous bone-grafting procedure or to the source (block or particulate bone from iliac crest or block bone from chin).

Patients and Methods

STUDY DESIGN/SAMPLE

Forty-eight consecutive patients treated from January 2000 through December 2005 were reviewed to gather pertinent information regarding the number of sinus lifting and grafting procedures, adjunctive surgical procedures, and surgical treatment outcomes. We conducted a retrospective chart review of 25 patients who had severe atrophy with sinus pneumatization and implant rehabilitation and who had received sinus floor elevation with different autogenous bone-grafting procedures (particulate or block from hip or block from chin). We excluded 10 patients who underwent surgical procedures unlike the described procedure, 6 patients who had 6 mm of sinus floor or more, and 7 patients who did not have a complete set of computed tomography (CT) scan data (before sinus lifting and grafting, just before implant insertion, and at 12 months after implant insertion). Written informed consent was obtained from all subjects included, and approval for this study was obtained from the Ethical Committee of the University of Pisa, Pisa, Italy.

RADIOGRAPHIC EXAMINATION

As part of the standard treatment protocol, all patients had CT scans taken by the same CT scanner (high-speed double-detector CT scanner; GE Medical Systems, Milwaukee, WI) as follows: immediately before sinus lifting (T_0), 3 to 5 months after the surgical procedure,[14,15] just before implant insertion (T_1), and 12 months after implant insertion (T_2).

Before the numerical computation, axial images of the original CT scans were reoriented parallel to the palatine vault. All measurements were performed with SimPlant 11.04 (Materialise Dental Italia, Rome, Italy). Measurements were performed on axial CT slices with a thickness of 1 mm. Area, volume, and density measurements of the bone grafts placed in the sinus were performed as per Smolka et al,[11] and the measurements of the remodeling of the inlay bone were performed as per Krennmair et al,[16] with total height preset to the maximum distance between the alveolar crest and the apical portion of the inlay bone graft (Fig 1) for the 2 time reference points after surgical treatment (T_1 and T_2).

SURGERY

Preoperative CT scan analysis (T_0) was used to assess the need for sinus lift for implant placement and to guide the choice of the procedure, as already described:[17] sinus lift according to Sailer[3] and autogenous bone block graft were performed in patients with a residual sinus floor of 3 mm or less, whereas the approach of Tatum[1] with autogenous particulate bone graft was followed in cases of residual sinus floor over 3 mm. The graft source, iliac crest or chin, was decided on according to the amount of bone needed for the complete reconstruction of the atrophic areas and the compliance of the patient. Before surgery, all the sinuses had to be free of pathologic signs, that is, any clinical sign of sinusitis and/or radiologic signs of localized disease, identified as sinus membrane thickness of 3 mm or greater on CT scan.[18] In the event of sinus pathology, the patients underwent nasal endoscopy followed by medical therapy with appropriate chemo-antibiotics and corticosteroids and, if required, functional endoscopic sinus surgery.[19] Admission to sinus lift surgery was based on meeting the aforementioned criteria. All surgeries were performed with the patient under general anesthesia with local administration of 2% mepivacaine plus epinephrine (20 mg/mL + 12.5 μg/mL) to reduce bleeding.

Two donor sites were used: the mandibular parasymphysis and the iliac crest area. We harvested 1 or 2 blocks, depending on need, from the parasymphyseal area, following the procedure described by Balaji[20] but using a horizontal mucosal incision 5 mm apical to the mucogingival junction. The block was

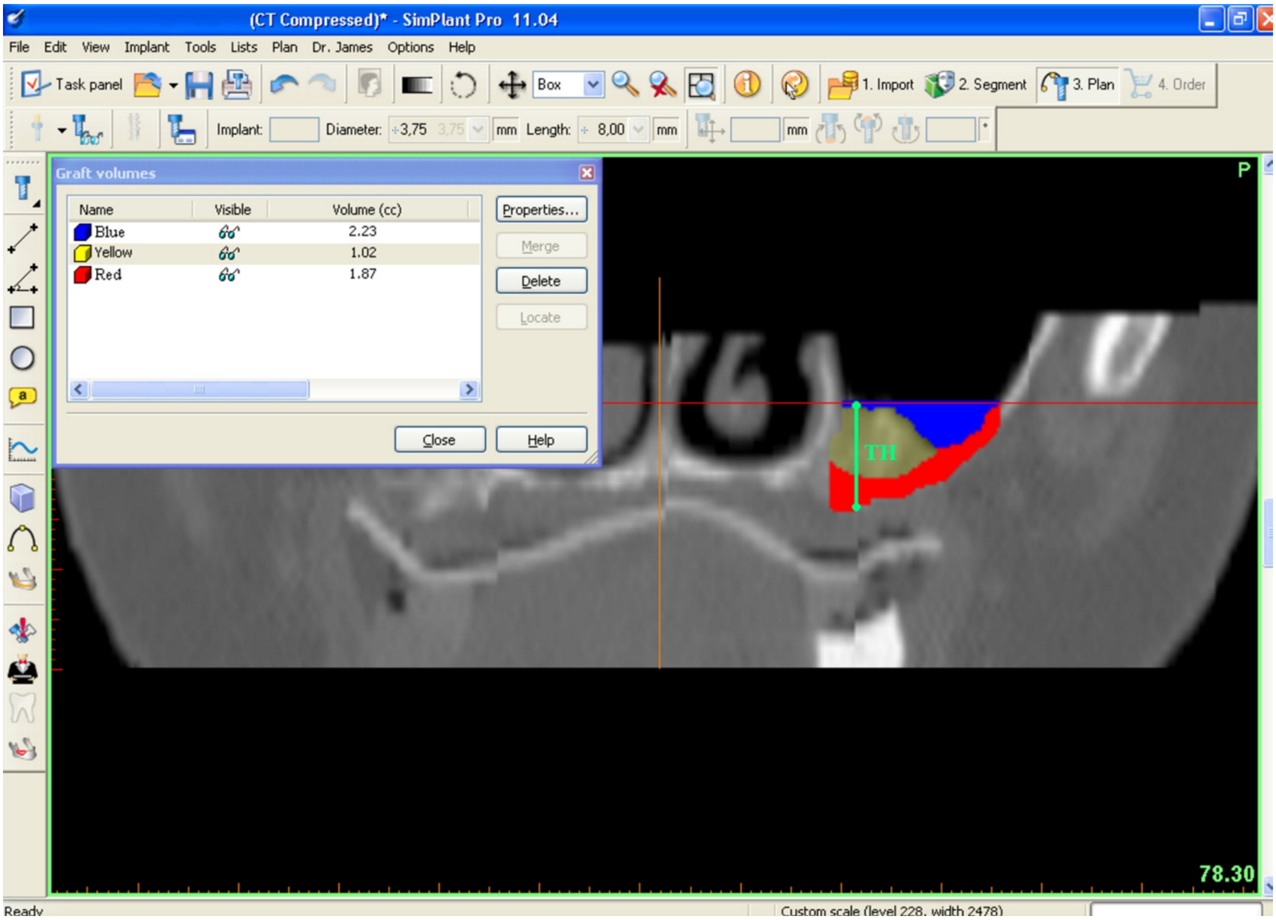

FIGURE 1. Display of software program SimPlant 11.04 showing measurements on maxilla. The volume of graft (in yellow), volume of basal bone (in red), and volume of vacuum sinus (in blue: upper limit was preset to total height) are evaluated by toolbar plan. In addition, the bone density is calculated in Hounsfield units by toolbar plan; the area of graft is calculated by toolbar segment.

Sbordone et al. Volume Changes in Sinus Augmentation. J Oral Maxillofac Surg 2011.

either reduced to particulate chips with a bone mill (Biocomp Minimill; Walter Lorenz Surgical, Jacksonville, FL) or grafted as a single block.[3] No material was used to fill the residual defect in the donor area. Iliac crest grafts were obtained according to the technique described by Grillon et al,[21] using a cutaneous approach via elective lines of incision, and the harvested bone was treated as described previously. The recipient site was approached through 2 different procedures: that of Sailer[3] when performing a block graft secured to the pristine sinus floor with a "lag screw technique"[22] or that of Tatum[1] when using a particulate graft.

Titanium dental implants—root-form implants, external-hex implants, and rough-surface screws—created by the same manufacturer were inserted into the graft areas from 3 months, in the case of bone block grafts,[14] to 5 months, for particulate grafts,[15] after reconstructive surgery.

At dental implant placement, all patients underwent appropriate antibiotic prophylaxis and analgesic anti-inflammatory therapy. Radiographic confirmation of the absence of implant protrusion into the sinus cavities was sought 1 week postoperatively.

Prosthetic restoration was performed 6 to 9 months after implants were placed: all patients received fixed prosthetic restoration with metal ceramic crowns and bridges, cemented either over a custom metal abutment or via a University of California, Los Angeles (UCLA)–type abutment.

VARIABLES

The outcome variables of interest for the grafted bone were *1*) the percentage of residual bone graft (%R) present at the 12-month recall, calculated as the ratio of the volume at the 12-month recall (V_{T2}) to the volume at T_1 (V_{T1}), and *2*) the density of the grafted bone measured in Hounsfield units at T_2 (D_{T2}).

The explanatory variables of interest obtained from the CT scan taken 3 to 5 months after the surgical procedure just before implant insertion (T_1) are described in the following sections.

Variables of Inlay Graft

Variables of the inlay graft included density at T_1 (D_{T1}) (ie, density measurement in Hounsfield of the inlay graft at time T_1); superior surface at T_1 (SS_{T1}) (ie, graft surface protruding into sinus cavity at T_1); and height index ($indexH_{T1}$) (Equation 1), which is the ratio between the volume of the grafted bone at T_1 (V_{T1}) and the contact surface area between the sinus inlay and the recipient site at T_1 (CS_{T1}). This index gives an indication regarding the height of the sinus inlay:

$$indexH_{T_1} = \frac{V_{T_1}}{CS_{T_1}} \quad (1)$$

We also assessed shape index ($indexS_{T1}$) (Equation 2), which is the ratio between the volume of the sinus inlay at T_1 (V_{T1}) and its superior surface (SS_{T1}):

$$indexS_{T_1} = \frac{V_{T_1}}{SS_{T_1}} \quad (2)$$

Variable of Recipient Site

Basal bone (BB_{T1}), or the volume of the recipient site below inlay graft at T_1, was determined.

Variables of Relationship Between Graft and Recipient Site

In addition, we assessed contact surface area (CS_{T1}) (ie, boundary surface between sinus inlay [in form of block or particulate] and receiving site) and volume index ($indexV_{T1}$) (Equation 3), which is the ratio between the volume of the recipient site (basal bone [BB_{T1}]) and the volume of the sinus inlay graft at T_1 (V_{T1}), testing for a correlation between graft remodeling and the volume of both the sinus inlay and the bone supporting the inlay graft:

$$indexV_{T_1} = \frac{BB_{T_1}}{V_{T_1}} \quad (3)$$

STATISTICAL ANALYSIS

All patient-related data were entered into a database (Access; Microsoft, Redmond, WA), thereby allowing selections to be performed automatically. Descriptive statistical analyses, such as the distribution of graft sources and procedures, were performed by use of a statistical tools package (Statistics Toolbox, MATLAB 7.0.1; The MathWorks, Natick, MA). All measurements in the text and tables are described as median and interquartile range (difference between 75th and 25th percentiles).

In the comparison and correlation tests, to overcome the dependency between bilateral sinus elevations, 1 sinus lifting procedure per patient was randomly selected.[23]

Because the measures obtained are not normally distributed, Wilcoxon matched pairs signed rank tests were used to assess the changes from T_1 to T_2 separately for each graft form (particulate crest, block crest, and block chin). The difference between the particulate crest and block crest form for each measure at T_1 and T_2 was assessed with the Wilcoxon rank sum test.

Spearman correlation (r_s) was used to assess the strength of the bivariate association between residual bone graft (%R) and each of the explanatory variables separately for each graft form. Statistically significant associations are illustrated in 2-dimensional and multidimensional scattergrams. For the multidimensional scattergrams, %R values are shaded from red (minimum resorption) to blue (maximum resorption) given specific combinations of explanatory variable values.[24]

The level of statistical significance was set at .05 for all analyses.

Results

In total 25 patients affected by severe sinus pneumatization were treated: 12 women and 13 men, ranging in age from 32.5 to 58.7 years (mean, 49.8 ± 7.3 years). Three patients (2 men and 1 woman) were wholly edentulous, whereas the remaining patients were partially edentulous. Of the latter group, 1 woman was partially edentulous in only the upper arch and completely edentulous in the lower arch. Nonsmoking patients accounted for 14 of 25 patients. Atrophy of the posterior maxilla, coupled with sinus hyperpneumatization, was the result of one of the following: a long-standing edentulous condition treated by removable prosthesis, alveolar bone loss due to periodontal disease, or a major trauma. No patient had undergone bone resection as part of an oncologic treatment.

A total of 35 sinus lift procedures, via either particulate or block autogenous bone grafting, were performed. We considered 25 sinus lift procedures, 1 per patient, for further analysis; 18 grafts were obtained from iliac crest and 7 from chin. Of the 18 hip grafts, 9 were in particulate form and 9 were in block form. All the chin grafts were in block form.

The median (interquartile range) of the volumes at time T_1 for particulate from iliac crest, block from crest, and block from chin grafts was 0.94 cm^3 (0.79 cm^3), 1.49 cm^3 (1.63 cm^3), and 1.01 cm^3 (0.61 cm^3), respectively (Table 1). Differences at a statistically significant level were recorded, for the iliac crest source, between the particulate and block procedure (P = .014) and for the block procedure between the 2 sources, chin and hip (P = .042). After 1 year, the volumes were not statistically significantly different

Table 1. MEDIAN AND INTERQUARTILE RANGE OF VOLUME AND DENSITY AT T_1 (V_{T1} AND D_{T1}) AND AT T_2 (V_{T2} AND D_{T2}), CONTACT SURFACE (CS_{T1}), BASAL BONE VOLUME (BB_{T1}), AND SUPERIOR SURFACE (SS_{T1}) AT T_1; MEDIAN OF RESIDUAL BONE GRAFT (%R) AND STATISTICAL COMPARISONS (WILCOXON RANK SUM TEST) BETWEEN GROUPS (PARTICULATE VS BLOCK WITH BONE HARVESTED FROM ILIAC CREST AND ILIAC CREST VS CHIN FOR BLOCK PROCEDURES); AND STATISTICAL COMPARISONS (WILCOXON MATCHED PAIRS SIGNED RANK TESTS) ASSESSING CHANGES IN TIME FOR EACH PROCEDURE FROM T_1 TO T_2

									Wilcoxon Matched Pairs Signed Rank Test	
	V_{T1} (cm^3)	D_{T1} (HU)	CS_{T1} (cm^2)	BB_{T1} (cm^3)	SS_{T1} (cm^2)	V_{T2} (cm^3)	D_{T2} (HU)	%R	V_{T1} vs V_{T2}	D_{T1} vs D_{T2}
Variable graft form										
Particulate crest	0.94 (0.79)	327 (257)	3.30 (1.48)	1.64 (1.31)	4.16 (3.78)	0.88 (0.84)	492 (103)	93.8 (64.9)	0.652	0.164
Block crest	1.49 (1.63)	284 (53)	5.44 (8.21)	3.23 (2.18)	5.01 (2.94)	1.47 (0.74)	461 (170)	83.3 (43.5)	0.074	0.008
Block chin	1.01 (0.61)	622 (167)	375 (219)	1.98 (2.40)	3.81 (0.84)	1.03 (0.66)	681 (318)	97.9 (35.8)	0.578	0.297
Wilcoxon rank sum test										
Part crest vs block crest	0.014	0.605	0.063	0.094	0.605	0.077	0.730	0.297		
Block crest vs block chin	0.042	0.0002	0.114	0.556	0.240	0.071	0.016	0.681		

NOTE. Statistical significance was set at the .05 level.

Sbordone et al. Volume Changes in Sinus Augmentation. J Oral Maxillofac Surg 2011.

from the preimplant condition: 0.88 cm^3 (0.84 cm^3) for particulate from iliac crest, 1.47 cm^3 (0.74 cm^3) for block grafts from hip, and 1.03 cm^3 (0.66 cm^3) for block grafts from chin. The resorption for both the particulate crest and block chin groups was negligible, whereas the median resorption for the block crest group was 16.7% (Table 1).

With regard to density, for the block graft procedure, statistically significant differences were recorded between the 2 groups (iliac crest and chin source) both at T_1 and at T_2, with a significance of 2×10^{-4} and 0.016, respectively. The median density at T_1 of particulate and block grafts from iliac crest and block grafts from chin was 327 HU (257 HU), 284 HU (53 HU), and 622 HU (167 HU), respectively (Table 1). After 1 year, though statistically significant only for the block procedure with bone from iliac crest, there was a common increase in the median density up to 492 HU (103 HU) for particulate grafts, 461 HU (170 HU) for block grafts from crest, and 681 HU (318 HU) for block grafts from chin (Table 1). The medians for the contact surface, the basal bone, and the surface of the inlay grafts protruding into sinuses for each type of graft are reported in Table 1.

The correlation analysis showed that in the particulate grafts from the iliac crest group, %R was statistically significantly correlated with two of the 3-dimensional features (SS_{T1} and BB_{T1}) and the indexH_{T1} (Table 2). In the block grafts from the iliac crest, %R was significantly correlated with the 3-dimensional features (CS_{T1} and BB_{T1}) but not SS_{T1} or indexH_{T1} (Table 2). In the group with block graft from chin, no statistically significant correlations were observed between %R and any of the explanatory variables.

Statistically significant associations for both iliac crest particulate graft and iliac crest block graft data points were illustrated in 2-dimensional and multidimensional scattergrams. Four-dimensional scattergrams of %R in function of the triad SS_{T1}-BB_{T1}-indexH_{T1} (Fig 2) and a 3-dimensional (3D) scattergram of %R in function of the couple CS_{T1}-BB_{T1} were obtained (Fig 3) and showed that the volume of negligible resorption (%R $\geq$100) was delimited for the iliac crest particulate group by SS_{T1} ranging from 50 to 500 mm^2, BB_{T1} ranging from 500 to 2,500 mm^3, and indexH_{T1} ranging from 1.5 to 4 mm; for the iliac crest block group, the volume of negligible resorption (%R $\geq$100) was delimited by CS_{T1} ranging from 100 to 400 mm^2 and BB_{T1} ranging from 1,000 to 2,500 mm^3.

Discussion

A relapse of sinus pneumatization may happen in grafted sinuses, with a marked decrease in graft height 2 to 3 years after surgical augmentation and

Table 2. SPEARMAN R_S CORRELATION COEFFICIENTS BETWEEN %R VALUES AND OVERALL FOR DENSITY (D_{T1}), AS WELL AS ALL 3-DIMENSIONAL FEATURES (CS_{T1}, SS_{T1}, AND BB_{T1}) AND INDEXES ($INDEXV_{T1}$, $INDEXH_{T1}$, AND $INDEXS_{T1}$), FOR GROUP WITH PARTICULATE AND BLOCK FROM CREST AND FOR CHIN BLOCK GROUP

	D_{T1}	CS_{T1}	SS_{T1}	BB_{T1}	$indexV_{T1}$	$indexH_{T1}$	$indexS_{T1}$
%R vs particulate crest							
Correlation coefficient (r_s)	−0.117	−0.600	−0.917*	−0.733*	0.483	−0.900*	0.083
Significance (two-tailed)	0.776	0.097	0.001*	0.031*	0.194	0.002*	0.843
No.	9	9	9	9	9	9	9
%R vs block crest							
Correlation coefficient (r_s)	−0.067	−0.850*	0.417	−0.783*	−0.300	0.167	−0.217
Significance (two-tailed)	0.880	0.006*	0.270	0.017*	0.437	0.678	0.581
No.	9	9	9	9	9	9	9
%R vs block chin							
Correlation coefficient (r_s)	−0.429	0.107	−0.090	0.393	0.143	−0.214	0.179
Significance (two-tailed)	0.354	0.840	0.860	0.396	0.783	0.662	0.713
No.	7	7	7	7	7	7	7

*Statistically significant at .05 level (2 tailed) for particulate graft from iliac crest in sinus lift procedures.

Sbordone et al. Volume Changes in Sinus Augmentation. J Oral Maxillofac Surg 2011.

further minimal changes.[25] Variable and unpredictable nonvascularized osseous graft remodeling may even result in insufficient bone quality and quantity for dental implant positioning. It has been speculated that local arterial blood supply is of great importance to maintain the vitality of the receiving bone and, therefore, graft revascularization and healing of the mucous membranes.[26] Such an osseous blood supply is progressively reduced with age and atrophy, and thus an antral floor reduced to a paper-thin lamella of compact bone receives its blood supply only from periosteal vessels.[26]

Three-dimensional CT scans have been used to assess the volume of bone grafts in relation to subtraction radiography.[27] Such detailed imaging allowed grafted bone volume measurements and the development of the external surface area.[16,28] The mean resorption of autogenous grafted bone has been reported to be 19.2% for calvaria harvesting[11]; the remodeling of iliac crest harvested bone has been reported to be much higher, with a mean of 49.5%.[12] Even though a long-term study on linear measurements of maxillary sinus bone graft maintenance was performed, measuring the mean amount of remaining bone from the top of the graft to the alveolar crest,[29] there is currently a lack of data correlating volume graft remodeling with its spatial rearrangement and the volume of the receiving site.

This survey highlighted a variable rearrangement of the grafted bone, showing minimal current median graft remodeling in every group analyzed, resulting from a moderate resorption counteracted by a volume gain in the grafted bone. This has been evident in cases in which autologous block bone grafts from chin were used and where a very positive median remodeling of 97.9% (35.8%) was registered (Table 1), whereas autologous particulate and block grafts, both from iliac crest, showed resorption, even if moderately low, with %R values of 93.8% (64.9%) and 83.3% (43.5%), respectively (Table 1).

All 3 groups of data were numerically adequate for the correlation analysis. The data attested to the significance of the relationship between %R and the specific variables SS_{T1}, BB_{T1}, and $indexH_{T1}$ for the iliac crest particulate graft that were illustrated by 4-dimensional scattergrams. The significance of the relationship for iliac crest block data between %R and the 2 variables CS_{T1} and BB_{T1} was shown on the 3D scattergram. The multidimensional scattergrams showed that, despite a minimal remodeling phenomenon, 2 opposite and antithetic behavior patterns could be identified: the values of negligible resorption (%R $\geq$100) were limited to a single, small cloud both in the scattergram volume, for the particulate group, and on the scattergram surface, for the iliac crest block group; these regions were completely separated from the small and unique clouds of maximal resorption values, in both the particulate and block groups, suggesting a predictable remodeling phenomenon through the study of the 3D anatomy of the grafted sinus.

For the iliac crest particulate group, several remodeling patterns could be identified for every possible triad (SS_{T1}-BB_{T1}-$indexH_{T1}$) (Fig 2). Extreme examples might include, on the one hand, a shallow particulate graft (maximum, 0.4 cm linearly), with a small-sized superior surface (maximum, 5 cm^2) in areas with a reduced sinus floor volume (maximum, 2.5 cm^3), experiencing a marked positive remodeling after implant insertion or, at the other extreme, a thick sinus

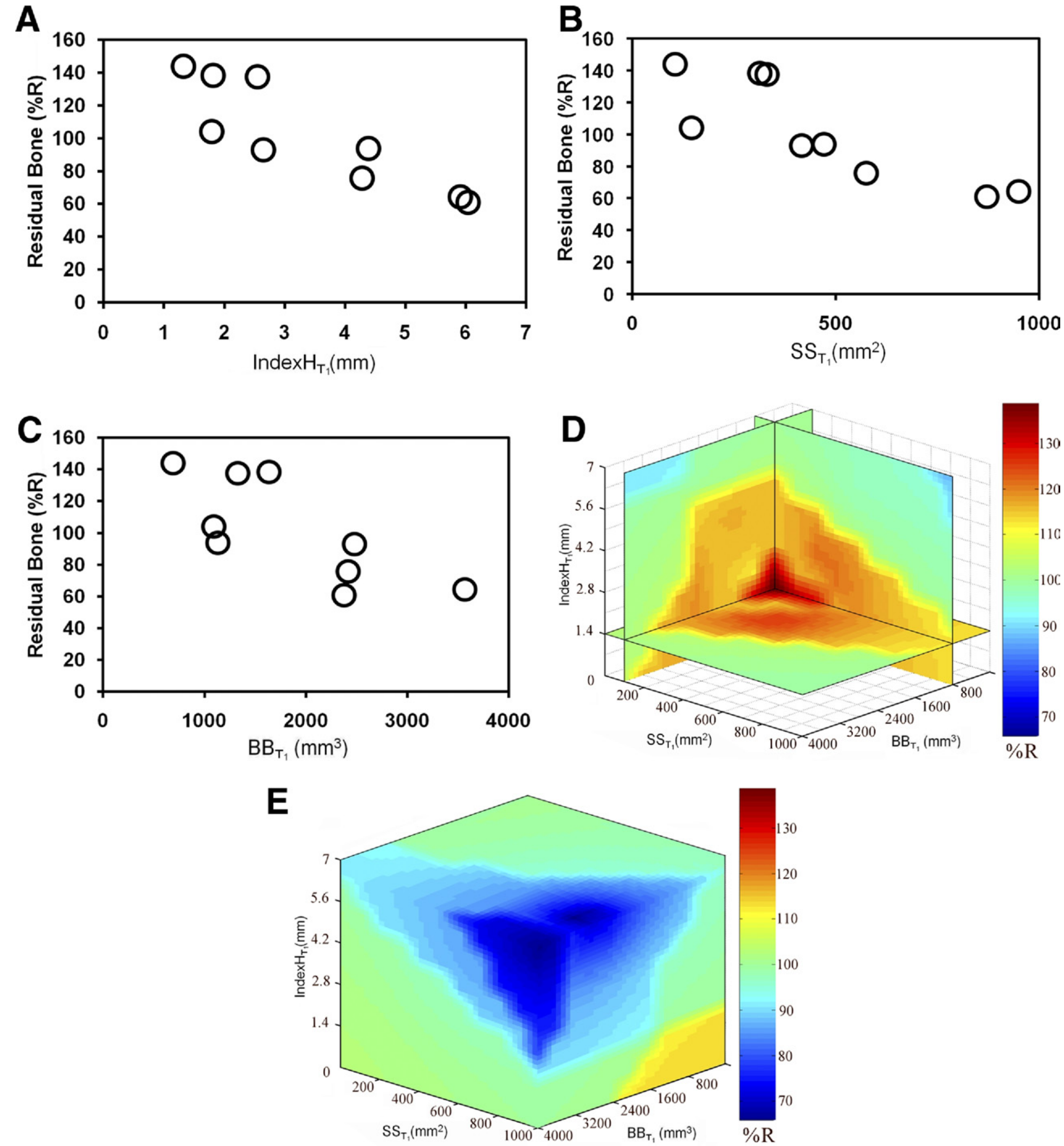

FIGURE 2. Two- and 4-dimensional scattergrams showing percentage of residual graft (%R) in sinus lift grafted with particulate bone from iliac crest in function of triad of indexH_{T1} (*A*), SS_{T1} (*B*), and BB_{T1} (*C*). The color bar shows the %R from maximum (red) to minimum (blue). *D*, The maximum conservation region of the particulate grafted bone harvested from iliac crest is shown as the deep-red volume bordered by orange contour. *E*, The minimum conservation region of the particulate grafted bone harvested from iliac crest is shown as the deep-blue volume bordered by navy-blue contour.

Sbordone et al. Volume Changes in Sinus Augmentation. J Oral Maxillofac Surg 2011.

graft with a large-sized superior surface and a remarkable volume of residual sinus floor showing an increased resorption.

Whereas iliac crest block grafts with a small-sized contact surface (maximum, 4 cm^2) in areas with a reduced sinus floor volume (maximum, 2.5 cm^3) experienced a marked positive remodeling after implant insertion, the increase in values of the couple CS_{T1}-BB_{T1} (Fig 2) produced a decrease in %R.

The results attested to the importance of the pristine bone volume below the grafted bone, rather than relying on a simple linear measurement, for both the

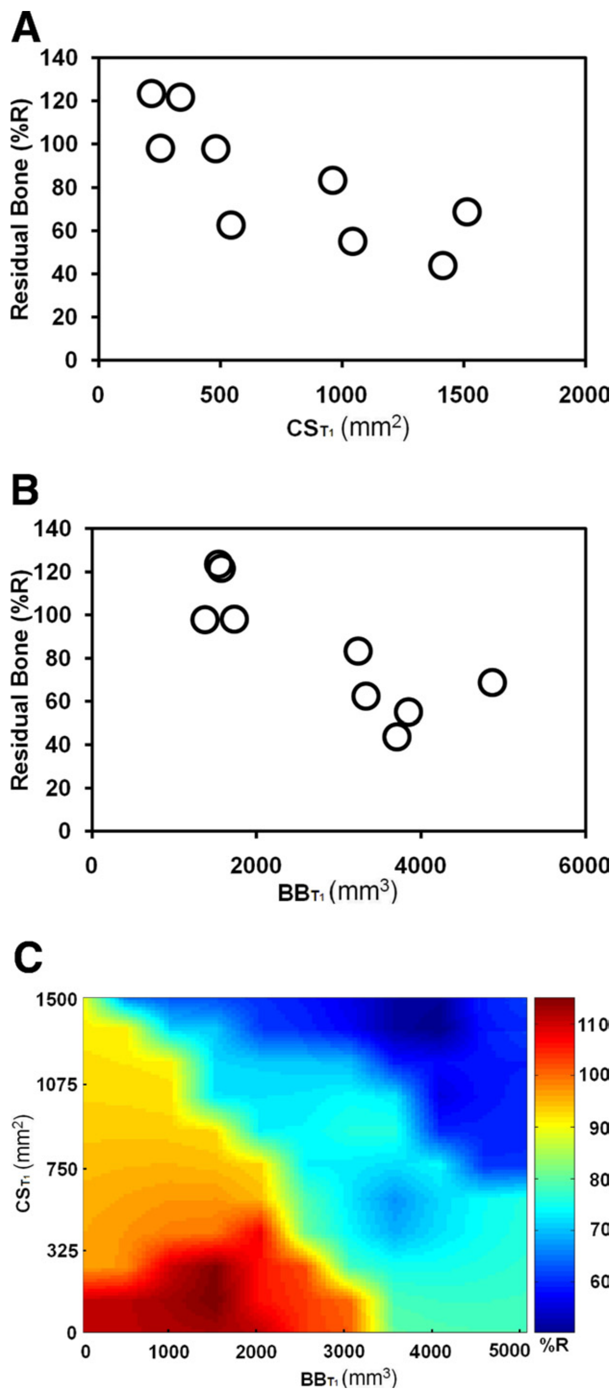

FIGURE 3. Two-dimensional (*A* and *B*) and three-dimensional (*C*) scattergrams showing percentage of residual graft (%R) in sinus lift grafted with block bone from iliac crest in function of contact surface area between sinus inlay and recipient site (CS_{T1}) (*A*), the volume of the recipient site below inlay graft (BB_{T1}) (*B*), and the 2 explanatory variables, CS_{T1} and BB_{T1} (*C*). The color bar shows the %R from maximum (deep red) to minimum (deep blue).

Sbordone et al. Volume Changes in Sinus Augmentation. J Oral Maxillofac Surg 2011.

iliac crest particulate and the block group; for the chin block group, the results appeared inconclusive with regard to pristine bone volume. A mean linear level of pristine bone in the sinuses of grafted patients could be obtained by the ratio between BB_{T1} and CS_{T1}, but this arithmetic operation led to a loss of information linked to multidimensional volumetric analysis.

Statistics attested that various augmentation procedures and sources, that is, block crest versus particulate crest group and block crest versus block chin group, showed several different outcomes in resulting bone quantity for implant insertion, probably because of differences both in pristine bone increase between procedures and in bone remodeling from T_0 to T_1 between sources.

No statistically significant differences were recorded for V_{T2} and %R among the 3 graft forms (particulate crest, block crest, and block chin) or in comparisons between T_1 and T_2 of volumes. This was probably *1*) because of the resorption phenomenon generally encountered by volume grafts and *2*) because volume reduction between T_1 and at T_2 was not so extreme as to attain matched pairs signed rank test significance. Statistically significant differences were recorded, in block procedure, for D_{T1} and D_{T2} between iliac crest and chin sources, attesting to the relatively higher percentage of the cortical portion in the chin grafts. Another difference at a statistically significant level was perceived between D_{T1} and D_{T2} for the iliac crest block group, in which an increase in mineralization for grafts was observed. Probably an initial higher density of the cortical part of the chin graft caused less variability in the remodeling phenomenon, thereby resulting in the non-significance of the results of the correlation analysis. With regard to the 2 crest groups, in the block procedure the cortical/cancellous set, with its cortical portion, probably supplied greater protection and promotion of mineralization for the cancellous part than that performed by autogenous particulate bone.

Our data show that the remodeling phenomenon is too complex to be reduced to a simple statistical analysis. Despite highly positive particulate (from iliac crest) and block (from iliac crest and chin) graft remodeling, further 2-dimensional and multidimensional scattergrams showed that the behavior of each graft was strictly dependent on the physical properties of both the graft and the recipient site.

It is noteworthy that the results of this analysis described the remodeling pattern of sinus grafts only after implant insertion and that such a pattern does not necessarily reflect the remodeling before this stage.

Because properties of the bone graft site other than its 3-dimensional features and density, for example, the cortical/cancellous composition and ratio, may interfere with graft remodeling, a further multidimensional analysis of the bone structure to arrive at a more accurate prediction of resorption could prove most useful. It is therefore considered that more studies are required to confirm our data.

References

1. Tatum HJ: Maxillary and sinus implant reconstructions. Dent Clin North Am 30:207, 1986
2. Boyne PT, James RA: Grafting of the maxillary sinus with autogenous marrow and bone. J Oral Surg 38:613, 1980
3. Sailer HF: The principle of removal of the sinus floor mucosa for new preprosthetic reconstruction methods (sinus inlay methods), *in* Fonseca RJ, Davis WH (eds): Reconstructive Preprosthetic Oral and Maxillofacial Surgery. Philadelphia, PA, Saunders, 1995, pp 457-464
4. Aghaloo TL, Moy PK: Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? Int J Oral Maxillofac Implants 22:49, 2007 (suppl)
5. Wallace SS, Froum SJ: Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Ann Periodontol 8:328, 2003
6. McAllister BS, Haghighat K: Bone augmentation techniques. J Periodontol 78:377, 2007
7. Moy PK, Lundgren S, Holmes RE: Maxillary sinus augmentation: Histomorphometric analysis of graft materials for maxillary sinus floor augmentation. J Oral Maxillofac Surg 51:857, 1993
8. Tadjoedin ES, DeLange GL, Lyaruu DM, et al: High concentration of bioactive glass material (Biogran®) vs autogenous bone for sinus floor elevation. Histomorphometrical observations on three split mouth clinical cases. Clin Oral Implants Res 13:428, 2002
9. Wanschitz F, Figl M, Wagner A, et al: Measurement of volume changes after sinus floor augmentation with a phycogenic hydroxyapatite. Int J Oral Maxillofac Implants 21:433, 2006
10. Kirmeier R, Payer M, Wehrschuetz M, et al: Evaluation of three-dimensional changes after sinus floor augmentation with different grafting materials. Clin Oral Implants Res 19:366, 2008
11. Smolka W, Eggensperger N, Carollo V, et al: Changes in the volume and density of calvarial split bone grafts after alveolar ridge augmentation. Clin Oral Implants Res 17:149, 2006
12. Johansson B, Grepe A, Wabbfors K, et al: A clinical study of changes in the volume of bone grafts in the atrophic maxilla. Dentomaxillofac Radiol 30:157, 2001
13. Chiapasco M, Zaniboni M, Boisco M: Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res 17:136, 2006 (suppl 2)
14. Krekmanov L, Heimdahl A: Bone grafting to the maxillary sinus from the lateral side of the mandible. Br J Oral Maxillofac Surg 38:617, 2000
15. Crespi R, Vinci R, Capparè P, et al: Calvarial versus iliac crest for autologous bone graft material for a sinus lift procedure: A histomorphometric study. Int J Oral Maxillofac Implants 22: 527, 2007
16. Krennmair G, Krainhofner M, Maier H, et al: Computerized tomography-assisted calculation of sinus augmentation volume. Int J Oral Maxillofac Implants 21:907, 2006
17. Sbordone L, Toti P, Menchini-Fabris GB, et al: Implant success in sinus-lifted maxillae and native bone: A 3-year clinical and computerized tomographic follow-up. Int J Oral Maxillofac Implants 24:316, 2009
18. Wippold FJ, Levitt RG, Evens RG, et al: Limited coronal CT: An alternative screening examination for sinonasal inflammatory disease. Allergy Proc 16:165, 1995
19. Pfleiderer AG: Antroscopy via the inferior meatal route under local anaesthetic: A practical guide to technique. J Laryngol Otol 101:1035, 1987
20. Balaji SM: Management of deficient anterior maxillary alveolus with mandibular parasymphyseal bone graft for implants. Implant Dent 11:363, 2002
21. Grillon GL, Gunther SF, Connole PW: A new technique of obtaining iliac bone graft. J Oral Maxillofac Surg 42:172, 1984
22. Keller EE, Tolman DE, Eckert S: Surgical-prosthodontic reconstruction of advanced maxillary bone compromise with autogenous onlay block bone grafts and osseointegrated endosseous implants: A 12-year study of 32 consecutive patients. Int J Oral Maxillofac Implants 14:197, 1999
23. Herrmann I, Lekholm U, Holm S, et al: Evaluation of patient and implant characteristics as potential prognostic factors for oral implant failures. Int J Oral Maxillofac Implants 20: 220, 2005
24. Koutouzis T, Wennstrom JL: Bone level changes at axial and non-axial-positioned implants supporting fixed partial dentures. A 5-year retrospective longitudinal study. Clin Oral Implants Res 18:585, 2007
25. Hatano N, Shimizu Y, Ooya K: A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2 : 1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. Clin Oral Implants Res 15:339, 2004
26. Solar P, Geyerhofer U, Traxler H, et al: Blood supply to the maxillary sinus relevant to sinus floor elevation procedures. Clin Oral Implants Res 10:34, 1999
27. Jensen J, Kragskov J, Wenzel A, et al: In vitro analysis of the accuracy of subtraction radiography and computed tomography scanning for determination of bone graft volume. J Oral Maxillofac Surg 56:743, 1998
28. Uchida Y, Goto M, Katsuki T, et al: Measurement of maxillary sinus volume using computerized tomographic images. Int J Oral Maxillofac Implants 13:811, 1998
29. Block MS, Kent JN, Kallukaran FU, et al: Bone maintenance 5 to 10 years after sinus grafting. J Oral Maxillofac Surg 56:706, 1998