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Volume changes of autogenous bone after sinus lifting and grafting procedures: A 6-year computerized tomographic follow-up

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ABSTRACT

Objectives: To evaluate long-term bone remodelling of autografts over time (annually, for 6 years), comparing the block and particulate bone procedures for sinus floor elevation, as well as to evaluate the survival of positioned dental implants.

Patients and methods: Twenty-three sinus lift procedures with autogenous bone were performed: seven sinus lift procedures using particulate graft and 10 with block autogenous bone were performed in 17 patients. Employing a software program, pre- and post-surgical computerized tomography (CT) scans were used to compare the volume (V) and density (D) of inlay grafts over time (up to 6 years), and to determine the percentage of remaining bone (%R). All variable (V, D and %R) measurements were then compared statistically.

Results: At the 6-year survey for block form, a resorption of 21.5% was seen, whereas for particulate grafts there was a resorption of 39.2%. Both groups exhibited bone remodelling between the first and second follow-up which was significant regarding volume for the block form and regarding density for the particulate group.

Conclusions: During the initial period of healing, the cortico-cancellous block bone grafted into the maxillary sinus underwent a negative remodelling of the volume, which is most probably due to graft cortex resorption, coupled with, primarily, an increase in density in the spongious area; for the particulate grafts, significant augmentations in density were obtained. The lack of significant differences among volumes was due to the wide degree of dispersion of the data. The rough data presented in this paper seem to support the use of a bone-block grafting procedure in maxillary sinus augmentation.

1. Introduction

Dental implant treatment in the posterior maxilla often requires bone augmentation procedures due to a high degree of pneumatization of the maxillary sinus, which can be coupled with a reduction in residual bone height. Where vertical augmentation has not been deemed a necessary cause for modifying the crown/root ratio (McAllister and Haghighat, 2007; Sakka and Krenkel, 2011), well-established and reliable maxillary sinus grafting procedures have been performed with autografts or non-autogenous grafting materials (Chiapasco et al., 2006; Acocella et al., 2011; Sakka and Krenkel, 2011; Barone et al., 2012).

The success of the implant-supported prosthesis depends on the long-term survival rate of dental implants placed in the grafted maxilla, so every factor that can jeopardize implant stability must be carefully considered: great attention was paid to a possible re-pneumatization phenomenon of the grafted maxillary sinus, revealed by linear and volumetric measurements, both for particulate

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autogenous bone and for bovine bone materials (Hatano et al., 2004; Kirmeier et al., 2008; Sbordone et al., 2009a; Covani et al., 2011).

Only diagnostic three-dimensional imaging can lead to accurate estimates regarding volumetric changes of sinus inlay grafts. Data regarding short-term outcomes of volumetric remodelling of sinus inlays, performed with either autograft or non-autogenous grafting materials, have been analyzed (Johansson et al., 2001; Smolka et al., 2006; Kirmeier et al., 2008; Sbordone et al., 2010; Dasmah et al., 2011), although the long-term results concerning volumetric stability of sinus inlay autografts are still not known. The aim of this retrospective chart review was to evaluate long-term bone remodelling of autografts over time (annually, for 6 yr), and to compare two procedures for sinus floor elevation: block and particulate bone. A second objective was to evaluate the clinical survival of implants positioned in the posterior maxillary areas.

2. Materials and methods

A retrospective chart review of 32 patients who had undergone sinus floor elevation with different autogenous bone-grafting procedures (particulate or block form) was performed: pertinent information regarding patients treated from January 2000 to December 2005, such as age (years), sex, and smoking habits, as well as that relating to the harvesting procedure (number, location and source), to dental implant placement, to surgical treatment outcomes, and to subsequent surgical procedures, with the addition of the number and points in time of CT scans, were collected and analyzed. No patient had undergone bone resection as part of an oncologic treatment. Fifteen patients not having a complete set of computed tomography (CT) scan data were excluded; maxillary CT scans up to 72 months postoperatively were considered. 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 (Ethical Approval Form 2626/2008 Protocol Number 58183).

2.1. Surgical methods

The need for sinus lifting, as well as the choice of surgical procedure, were determined by a preoperative CT scan analysis. In the event of a sinus pathology, that is, any clinical sign of sinusitis and/or radiologic signs of localized disease (sinus membrane thickness of 3 mm or greater on preoperative CT scan [Wippold et al., 1995]), patients underwent a nasal endoscopy followed by medical therapy, with appropriate chemo-antibiotics and corticosteroids, as well as, if necessary, functional endoscopic sinus surgery (Pfleiderer, 1987).

The mandibular parasymphysis and the iliac crest area were used as intraoral or extraoral harvesting sites: 1 or 2 blocks, depending on need, were harvested from the chin following the procedure described by Balaji (2002) (Sbordone et al., 2009b), but using a horizontal mucosal incision 5 mm apical to the mucogingival junction. Iliac crest grafts were obtained according to the technique described by Grillon et al. (1984), using a cutaneous approach via elective lines of incision, and the harvested bone was then treated as previously described. When autogenous bone was not grafted as a single block, it was reduced to particulate chips with a bone mill (Biocomp Minimill; Walter Lorenz Surgical, Jacksonville, FL).

Sinus lifting with autogenous bone was performed approaching the recipient site through two different procedures: Sailer's (Sailer, 1995), when performing a block graft secured to the pristine sinus floor with a "lag screw technique" (Fig. 1) (Keller et al., 1999; Sbordone et al., 2010), or that of Tatum when using a particulate graft (Tatum, 1986) as was previously reported (Sbordone et al., 2009a; Sbordone et al., 2011a).

After reconstructive surgery, delayed titanium dental implants (root-form, external-hex, and rough-surface) were inserted into the grafted areas at 3 months, in the case of bone-block grafts (Krekmanov and Heimdahl, 2000), or at 5 months, for particulate grafts (Crespi et al., 2007).

Patients received fixed prosthetic restoration with metal ceramic crowns and bridges, cemented 6–9 months after implant placement either over a custom metal abutment or via a University of California, Los Angeles (UCLA)–type abutment.

2.2. Variables and data collection

As part of the standard treatment protocol, patients had CT scans (High Speed double detector CT scanner, General Electric Medical System, Milwaukee, WI, USA) taken immediately before bone grafting, 3–5 months after the graft and just before implant insertion (Krekmanov and Heimdahl, 2000; Crespi et al., 2007), and then annually following clinical and radiologic examination, as provided in the postoperative maintenance program; a survey of the dental implants was also conducted.

Values of the volume and density of the inlay grafts were taken using axial CT slices having a thickness of 1 mm. Before the numerical computation of volume, axial images of the original CT scans were reoriented parallel to the palatine vault: measurements of the sinus vacuum were performed using SimPlant Pro 12.02 with Segment tool (Materialise Dental Italia. Via L. Fincati 13/f, 00154 Roma, Italy), as per Krennmair et al. (2006), with total height preset to the maximum distance between the alveolar crest and the apical portion of the inlay bone graft. For the Density measurement, tomographic CT scan data were entered into a software program, and pre- and postoperative axial images were superimposed (Image Processing Toolbox, MatLab 7.0.1, The MathWorks, Natick, MA), as was recently suggested by Sbordone (Sbordone et al., 2012). The numerical computation of density was performed using SimPlant Pro 12.02 with Prepare for planning tool (Materialise Dental Italia, Via L. Fincati 13/f, 00154 Roma, Italy) with dental implant areas deletion from all axial CT slices.

The timing of the CT scans allowed data ranking, with the six time intervals being set as follows: T1 (0–12 mos), T2 (13–24 mos), T3 (25–36 mos), T4 (37–48 mos), T5 (49–60 mos) and T6 (61–72 mos). Volume measurements of the bone grafts, relating to the CT scans acquired after dental implant placement (V2, V3, V4, V5 and V6), were compared to the data obtained from CT scans recorded at time T1 (V1), in order to determine the percentage of residual bone graft (%R): i.e., %RX at X-time (with $X = 2,3,4,5$ and 6) was obtained as the ratio between the volume at time X (or VX) and the time T1 block volume (V1). Percentages were rounded off to the nearest 0.1%.

2.3. Statistical analysis

All patient-related data were entered into a database (Access, Microsoft Corp, Redmond, WA), allowing calculations to be performed automatically. Descriptive statistical analyses were performed using a statistical tools package (Statistics Toolbox, MatLab 7.0.1, The MathWorks, Natick, MA).

A normal distribution for each data set was carried out, but not confirmed, using the Lilliefors test for data, establishing different follow-up time intervals. The data are assumed to come from a continuous, symmetrical distribution around its medians.

All measurements in the text and Tables are described as median and interquartile range (difference between 75th and 25th percentiles). In the Figures, distributions have been depicted by box-and-whiskers plot, in which the box line represents the lower quartile, median, and upper quartile values, while the whisker lines include the rest of the data. Outliers were data with values beyond the ends of the whiskers.

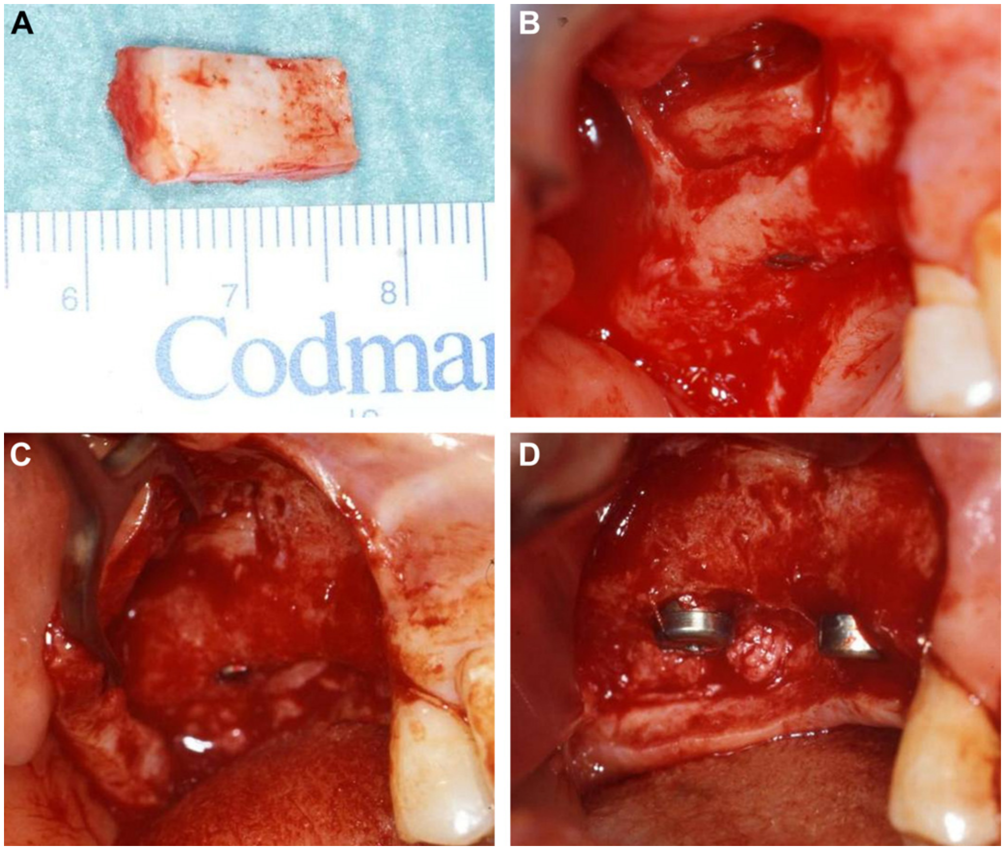

Fig. 1. Patient #11. Autogenous inlay bone graft in maxillary sinus in block form: A) block bone before grafting procedure; B) bone blocks secured by titanium lag screw; C) grafted site 4 months after reconstruction; D) implants positioned in grafted sinus.

In the comparison tests, to overcome the differences between bilateral sinus lifting and grafting procedures in the same patient, only one treated sinus per patient was randomly selected (Herrmann et al., 2005).

Because the measurements obtained are not normally distributed, Wilcoxon matched pairs signed rank tests were used to assess the changes between times. The difference between the particulate and block forms for all the variables introduced (V, D and %R) at the same time was assessed using the Wilcoxon rank sum test. The level of statistical significance was set at 0.05 for all analyses.

3. Results

In this retrospective study, 10 of the 17 enrolled patients affected by severe sinus pneumatization, and ranging in age from 37.5 to 63.3 years, were female. As regards the upper arch, there were 14 partially-edentulous patients, while 2 men and 1 woman were completely edentulous.

A total of 23 sinus lift procedures with autogenous bone were performed, 7 in which particulate grafts were employed, and 10 featuring block autogenous bone grafts. Only 17 sinus lift procedures, 1 per patient, were considered for further analysis (Table 1). In Table 2, the patient list showing surgery and implant information, as well as the respective final percentage of residual bone (%R) obtained at 6 years, is described: a negative value attested to a complete resorption of the grafted bone, with a new pneumatization of the grafted sinus. For block bones grafted into the maxillary sinus, a residual bone percentage of 78.5 (56.8)% was obtained, whereas, for maxillary particulate inlay grafts, bone remodelling yielded a percentage value of the residual bone of 60.8 (72.2)%. The data distribution regarding bone volume and density are described in Fig. 2 using box-and-whiskers plot.

Table 1
Distribution of patients, grafts, and implants placed by procedure.

Procedure	No. of patients	No. of grafts	No. of grafts enrolled	No. of implants placed in enrolled grafts	No. of failed implants
Block	10	13	10	16	0
Particulate	7	10	7	15	2 (early)
Total	17	23	17	31	2

Statistical comparisons between groups showed no statistical differences for any of the variables considered (Volume, Density, and percentage of residual bone) at any of the follow-up times. Statistical differences were recorded for the time comparisons performed in each procedure.

For the block-graft group, 4 statistically-significant differences were recorded regarding volume and only 1 such difference was recorded regarding density variables: the median (interquartile range) of the volumes for block procedure at times T1, T2, T3, T4, and T5 were 1.23(0.78) cc, 0.66(0.78) cc, 0.98(0.51) cc, 0.85(0.52) cc, and 0.87(0.36) cc, respectively, whereas descriptive values for density at times T1 and T2 were 851(336) Hu and 931(316) Hu, respectively. As reported in Table 3, in regard to volume variables, differences at a statistically-significant level were recorded between T1 and times T2, T3, T5 (p12 0.0156, p13 0.0273 and p15 0.0098, respectively), and between V2 and V4 (p24 0.0195), whereas for density variables, a statistically-significant difference was recorded between D1 and D2 (p12 0.0371) (Table 4).

Table 2
Descriptive analysis of data. Enrolled bone dimension at T1 (cc); and percentage of residual bone (%R) at 6 years for block and particulate procedure in the sinus lifting and bone-grafting augmentation procedures.

Patient	Age (years)	Gender	Smoking habits	Type of graft (cc)	Sources	No. of implants placed in enrolled grafts	6-Year graft %R
1	58.7	F	N	Block	Hip	2	75.4
2	48.7	F	Y	Block	Hip	1	148.7
3	63.3	M	N	Block	Hip	2	59.5
4	62.2	F	Y	Particulate	Hip	2	−43.9
5	54.6	F	N	Particulate	Chin	3	−18.2
6	51.1	M	Y	Particulate	Hip	2	132.8
7	42.5	F	Y	Particulate	Hip	3	69.9
8	56.4	M	N	Block	Chin	2	31.9
9	54.2	F	Y	Block	Chin	2	124.0
10	48.1	M	N	Block	Chin	2	105.7
11	50.2	M	N	Block	Chin	2	64.2
12	58.7	F	Y	Block	Hip	1	125.7
13	52.2	F	Y	Particulate	Hip	2	101.7
14	56.1	M	Y	Particulate	Hip	1	45.5
15	37.5	F	Y	Particulate	Hip	2	60.8
16	51.4	M	N	Block	Chin	1	62.0
17	59.2	F	Y	Block	Chin	1	81.6
Total	54.2 (8.5)						69.9 (46.2)

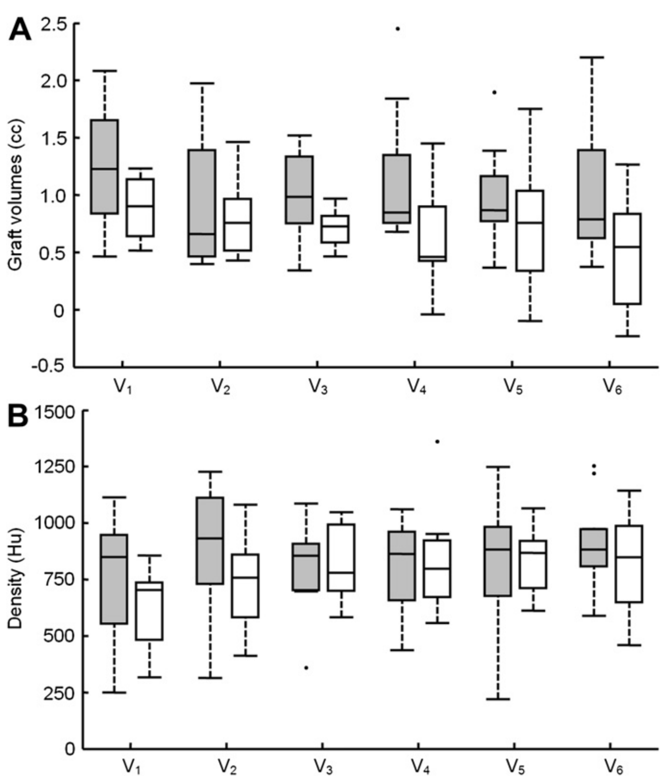

Fig. 2. Box plots for volume A) and density B) measurements expressed in cc and Hu among different follow-up times: T1 (0–12 mos), T2 (13–24 mos), T3 (25–36 mos), T4 (37–48 mos), T5 (49–60 mos), T6 (61–72 mos) for block group in light grey; and for particulate group in white.

For the particulate group, 5 differences at a statistically-significant level were recorded among density variables: descriptive values for D1, D2, D3, D4, and D5 were 704(213) Hu, 758(202) Hu, 779(244) Hu, 796(193) Hu, and 868(169) Hu, respectively. Statistically-significant differences were recorded for densities between D1 and D2, D3, D4, D5 (p12 0.0156, p13 0.0469, p14 0.0469 and p15 0.0313, respectively), and between D2 and D4 (p24 0.0469).

Thirty-one dental implants were positioned in the enrolled grafts, 15 in particulate bone, and 16 in block grafts, as is seen in Table 1; two early failures were recorded in the particulate group (pre-loading) in one female patient (*n*. #5), yielding a failure rate, after 1 year of follow-up, of 86.6%. No other failure was recorded.

Table 3
Statistical significance analysis; comparing volumetric dimensions of block grafts (V) and respective value of density (D) among different follow-up time intervals: T1 (0–12 mos), T2 (13–24 mos), T3 (25–36 mos), T4 (37–48 mos), T5 (49–60 mos), T6 (61–72 mos) both for block and particulate procedure. Wilcoxon matched pairs signed rank tests. Statistically-significant differences in bold.

Volume	V_1	V_2	V_3	V_4	V_5	
Block procedure						
V_6	0.2754	0.0801	0.8457	0.3750	0.4922	
V_5	**0.0098**	0.4316	0.5566	0.0645		
V_4	0.5566	**0.0195**	0.3750			D_1
V_3	**0.0273**	0.3223			**0.0371**	D_2
V_2	**0.0156**			0.1602	0.4316	D_3
V_1			1	0.1308	0.5566	D_4
V_0		0.8457	0.8457	0.4316	0.3750	D_5
	0.3223	0.0840	0.0510	1	0.1055	D_6
	D_5	D_4	D_3	D_2	D_1	Density
Particulate procedure						
V_6	0.0781	0.2969	0.2188	0.2969	0.1563	
V_5	0.3750	0.8125	1	0.6094		
V_4	0.1563	0.3750	0.3750			D_1
V_3	0.0510	0.4688			**0.0156**	D_2
V_2	0.8125			0.3750	**0.0469**	D_3
V_1			0.7813	**0.0469**	**0.0469**	D_4
V_0		1	0.3438	0.7813	**0.0313**	D_5
	0.8125	1	0.5781	0.6875	0.1563	D_6
	D_5	D_4	D_3	D_2	D_1	Density

Table 4
Statistical significance analysis; comparing volumetric remodelling, both regarding volume and %R, and density between block and particulate procedure for all follow-up time intervals: T1 (0–12 mos), T2 (13–24 mos), T3 (25–36 mos), T4 (37–48 mos), T5 (49–60 mos), T6 (61–72 mos). Wilcoxon rank sum tests. No statistically-significant differences were recorded.

Block vs particulate	Time intervals					
	1	2	3	4	5	6
Volume	0.2699	0.9623	0.1331	0.0702	0.3638	0.2295
%R		1	0.5362	0.1932	0.8868	0.2295
Density	0.1613	0.2295	0.7396	0.8257	0.9802	0.6009

4. Discussion

The aim of this retrospective study was the long-term evaluation of volumetric changes for grafted areas with autogenous bone after maxillary sinus augmentation performed using two different surgical procedures.

Recent review papers have shown increased rate of clinical success and a high level of predictability for dental implants placed

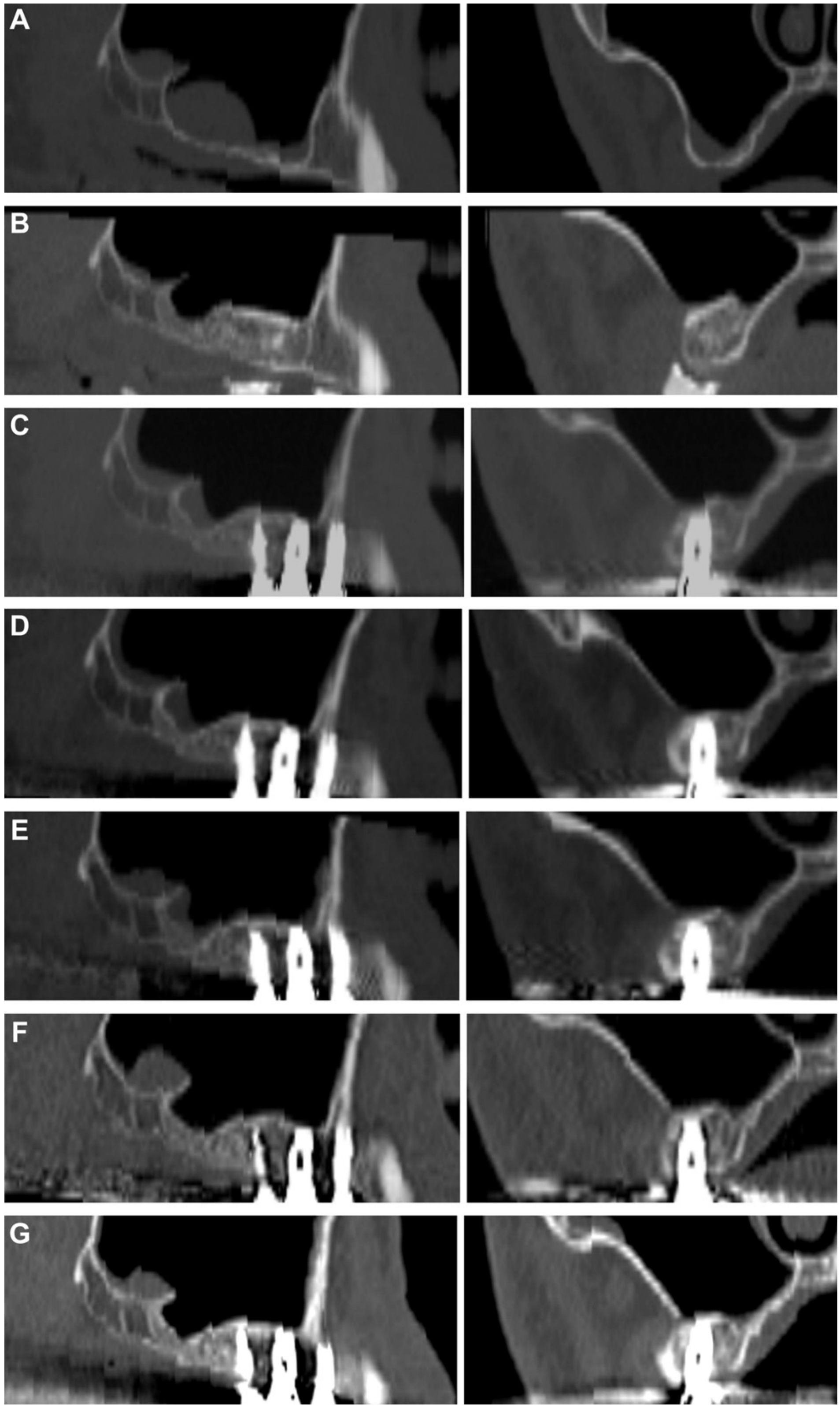

Fig. 3. Preoperative (A) and postoperative CT scans in sagittal- and frontal-view of the autogenous bone-block graft from the chin grafted into the maxillary sinus after 3 (B), 21 (C), 30 (D), 39 (E), 52 (F), 70 (G) months following alveolar bone augmentation procedure in patient #10. The final percentage of residual bone was recorded as being close to 105.7% for this patient.

in augmented sinus sites with the employment of several diverse materials: similar results were recorded between autogenous bone and non-autogenous grafting materials in terms of reliability for simple sinus floor elevation, clinical outcomes, and implant survival (Chiapasco et al., 2006; Nkenke and Stelzle, 2009), and autograft has been preferred when sinus- and onlay-grafting procedures were paired (Chiapasco et al., 2006). The phenomenon of apical dental implant bulging into the maxillary sinus, identified both for auto- (Sbordone et al., 2009a) and xeno-grafts (Hatano et al., 2004), revealed the presence of an unidentified bone remodelling of inlays that led to a re-pneumatization of the maxillary sinus. Three-dimensional data analyses of bone remodelling for inlays in maxillary sinuses, performed using CT scans, attested to a variable behaviour regarding several materials for which the volumetric resorption rates were 29%, 13.9%, 19.2%, 49.5% and 26%, with a short-term follow-up of 3 mos, 6.1 mos, 12 mos, 18 mos and 18.7 mos, respectively (Johansson et al., 2001; Smolka et al., 2006; Wanschitz et al., 2006; Zizelmann et al., 2007; Kirmeier et al., 2008). Certainly, inlay bones modified their volumes over time, but a systematic analysis of bone remodelling for a long-term follow-up could determine the ideal form of grafting materials, whether this involves particulate or block bone.

For autogenous block groups, statistically-significant differences were recorded between the volume at T1 and volumes at times T2, T3 and T5; maxillary sinuses showed a re-pneumatization phenomenon between the first and second follow-up times, for which the median values of volumes were 1.23(0.78) cc and 0.66(0.78) cc, respectively: the absence of significant modification in graft volume for the block group among the later follow-up times indicated that an ample remodelling process was restricted to just the first year of healing (Fig. 3). As regards graft density, just a single significant difference was found between D1 and D2 values, which were 851(336) Hu and 931(316) Hu, respectively. Block bone grafted into the maxillary sinus during the first period of healing, although showing a negative remodelling of the volume, also manifested an increase in density; this more than likely occurred for reasons similar to those recorded for autogenous cortico-cancellous onlay graft, for which the acquired data suggested an early graft cortex resorption in the first half-year, whereas in the second half-year the bone density increased both in the spongious area and in the remaining overlying cortex (Verhoeven et al., 2000). The percentage value of residual bone obtained in the first two years, %R2 of 75.2 (29.3)%, led to a resorption percentage of 24.8%, which was higher than the 19.2% recorded by Smolka et al. (2006), although this was related to just 1 year of follow-up, and the methods were not the same as in his study calvaria bone was employed, and onlay- and inlay-blocks were all grouped together in his analysis.

For particulate procedures, no statistically-significant differences were recorded among volumes for the various times considered. But, as indicated by significant values obtained from density measurements, the particulate bone seemed to undergo a minimal re-pneumatization phenomenon; D1 was statistically different from D2, D3, D4 and D5, and a statistical difference was also seen between D2 and D4. There was a change in the density value from the 704(213) Hu of T1, to the 868(169) of T5, showing an increase in the mineralization of particulate bone. As was earlier stated, in Fig. 2 a decrease in particulate graft volumes was observed; graft volumes remodelled from time T1 to time T6 showed the following values: from 0.91(0.40) cc to 0.55(0.59) cc, for the first and last follow-up times, respectively. This lack of significance was likely to be due to a dispersion of data regarding the particulate group, which, at T6, was greater than that of previous times, as can be seen in Fig. 2. In Table 2, few negative final percentages of residual bone (−%R6s) indicated an extensive re-pneumatization of the maxillary sinus; this occurred mainly for particulate grafts, in which, in some patients, graft volume measurements yielded only tiny values (Fig. 2).

The percentage of resorption at the second follow-up time, which was 22% obtained from the percentage of residual bone, %R2 of 78.0(65.2)%, was similar to that of 26% obtained by Kirmeier et al. with a mean follow-up period of 18 months, although, here, mainly xenogeneic materials were employed in the grafting (Kirmeier et al., 2008).

Nevertheless, no statistically-significant differences were recorded between V6 and the other measured volumes, regarding both the particulate and the block form procedures, or between the volumes recorded in the two groups; the final resorption rates at 72 mos were 39.2% and 21.5% for the particulate and block procedures, respectively. As has been reported in several papers, sinus floor elevation with particulate materials is a less demanding procedure, especially if non-autogenous materials are used (Acocella et al., 2011). As this paper describes, a mean resorption volume of particulate bone, due to extreme negative remodelling exhibited by a subgroup of a few patients, was recorded, and this same phenomenon, albeit at a much slower rate than that recorded for autogenous bone, may also occur for non-autogenous particulate grafting materials (Sbordone et al., 2011b). In long-term prosthetic rehabilitation, unavoidable apical dental implant bulging into the maxillary sinus could jeopardize implant stability; the results of this paper suggest that, in cases in which autografts have been preferred, the employment of block-bone, which seemed to maintain its volumetric dimension over time in the overall group of patients, rather than particulate materials, which yielded uncertain results due to a high rate of data dispersion, may lead to an extreme negative outcome as regards the maintaining of volume of the grafts in a small subgroup of patients.

Data suggests that the minimal remodelling seen during long-term follow-up may not affect the survival of dental implants placed in enrolled autografts, since the two recorded implant failures were early on, and in a single female patient. Further studies are required in order to confirm this data.

5. Conclusions

A long-term evaluation of changes in volume and density in grafted areas in which autogenous bone had been employed following maxillary sinus augmentation performed with either particulate or block procedure was conducted. Although no statistically-significant differences were recorded between the two groups considered, they did exhibit different behaviours: the resorption percentages obtained at 72 mos were 39.2% for the particulate procedure and 21.5% for the block-procedure. During the first period of healing, the cortico-cancellous block bone grafted into the maxillary sinus underwent negative remodelling in the volume, which was most likely to be due to graft resorption of the cortex, coupled with, primarily, an increase in the density of the spongious area; for the particulate grafts, significant increases in density were obtained, while the lack of significant differences among volumes was due to a high degree of dispersion of the data. The rough data presented in this paper, regarding the use of autografts, seem to suggest the use of a bone-block grafting procedure in maxillary sinus augmentation: en block bone seemed to give less dispersion of data, and therefore more certain results in terms of the maintaining of volume in long-term analysis for the overall group of patients.

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Conflict of interest statement

All the authors declare that no conflict of interest exists in relation to any financial organization regarding the material discussed in the manuscript.

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