Marginal Bone Loss in Implants Placed in Grafted Maxillary Sinus

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ABSTRACT

Purpose: The purpose of this study is to evaluate the vertical and horizontal graft bone resorption (GR) in grafted maxillary sinuses and the marginal bone loss (MBL) around implants placed in the sinuses with different prosthetic connections and to determine the effect of other clinical factors on these tissue responses at 6 and 18 months postloading.

Material and Method: A total of 254 implants were placed in 150 grafted maxillary sinuses of 101 patients (51.5% female) with mean age of 52.2 years (range, 32–82 years). GR and MBL measurements were made in implants placed with two different prosthetic connections (internal and external) at 6 and 18 months postloading. The complex samples general linear model was used to analyze the influence of patient age, gender, smoking habit, history of periodontal disease, implantation timing (simultaneous vs deferred), and prosthetic abutment length on radiographic GR and MBL values.

Results: At 18 months postloading, the MBL ranged from 0 mm to 5.89 mm; less than 1 mm was lost around 49.0% (mesial) and 44.3% (distal) of the implants, while no bone was lost around 32.9% (mesial) and 26.7% (distal). The GR was significantly affected by smoking, remnant alveolar bone height, graft length, graft height, gender, and age, and it significantly decreased over time. The MBL was influenced by the type of connection, implantation timing, and prosthetic abutment length. The MBL was greater with longer postloading interval and higher patient age and in smokers.

Conclusion: Resorption of grafts that combine autogenous cortical bone with anorganic bovine bone is dependent on the anatomic features of the sinus and is not affected by the time elapsed after the first 6 months. The MBL in implants placed in these grafted areas is time dependent and mainly related to potentially modifiable clinical decisions and patient habits.

KEY WORDS: bone resorption, grafted bone, implant, marginal bone loss, maxilla bone, prosthetic connection

INTRODUCTION

Maxillary sinus elevation has proved to be a highly predictable clinical procedure to restore patients with posterior bone atrophy or extensive pneumatization. Numerous techniques and a large number of biomaterials have proven effective to achieve satisfactory clinical outcomes, but there is considerable debate about the optimal method. Good success rates have recently been reported applying modified techniques without utilizing biomaterials by means of a lateral[1] or crestal[2] approach.

The aim of these techniques is to produce new mature bone in the maxillary area to permit implantation and restore occlusal function for the longest possible time period. Relevant outcomes for their evaluation include the maturation and stabilization of the new bone created and the long-term functional performance of the implants placed in it.

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Ideally, the biological, biomechanical, and histomorphometric characteristics of the new bone should be similar or superior to the patient's pristine bone in the same area. The mineral component of pristine bone in the posterior maxilla ranges from 23 to 28% depending on age and gender.[3,4] A three-dimensional repneumatization phenomenon can be expected in sinuses grafted with certain biomaterials, especially particulate bone.[5] It is important to assess the initial and medium/long-term resorption of the biomaterial selected, which determines the final availability of bone to support functional load. Evidently, once this bone reaches a degree of maturation, it will be remodeled according to the specific remodeling characteristics of each patient and the functional load that it bears. Hence, the resorptive component of each biomaterial should be assessed in the context of its 'proposed function when used for tissue regeneration.

Further important criteria of success are related to the functional maintenance of implants in this type of bone, especially the marginal bone loss (MBL), which indicates peri-implant health over time. A slight tendency has been observed for a greater loss in implants placed in maxillary bone grafts in comparison to pristine bone.[6] Factors known to influence the MBL around implants in regenerated bone include the nature of this bone, the residual crest,[7] the occlusion function, and the timing of the implantation.[8]

The objectives of this prospective study were to analyze the resorptive pattern of new bone formed after grafting the maxillary sinus with a combination of cortical autogenous bone and anorganic bovine bone and the MBL around implants placed in the grafted sinus at 6 and 18 months postloading as a function of patient characteristics and habits, implant design, and prosthetic features.

MATERIAL AND METHODS

Study Population

The eligible population for this retrospective correlational study comprised consecutive patients undergoing functional restoration of the posterior maxilla by a single surgeon at two private clinics in Andalusia. The study was conducted according to the Helsinki's declaration[9] and was approved by the ethical committee of the University of Granada for studies involving human subjects. Patients consented to participate in the study during the screening phase.

Inclusion criteria were: age of 18 to 85 years, American Society of Anesthesiologists (ASA) physical status I or II, absence of systemic diseases or conditions known to alter bone metabolism, and O'Leary's Plaque Score ≤15%.[10] Exclusion criteria were receipt of drugs known to modify bone metabolism (e.g., bisphosphonates) or of antibiotics for more than 2 weeks during the previous 3 months, pregnancy or attempts to become pregnant, presence of acute or chronic sinus pathology (e.g., sarcoidosis, osteomas, carcinomas, etc.), active sepsis or mucocutaneous disease, history of cancer and/or radiation to the head and neck in the previous 18 months, or chemotherapy in the previous 12 months.

The study included 101 patients (51.5% females) with a mean age of 52.2 years (range, 32–82 years) who received a total of 204 Astra Tech^{TM} internal-connection implants (Astra Tech AB, Mölndal, Sweden) and 50 Microdent® external-connection implants (Microdent Implant System, Barcelona, Spain). The selection of implant was solely governed by the availability of stock at each clinic and was not affected by any characteristic of the patient.

Surgical and Restorative Procedures

All patients were instructed to take amoxicillin/clavulanic acid every 8 hours (875/125 mg tablets) or, if allergic to penicillin, clindamycin (300 mg tablets/8 hours) during the day before surgery. Surgical procedures were conducted under local anesthesia (Ultracain®, Aventis Inc., Frankfurt, Germany). Sinus augmentation procedures were performed by using the bone scraper technique.[11] Briefly, all sinus cavities were grafted with scraped autologous cortical bone combined (1:1 ratio) with anorganic bovine bone particles ranging from 250 to 1,000 μm (Bio-Oss® – Geistlich Pharma AG, Wolhusen, Switzerland). When the remnant alveolar bone height was >4 mm, the implant was inserted in the same act. Before placing the bone graft, implant osteotomy was performed while protecting the Schneiderian membrane with a blunt metal instrument, following the implant manufacturer's instructions. The grafting material was then used to fill the medial half of the sinus cavity, followed by insertion of the implant(s) and the filling of the rest of the sinus cavity. An absorbable collagen membrane (Bio-Gide® – Geistlich Pharma AG) was trimmed and fitted to the lateral aspect of the bony window. When the remnant alveolar bone height was <4 mm, a differed implantation protocol was followed. In all patients, primary wound closure was achieved by approximating and suturing the soft tissues. After the surgery, all patients continued with their preoperative medication regimen for 7 days and were also prescribed with anti-inflammatory medication (ibuprofen 600 mg tablets 4–6 times per day), not exceeding 3,600 mg per day. In the one-stage or simultaneous protocol, trans-epithelial abutments were placed in a second surgical procedure after a 5-month healing period. In the differed protocol, the implants were placed after 5 months of graft maturation, following the manufacturers' instructions, and peri-implant healing was left undisturbed for a further 5 months. In both the simultaneous and differed protocols, the implant-supported prostheses were delivered at 4 weeks after uncovering the implants. All definitive restorations were screw-retained fixed partial dentures. Occlusal adjustment was performed at the time of delivery. After functional loading, all patients were included in a maintenance program.

Variables

Data were gathered from the records of each patient on their age, gender, type of edentulism (partial edentulism [at least one missing maxillary posterior tooth, excluding third molars] or complete edentulism [no teeth in the upper arch]), smoking habit at the time of surgery, and history of periodontal disease, on the design of the implant and length of the prosthetic abutment, on the mesial and distal MBL of the implant at 6 and 18 months postloading, and on the vertical and horizontal graft bone resorption (GR) at the same time points (Figures 1–3). Smoking was scored as follows: 0 = non-smoking, 1 = mild smoker ≤10 cigars/day, and 2 = heavy smoker >10 cigars/day.[12] A history of periodontal disease history was defined by the presence of at least four sites with clinical attachment loss ≥3 mm (excluding third molars), using a Michigan O probe (Hu-Friedy, Chicago, IL, USA). Two types of implant connection were evaluated, flat-to-flat (external) and conical (internal). The prosthetic abutment length was measured as 0 mm, 0.5 mm, 1 mm, 2 mm, or 4 mm according to the distance between the neck of the implant and the base of the final screwed crown.

Radiographic Evaluation

Standardized digital panoramic radiographs (Kodak ACR-2000, Eastman Kodak Company, Rochester, NY, USA) were obtained at five time points: first appointment, immediately before sinus augmentation and implant placement surgery, final restoration delivery (baseline), and 6 and 18 months after functional loading. An independent calibrated examiner (A.F-J.) used Dent-A-View v1.0 software (DigiDent, DIT, Nesher, Israel) to make linear MBL measurements from the most mesial and distal point of the implant platform to the crestal bone on panoramic radiographs taken at the different measurement time points.

Statistical Analysis

SPSS® v. 17 (IBM, Chicago, IL, USA) was used for the statistical analysis, using the general linear model (GLM) for complex samples to determine the effect of the type of connection on the GR and MBL at 6 and 18 months after functional loading. Bivariate tests were applied to analyze the relationship of age, gender, smoking habits, history of periodontitis, implant site, implant width and length, implantation timing (simultaneous/deferred), and the initial height and initial length of the grafted bone with the GR and MBL at mesial and distal sites at 6 and 18 months. Significant variables then served as covariates in univariate analyses of covariance (ANCOVAs), one for each dependent variable, in which the type of connection (internal vs external) was the between-subject factor. Finally, monthly MBL rates at mesial and distal sites were calculated as the difference between losses at 18 and 6 months divided by 12. The GLM for complex samples was then applied, with the monthly MBL rate as dependent variable and the type of connection and remaining study variables (see above) as independent variables.

RESULTS

Two hundred fifty-four implants, placed in 150 grafted maxillary sinuses of 101 patients, were evaluated in this study. After 18 months of follow-up, MBL values in our sample ranged from 0 mm to 5.89 mm; less than 1 mm was lost around 49.0% (mesial) and 44.3% (distal) of the implants, and no bone was lost around 32.9% (mesial) and 26.7% (distal). All the implants were still in function in the last temporal frame. Table 1 displays the mean MBL (Table 1A) and GR (Table 1B) values and standard deviations as a function of postloading interval, peri-implant site, type of connection, and grafted bone height and length. Table 1C displays the average

TABLE 1A Complex Samples Analysis: Means Marginal Bone Loss Values with Standard Error (in Parentheses) according to the Type of Implant Connection and Postloading Interval in Months

	Connection	
	Internal Astra Tech	External Microdent
MBL-M6	0.47 (0.03)	1.14 (0.05)
MBL-D6	0.54 (0.03)	1.37 (0.05)
MBL-M18	0.90 (0.05)	1.93 (0.06)
MBL-D18	0.99 (0.05)	2.16 (0.06)

MBL, marginal bone loss; M6, mesial MBL at 6 months; D6, distal MBL at 6 months; M18 and D18, mesial and distal MBL, respectively, at 18 months.

TABLE 1B Complex Samples Analysis: Mean Horizontal and Vertical Graft Length and Grafted Bone Resorption Values with Standard Errors (in Parentheses) as a Function of Implant Connection Type and Postloading Interval

	Connection	
	Internal Astra Tech	External Microdent
Graft length	17.19 (0.09)	15.5 (0.15)
Graft height	12.09 (0.11)	11.48 (0.13)
GR-V6	1.35 (0.04)	1.05 (0.06)
GR-H6	1.53 (0.03)	1.28 (0.03)
GR-V18	2.26 (0.04)	1.95 (0.08)
GR-H18	2.48 (0.03)	2.42 (0.05)

GR, grafted bone resorption; V6 and H6, vertical and horizontal resorption, respectively, at 6 months; V18 and H18, vertical and horizontal resorption, respectively, at 18 months.

and standard errors as a function of postloading interval, implantation timing, periodontitis, and smoking habits

Table 2 reports on the association of clinical and sociodemographical variables with MBL (Table 2A) and GR (Table 2B). MBL was significantly affected by smoking, age, length of abutment, implantation timing, and type of connection. Periodontitis was associated with greater MBL at 18 months but not at 6 months postloading. Implant type affected mesial loss alone and only at 6 months. The width and length of GR at 6 and 18 months were independently influenced by the graft length at baseline, the graft length and width at follow-up times, type of implant connection, and by the smoking habit, age, and periodontal status of the patient.

Table 3 shows the results of the four univariate ANCOVAs for the effect of connection type on MBL, in which smoking habit and implantation timing were included as covariates. The abutment length was not included due to the potential for confounding with the type of connection. Application of the sequential-Bonferroni correction (Table 3) confirmed that the MBL was significantly affected by patient age and smoking habit, the implantation timing, and the connection type. Thus, the MBL was greater with higher age (lower estimate slope = 0.05 mm/year), smoking habit (lower estimate = 0.014), simultaneous procedure (minimum estimated difference = 0.2 mm mesial MBL at 6 months), and external connection (minimum estimated difference = 0.61 mm mesial MBL at 6 months,

TABLE 1C Complex Samples Analysis: Mean MBL and GR with Standard Errors (in Parentheses) as a Function of Postloading Interval, Implantation Timing, Periodontal Status, and Smoking Habits

	Implantation Timing		Periodontitis		Smoking	
	Simultaneous	Delayed	No	Yes	No	Yes
MBL-M6	0.66 (0.03)	0.42 (0.06)	0.57 (0.06)	0.62 (0.02)	0.51 (0.03)	0.76 (0.04)
MBL-D6*	0.79 (0.03)	0.45 (0.05)	0.62 (0.05)	0.75 (0.03)	0.59 (0.03)	0.92 (0.04)
MBL-M18*	1.23 (0.04)	0.73 (0.07)	0.9 (0.08)	1.2 (0.04)	1.03 (0.04)	1.26 (0.05)
MBL-D18*	1.36 (0.04)	0.85 (0.09)	0.93 (0.07)	1.36 (0.04)	1.12 (0.05)	1.44 (0.05)
GR-V6	1.25 (0.03)	1.31 (0.07)	1.29 (0.06)	1.26 (0.03)	1.32 (0.04)	1.18 (0.04)
GR-H6	1.43 (0.02)	1.55 (0.04)	1.29 (0.03)	1.52 (0.02)	1.56 (0.02)	1.29 (0.03)
GR-V18	2.11 (0.04)	2.41 (0.08)	2.2 (0.07)	2.16 (0.04)	2.33 (0.04)	1.92 (0.06)
GR-H18	2.41 (0.02)	2.58 (0.07)	2.15 (0.04)	2.56 (0.03)	2.47 (0.03)	2.42 (0.04)

MBL, marginal bone loss; GR, grafted bone resorption; M6, mesial MBL at 6 months; D6, distal MBL at 6 months; M18 and D18, mesial and distal MBL, respectively, at 18 months; V6 and H6, vertical and horizontal resorption, respectively, at 6 months; V18 and H18, vertical and horizontal resorption, respectively, at 18 months.
*$p < 0.05$.

TABLE 2A Clinical and Sociodemographical Variables Independently Associated to Marginal Bone Loss. Complex Samples Adjusted Wald *F* Statistics and Its Significance

	Marginal Bone Loss			
	M6	D6	M18	D18
Initial length	2.34	1.51	5.41	0.83
Graft length	1.76	5.11	0.36	7.16
Graft width	8.33	10.96	1.33	0.63
Smoking	43.95*	51.76*	18.83*	22.35*
Age	18.29*	22.92*	19.63*	44.34*
Type of implant	22.86*	6.14	5.49	0.77
Periodontitis	0.71	5.69	15.71*	38.97*
Connection	170.69*	231.01*	251.63*	258.13*
Gender	4.31	4.46	0.05	0.09
Localization	0.18	0.01	0.49	0.55
Implant length	4.21	0.45	0.21	0.01
Length of abutment	218.68*	314.93*	294.64*	348.47*
Implantation timing	13.09	35.18*	33.52*	26.46*
Implant width	10.61	14.53*	7.58	14.99*
Initial HRB	0.79	0.34	2.06	0.36

*$p < .05$, according to the Bonferroni correction; M, mesial; D, distal; 6 and 18, postloading intervals in months; HRB, height of residual alveolar bone.

maximum estimated difference = 1.05 distal MBL at 18 months).

Table 4 displays the results of the four univariate ANCOVAs for the effect of connection type on the GR, in which age, smoking habits, initial length, graft length, graft height, type of prosthesis, gender, and implantation timing were included as covariates. Application of the sequential-Bonferroni correction revealed that

TABLE 2B Clinical and Sociodemographical Variables Independently Associated with Grafted Bone Resorption. Complex Samples Adjusted Wald *F* Statistics and Significance

	Grafted Bone Resorption			
	V6	H6	V18	H18
Initial length	15.01*	18.49*	20.01*	20.23*
Graft length	46.59*	203.06*	50.45*	168.42*
Graft width	100.42*	21.2*	198.24*	16.18*
Smoking	19.77*	37.06*	19.01*	0.51
Age	31.67*	24*	11.41	15.35*
Type of implant	18.06*	11.09*	2.37	13.21*
Periodontitis	0.21	21.01*	1.34	51.54*
Connection	22.55*	57.02*	11.79	0.57
Sex	7.67	6.11	13.86*	14.19*
Localization	0.08	1.35	0.54	0.01
Implant length	0.23	2.82	0.16	0.05
Length of abutment	0.92	6.89	0.11	0.01
Implantation timing	0.59	6.65	11.54	3.48
Implant width	2.72	6.76	2.19	3.06
Initial HRB	0.24	1.45	2.23	0.51

*$p < .05$, according to the Bonferroni correction; V, vertical; H, horizontal; 6 and 18, postloading interval in months; HRB, height of residual alveolar bone.

TABLE 3 Adjusted Wald *F* for the Four Univariate ANCOVAs with Type of Connection as the Between-Subjects Factor, on MBL at Mesial and Distal Sites at 6 and 18 Months after Loading

	MBL-M6	MBL-D6	MBL-M18	MBL-D18
Connection	117.74**	148.64**	165.14**	176.78**
Age	4.22*	5.37*	3.37*	9.67*
Smoking	36.73**	47.99**	17.21**	21.05**
Implantation timing	5.24*	17.09*	17.56*	12.42*

*Sequential Bonferroni, $p < .05$. ** $p < .01$.
ANCOVAs, analyses of covariance; MBL, marginal bone loss; M, mesial; D, distal; 6 and 18, postloading intervals in months.

TABLE 4 Adjusted Wald *F* for the Four Univariate ANCOVAs with Type of Connection as the Between-Subjects Factor, on Vertical and Horizontal Grafted Bone Resorption at 6 and 18 Months

	GR-V6	GR-H6	GR-V18	GR-H18
Connection	3.09	2.21	1.68	9.01°
Age	24.38*	54.05*	2.14	14.12*
Smoking	10.11*	25.92*	9.21*	0.01
Initial width	12.92*	2.31	17.25*	23.71*
Graft length	15.63*	137.04*	7.06°	114.05*
Graft height	67.22*	0.04	119.59*	6.67
Prosthesis	3.23	0.64	1.83	0.07
Gender	0.13	32.23*	0.83	69.77*

*Sequential Bonferroni, $p < .05$; °uncorrected p value $< .003$.
ANCOVAs, analyses of covariance; GR, grafted bone resorption; V6 and H6, vertical and horizontal resorption, respectively, at 6 months; V18 and H18, vertical and horizontal resorption, respectively, at 18 months.

horizontal and vertical GR values were significantly influenced by patient age, smoking habit, remnant alveolar bone, and graft height and length. Gender affected the length but not height of the GR, while the connection type only had a borderline significant effect on the length of the GR at 18 months alone.

With regard to the monthly rates of MBL and GR, the ANCOVA for the mesial MBL rate showed significant effects for the type of connection and implantation timing (Adj Wald $F = 32.31$, $p < .001$, and Adj Wald $F = 20.99$, $p < .001$, respectively). Thus, the mesial MBL rate was higher with the external (0.064 mm/month) versus internal (0.037 mm/month) connection and with the simultaneous (0.055 mm/month) versus differed (0.036 mm/month) procedure. The connection type also had a significant effect on the distal MBL rate (Adj

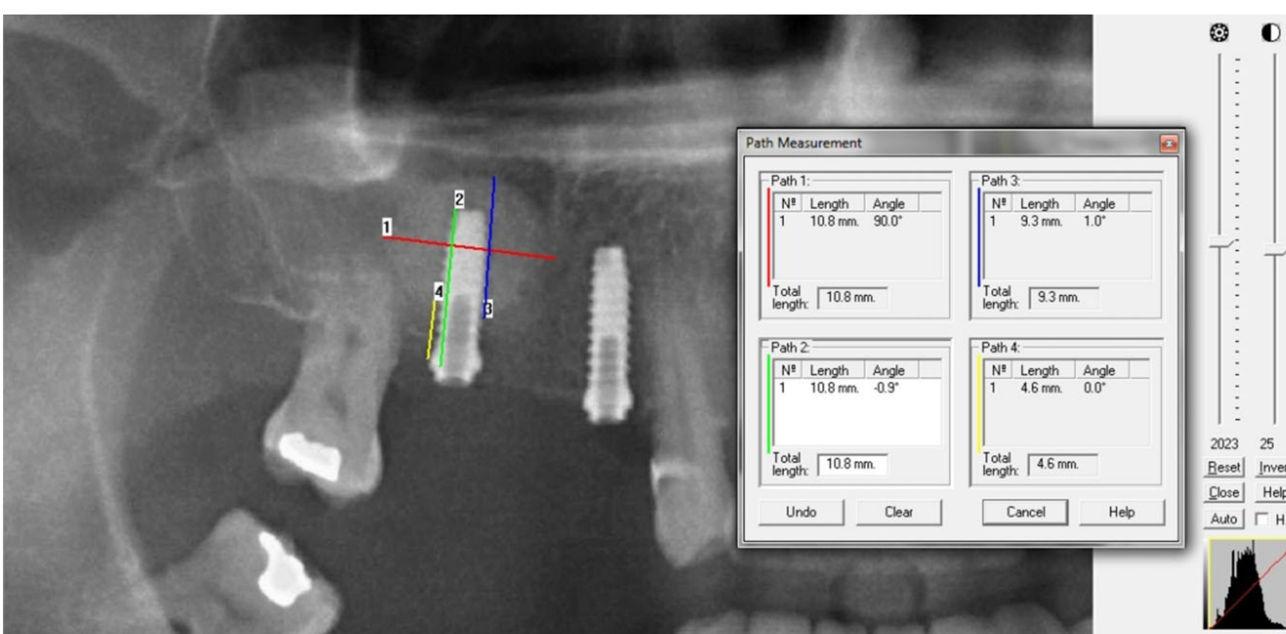

Figure 1 Vertical and horizontal graft dimensions at implant placement stage (baseline).

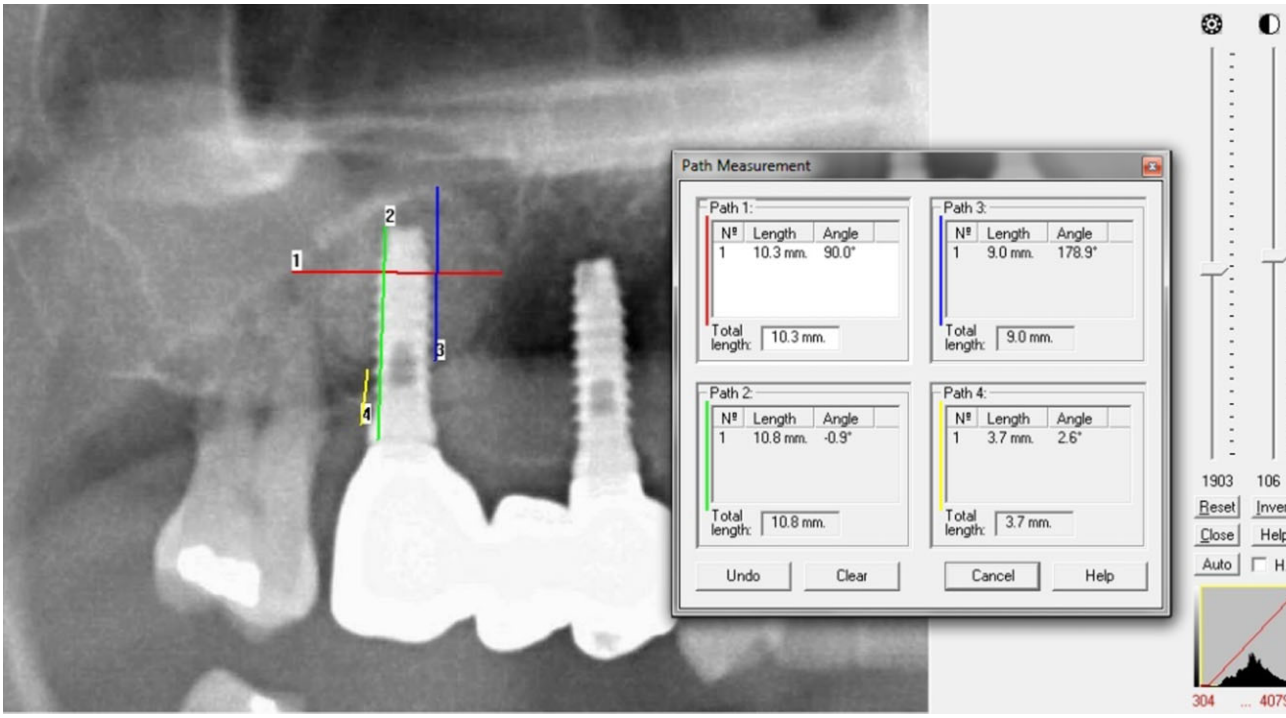

Figure 2 Graft dimensions 6 months after implant loading.

Wald $F = 46.58$, $p < .01$, 0.038 mm/m vs 0.064 mm/m for internal vs external, respectively). No other significant effect was found. Thus, the type of connection was the only factor related to the MBL rate at both mesial and distal sites, while the implantation timing influenced the mesial MBL rate alone.

The horizontal GR rate was significantly affected by the type of connection (Adj Wald $F = 15.81$, $p < .001$),

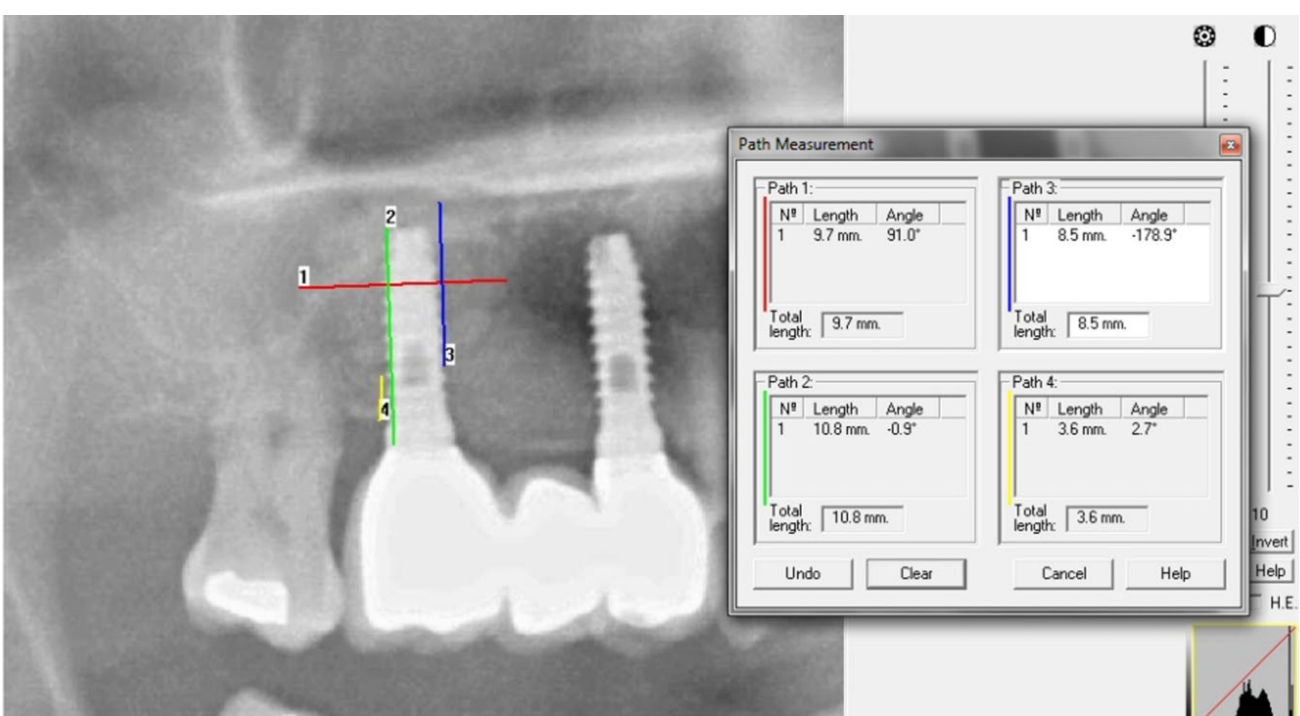

Figure 3 Reevaluation of graft dimensions 18 months after implant loading.

smoking (Adj Wald $F = 14.12$, $p < .001$), remnant alveolar bone height (Adj Wald $F = 23.73$, $p < .01$), graft length (Adj Wald $F = 10.50$, $p = .01$), graft height (Adj Wald $F = 7.77$, $p = .005$), and gender (Adj Wald $F = 23.49$, $p < .01$). However, the vertical GR rate was affected by age (Adj Wald $F = 6.25$, $p = .012$), remnant alveolar bone (Adj Wald $F = 6.47$, $p = .011$), and graft height (Adj Wald $F = 17.06$, $p < .01$). Thus, it seems that the type of connection affected the vertical but not the horizontal GR rate, while remnant alveolar bone and graft height affected both horizontal and vertical GR rates. The GR rates during the first 6 months of follow-up were significantly lower than those during the next 12 months in both the horizontal dimension (0.244 mm/month during first follow-up period [95% CI 0.238–0.249] vs 0.082 mm/month during the second) and the vertical dimension (0.212 mm/month during first period [95% CI 0.201–0.221] vs 0.076 mm/month during the second [95% CI 0.071–0.081]).

When only internal-connection implants were considered, complex samples GLM analysis showed that both mesial and distal MBL rates were significantly affected by the abutment length (mesial: Adj Wald $F = 21.965$, $p < .001$; distal: Adj Wald $F = 9.81$, $p < .001$) and history of periodontitis (mesial: Adj Wald $F = 11.79$, $p = .001$; distal: Adj Wald $F = 17.99$, $p < .001$). However, MBL rates were only significantly affected by abutment lengths ≤2 mm (mesial: rates of 0.061, 0.037, and 0.032, respectively, for lengths of 0.5, 1.0, and 2.0 mm with respective 95% CI of [0.053–0.070], [0.025–0.049], and [0.024–0.040]); distal: 0.054, 0.037, 0.039, respectively, for 0.5, 1.0, and 2.0 mm with respective 95% CI of [0.044–0.064], [0.019–0.055], and [0.031–0.049]).

DISCUSSION

In this study of 254 implants placed in maxillary sinuses grafted with combination of autogenous maxillary cortical bone and anorganic bovine bone, various factors were found to influence the GR and MBL in the short and longer term (6 and 18 months).

Different biomaterials follow different patterns of maturation, and therefore, of resorption. β-Tricalcium Phosphate (β-TCP) has evidenced vertical maturation in sinus augmentation from the remnant alveolar bone,[13,14] whereas allograft[15] or anorganic bovine bone[16] has shown an "implosive" maturation from all walls of the cavity,[17,18] even from Schneider's membrane.[19] Our group has considerable experience with the combination of autogenous maxillary cortical bone and anorganic bovine bone[20] and has gained in-depth knowledge on its maturation in relation to the ratio used,[16] and on the amount of new bone formation, its cellularity,[21] resorption features,[22] and neo-angiogenesis,[23] as well as the influence of patient-dependent clinical variables on its maturation.[24]

Vertical and horizontal graft resorption values were measured at 6 and 18 months after implant loading. Vertical and horizontal resorption rates were only 0.082 mm/month and 0.076 mm/month, respectively, over the whole 18-month period, being especially low over the last 12 months of follow-up. Sbordone found a similar resorptive pattern for anorganic bovine bone, observing a higher resorption during the first year and a lesser resorption during the second year of follow-up.[25] The slow and decreasing resorption of anorganic bovine bone[22] is associated with a reduction in the amount and resorptive activity of osteoclasts.[22] There have even been a number of studies that observed no resorption of these particles over time.[26] A further key factor is the maturation model. If the biomaterial promotes early bone formation in the apical section of the graft, the graft is less likely to collapse due to hyperpneumatization or air pressure. This possibility is also reduced by the presence of mineralized tissue in the apical section of the graft, beneath the Schneider's membrane, and by a lower amount of nonmineralized tissue in the graft. Our composite graft contains a smaller proportion of nonmineralized tissue in comparison with other materials reported in the literature. Finally, functional remodeling would evidently be higher during the immediate postloading period than after the grafted bone has adapted to the functional demands. Successful graft consolidation relies on the progressive apposition of newly formed vital bone, followed by functional remodeling and progressive replacement of the grafting material by vital tissue.[27]

During the first 6 months postloading, dimensional changes were observed in the domed area of the graft. Horizontal and vertical resorption values were higher with longer mesial–distal width of the graft, with a greater horizontal than vertical resorption. This may be due to the particulate nature of the graft, which would be more likely to produce vertical collapse in higher areas through resorption at the base of the graft.

We observed higher resorption, especially vertical resorption, with greater bucco-palatal width of the alveolar crest. Avila and colleagues found that the total percentage of vital bone in maxillary sinus was lower with greater bucco-palatal distance.[28] These results suggest that the proper formation of vital bone requires a longer time period in larger sinuses. Besides the volume of the sinus, resorption can be significantly influenced by various factors including the remnant alveolar bone,[28] the incidence of Schneiderian's membrane perforation,[29] and the size of the lateral window.[30] Until additional data become available, clinicians may consider allowing longer time for sinus cavities with a bucco-palatal distance >15 mm to heal for extended periods of time.[28] There remains a need to test whether there is an eventual formation of homogeneous mature bone in larger cavities or whether larger sinuses are prone to less favorable bone formation.

The second aim of this study was to analyze the bone evolution around the implants placed in grafted sinus. The MBL is a key indicator of implants success or failure. While the osseous support of implants in pristine maxillae is exclusively native bone, peri-implant tissues may also contain remnant graft particles after maxillary sinus floor elevation. Finite element analyses have suggested that the load distribution and MBL around implants placed in grafted sinus cavities may be strongly conditioned by the characteristics of the grafting material.[31–33] Thus, it was observed that when the grafted volume was less stiff than the native bone, functional loading increased the concomitant stress at crestal bone level,[33] which is typically associated with MBL.[34] With regard to the biomaterial composite used in the present study, anorganic bovine bone material behaves in a similar way to autologous chin bone particles in augmented sinus areas except for a much slower resorption rate in comparison with autogenous grafts.[35]

Besides the passage of time, other factors played a significant role in the MBL observed in this study. Mesial and distal bone losses at both 6 and 18 months were significantly greater in Microdent implants (with the external flat-to-flat connection) than in Astra Tech implants (with the internal conical connection) in agreement with previous reports.[36,37] Pozzi and colleagues reported a similar trend in the lower maxilla[38] and our group observed a similar pattern in posterior maxilla pristine bone, which showed a slightly lesser MBL in comparison with the grafted bone in the present study,[6] with the difference in prosthetic connection being a key factor in both types of bone.

Biological width is established around each implant.[39] Conical internal or flat-to-flat connections condition the type of restoration. The height of the prosthetic abutment may play an important role in the maintenance of peri-implant tissue, given that a greater length would provide more space for soft tissue anchorage. In the present study, in Astra Tech (internal-connection) implants, mesial and distal MBL values were higher with shorter abutments at both 6 and 18 months (Table 2A). However, above a critical length of more than 2 mm, we did not found evidence of further diminution of bone loss rates. These results suggest that the optimal abutment length for reducing the MBL may be within the 2 to 3 mm range.

The selection of a simultaneous or differed implant placement depends on the remnant alveolar bone. A simultaneous placement has traditionally been recommended in the presence of 4 to 5 mm of alveolar crest,[40] although a lower threshold has recently been proposed[41] with the advantage of avoiding additional surgery if adequate primary stability can be achieved. Although the implant survival rate is not affected by the timing,[7] it can affect the primary stability[42] and peri-implant marginal tissues. In the present study, a greater mesial and distal MBL at 18 months was observed with simultaneous versus deferred implant placement. In contrast, Rodoni and colleagues[43] found no significant difference in MBL between simultaneous and differed implantation in patients undergoing sinus bone grafting after a mean follow-up of 4.6 ± 1.4 years. Kim and coworkers[44] used a similar composite to the present biomaterial and reported greater MBL with simultaneous versus deferred implants (0.65 ± 0.48 mm vs 0.58 ± 0.57 mm at 12 months) and an increase over time (0.80 ± 0.51 mm vs 0.62 ± 0.54 mm at 20 months), similar to the present findings (Table 1C).[44]

The utilization of cone beam computed tomography to obtain radiographic MBL measurements would have offered greater accuracy and the possibility of performing a three-dimensional analysis but was ruled out for this study to avoid multiple exposures to radiation, as required by the ethical committee of our institution. On the other hand, although periapical radiographs have been preconized as the ideal technique to measure MBL around implants, upper maxilla generates an important limitation to standardize this radiographic technique due to the palatal angulation.

In the contrary, panoramic radiographs allow standardized parallel technique, easier to be reproduced in each temporal frame.

According to our results, the MBL around implants in regenerated bone increases over time and is influenced by multiple factors including the age and tobacco habit of the patient, the height of the prosthetic abutment, type of prosthetic connection, and the timing of the implant placement. Peri-implant tissue health and stability is mandatory to control the MBL, and further research is required to clarify the role of the above factors in this process.

CONCLUSION

Resorption of grafts composed of autogenous cortical bone combined with anorganic bovine bone could be dependent on the anatomic features of the sinus and is negligible after the first 6 months postloading. MBL around implants placed in these grafted areas is time dependent and largely related to potentially modifiable clinical decisions and patient habits.

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