Histomorphometric Analysis of Human Maxillary Sinus Lift with a New Bone Substitute Biocomposite: A Preliminary Report

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ABSTRACT

Purpose: To analyze radiographic and histological outcomes of maxillary sinus floor augmentation using a calcium-sulfate based allograft containing demineralized bone matrix particles.

Materials and Methods: Fifteen maxillary sinus lift procedures with simultaneous placement of titanium implants were performed in 12 patients of both genders aged 36–71 years. Each sinus cavity was filled by the biocomposite. After 3 months of healing, all surgical sites were uncovered and bone biopsies were retrieved for undecalcified histology and histomorphometry. The ratio between the original and the grafted sinus height (GSH/OSH) was computed using a panoramic radiography taken immediately after surgery and at 3 months of healing, and the two ratios were compared by Wilcoxon signed-rank test.

Results: By 3 months, all implants were stable without clinical and radiographic signs of infection. Significant changes in GSH/OSH during healing were seen (2.7 ± 0.6 initially vs. 2.6 ± 0.5 after healing; $p = 0.01$). Histologic findings showed newly formed bone surrounding the residual grafted particles without inflammation. At 3 months, mean regenerated bone density was $33.8 \pm 8.6\%$; marrow spaces amounted to $32.3 \pm 10.3\%$; residual graft was $33.9 \pm 9.0\%$. Similar histomorphometric and radiographic results were obtained independently from patient age or sex.

Conclusions: The analysed putty seems to be a safe and effective graft material for maxillary sinus floor augmentation by accelerating bone regeneration and thus reducing the healing time.

KEY WORDS: allograft, histology, maxillary sinus floor augmentation

INTRODUCTION

The restoration of masticatory function in edentulous patients by using endosseous dental implants has become a predictable treatment.[1–3] Also, bone augmentation at the inferior aspect of the maxillary sinus may be performed to accept dental implants in severely resorbed alveolar ridges.[4–9] Although the surgical techniques of creating an appropriate base for implantation of biomaterials in the floor of the maxillary sinus are well described,[5,6,10] the research on which material is best suited for augmentation undergoes constant development.[11,12]

At present, fresh intraoral and extraoral (iliac, calvaria) autologous bones remain the most effective graft material, demonstrating a high capacity to promote osteogenesis and an optimal ability to become incorporated without immunologic sequelae.[7,9,11–13] Nevertheless, autologous bone grafts require a second surgical exposure to harvest the graft with a significant risk of postoperative diseases and a decreased mechanical strength at both intraoral and extraoral donor sites.[13,14] Consequently, alternatives to autogenous grafts continue to be investigated. Several choices are available to the clinician including allogenic, xenogenic, and a variety of alloplastic synthetically derived materials.[9,11] According to recent reviews, the most extensively studied bone substitutes are the tricalcium phosphate ceramics[3,9,14] and the deproteinized bovine bone[8,15]; both

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materials are slowly resorbable/nonresorbable, thus allowing the new bone to mature. Alloplastic and xenogenic bone grafts act as mechanical spacers to prevent soft tissue in-growth, which would be detrimental to osteogenesis and healing, but they do not provide the osteogenic elements.[5,13] To promote osteogenesis, researchers added particles of autologous bone or bone marrow components to the xenograft.[4,5]

The demineralized bone matrix (DBM) is a bone graft substitute, capable of enhancing bone regeneration by releasing osteoinductive factors.[5,16] The demineralized bone implants are processed by acid extraction, which removes the mineral matrix and some organic matrix, and theoretically maximizes the bioavailability of bone morphogenetic proteins (BMP). The BMP are responsible for a biologic cascade consisting of chemotaxis and attachment of mesenchymal cells to the matrix, cell proliferation, and differentiation of cartilage, bone, and marrow.[16] DBM shows a rapid osteoinductive activity without a delayed graft resorption, particularly beneficial during craniofacial augmentation surgery. Unfortunately, the DBM does not possess ideal handling characteristics or sufficient structural strength for some grafting procedures. Therefore, DBM is sometimes mixed with stiffer biomaterials such as non-demineralized bone allograft or xenograft to obtain a final putty-like consistency.[5,8,16] Simple handling and adequate form are considered important features of bone substitutes.[5,13] For example, the particulate forms of such materials amplify the tissue reaction because of the greater surface areas available to interact with the recipient bed.[17] Calcium sulfate is a highly biocompatible synthetic bone substitute that has been successfully used in maxillary sinus lift for more than 100 years.[18] It mimics the mineral phase of bone and it has a rapid rate of resorption, thus allowing an early ingress of osteoprogenitor cells.[11,18]

The present study aimed to analyze the radiographic and histological outcomes of maxillary sinus floor augmentation using a calcium sulfate-based bone allograft biocomposite, consisting of a freeze-dried DBM powder. This osteoinductive and osteoconductive biomaterial was already tested and proved to be safe and efficient in orthopedic and craniofacial reconstructive surgery,[19–22] but it has never been employed for oral implant surgery. In both experimental histologic and previous clinical/radiographic orthopedic studies,[20,22] a considerable amount of new bone was found 3 months after the use of the allograft. Therefore, the working hypothesis of the current investigation was to find the presence of newly formed bone approximately 3 months after implantation of this allograft in maxillary sinus lift, mimicking the protocol used in orthopedic surgery.[20,22]

MATERIALS AND METHODS

Patients

There were a total of 12 nonsmoking patients, six of each sex, aged 36–71 years (mean age 54.1 ± 12.8), with maxillary partial edentulism involving the premolar/molar areas participating in the study (see Table 1).

TABLE 1 Patient Demographic and Clinical Data

Patient	Age (years)	Operated Side	Healing (months)	Implants (n)
F1	60	Bilateral	2.5	4
F2	70	Left	2.5	1
F3	57	Right	3	3
F4	41	Bilateral	3	4
F5	59	Right	3	2
F6	71	Right	2	3
M1	58	Left	3	3
M2	39	Left	3	2
M3	65	Right	2.5	2
M4	36	Right	3	4
M5	36	Right	3	2
M6	57	Bilateral	2.5	6
Mean	54.1		2.8	3.0
SD	12.8		0.3	1.3

The selected subjects were either completely or partially edentulous in the maxillary molar region and showed atrophy of the posterior maxillary alveolar process. All patients had no craniofacial trauma or previous surgery in the involved area and were in general good health, free from systemic, periodontal, and maxillary sinus diseases. After the initial clinical examination, a panoramic radiography was performed in each subject. A clinical intraoperative measurement of the maxillary alveolar ridge using a specific caliper revealed a residual crestal bone height of 4–5 mm. All patients underwent a unilateral (nine patients) or bilateral (three patients) maxillary sinus lift with a lateral window procedure and the use of a bone allograft biocomposite (Allomatrix Injectable Putty, Wright Medical Technology, Inc., Arlington, TN, USA).

Prior to the commencement of the treatment, all patients gave their written informed consent to participate in the research. The study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki (version, 2002) and was approved by the Ethical Committee of the Department of Human Morphology (University of Milan, Italy).

Surgical Procedures

Bilateral interventions were performed in three patients, for a total of 15 maxillary sinus augmentations. For all cases, a one-stage approach, which included sinus lifting and implant placement, was conducted according to Tatum.[6] All surgeries were performed by a single experienced oral surgeon in a private practice. After mouth rinsing with chlorhexidine digluconate solution 0.2% for 2 minutes, a mid-crestal incision and two buccal releasing cuts were performed under local anesthesia. A full-thickness flap was elevated to expose the alveolar crest and the lateral wall of the maxillary sinus. Using a round bur under sterile saline solution irrigation, a trap door was made in the lateral sinus wall. The buccal door was rotated inward and upward with a top hinge to a horizontal position. The sinus membrane was delicately elevated until it became completely detached from the lateral and inferior wall of the sinus.

Each site received one to four titanium oxidized implants of at least 11 mm in length and of 4–5 mm of diameter (Bio-micron s.a.s, Limbiate, Italy). The implants had an external exagon made of pure titanium cleaned by titanium sandblasting combined with acid etching, decontaminated through radio-frequency, and then sterilized by gamma radiation (25 kg). They are provided by manufacturers in a titanium hose and are protected by a sealed glass vial, which maintains a 5-year period of sterility. A total of 36 endosseous implants were inserted in the sites correspondent to the elevated sinus cavity.

After placement of the implants, the grafting components were mixed for about 30–60 seconds by combining a blend of powdered surgical-grade calcium sulfate hemihydrate DBM (86% by volume, bioassayed) with a solution of sterile water to obtain a putty-like consistency. The allograft mixture (about 2 mL) was carefully packed in the sinus cavity to completely fill the compartment. The surrounding mucosa was then carefully mobilized and closed over the implants. No membrane was used to close up the buccal window. A panoramic radiography was taken immediately after surgery. Antibiotics (1 g of amoxicillin twice a day) and analgesics were given for 1 week. Sutures were removed 2 weeks after surgery. During the postoperative period, the patients were followed up at monthly intervals.

After a healing period of 2.5–3 months, the reentry procedure was performed. During the uncovering stage, panoramic radiographs and bone biopsies were taken. Cores of bone were harvested horizontally (4 mm in depth) from the distal part of each grafted site by a 3 mm (outer)–diameter trephine burr (inner diameter 2 mm) for undecalcified histology and histomorphometry. Attention was given to take the biologic material from the grafted area. Therefore, 15 bone biopsies were totally retrieved.

Abutment connection was then performed, and fixed prosthetic restorations were fabricated.

One year after prosthetic loading, clinical examinations with peri-implant probing and percussion test were conducted to assess implant stability and survival.

Histologic Processing and Histomorphometry

The graft biopsies were immediately fixed in 10% formalin/0.1 M phosphate buffer saline solution (PBS, pH 7.4) at room temperature. The specimens were then dehydrated in ascending grades of ethanol (70, 80, 90, 95, 100%) and embedded in a polymethyl-methacrylate resin (Kulzer Technovit 7200 VLC, Bio-Optica, Milano, Italy). The undecalcified cores were cut to obtain two ~250 μm thick longitudinal sections in bucco-lingual direction and subsequently ground (Micromet & LS2, Remet, Bologna, Italy). The sections were mounted on

plastic slides using an adhesive layer, to a final total thickness of about 80 μm and stained using toluidine blue/pyronine G (Sigma-Aldrich, St. Louis, MO, USA). All slices were examined with a Nikon light microscope (Eclipse E600, Nikon, Tokyo, Japan) equipped with a calibrated digital camera (DXM1200, Nikon). For histomorphometric analysis, the volume fraction of different tissues was computed according to the Delesse formula, $V_V = P_P$. The volume fractions (V_V) of residual allograft (V_VA) of new bone (V_VB) and of connective tissue/marrow spaces (V_VC) were calculated by a computer-assisted differential point counting technique.[23] A lattice grid consisting of 100 test points was placed over each microscopic field to be analyzed at a microscopic magnification of ×100. The tissue underlying each grid intersection was recorded as either new bone, residual graft, or connective tissue/bone marrow spaces. The number of hits containing new bone, grafted particles, or connective tissue/bone marrow spaces were separately divided by the total number of possible intersections and thus expressed in percentage values representing the volume density of these 3 components. The number of hits containing new bone, grafted particles, or were separately divided by the total number of possible intersections, and thus expressed in percentage values represent the volume density of these three components.

Radiographic Assessment

Using a digital ruler, the alveolar ridge height at the maxillary sinus floor was measured on both the panoramic radiographies performed immediately post-surgery and on those made during the reentry procedure (after approximately 3 months of healing). The following variables were calculated according to Hatano and colleagues[24]: (1) original sinus height (OSH), defined as the distance from the intraoral marginal bone to the lowest point of the original sinus floor; and (2) grafted sinus height (GSH), defined as the distance from the intraoral marginal bone to the grafted sinus floor directly above the lowest point of the OSH. To avoid problems arising from distortion of panoramic films, the GSH/OSH ratio was computed for each radiograph; a value of 1.0 or higher indicates that the grafted sinus floor is above the original sinus floor.

Outcomes Evaluation

To measure the outcome of augmentation at 3 months of healing, the following success criteria were used: (1) clinical: good healing without complications, implant stability by percussion test (tapping of a mirror handle against the implant carrier may elicit a ringing sound from the implant as an indication of good stability),[25] no sinus membrane perforation (assessed using the Valsalva maneuver) and related complications (acute or chronic sinus infection, bacterial invasion, swelling, bleeding, wound dehiscence, loss of the graft material, and/or a disruption of normal sinus physiologic function),[26] no mucosal recession, and no suppuration or pain; (2) radiographic: no linear lucencies at the interface between the graft and the new bone, small volume reduction of the grafted sites; and (3) histologic: presence of new bone and remodeling activity of the allograft.

Data Analysis and Statistical Calculations

For the ratios between the OSH and the GSH (GSH/OSH), and for each histomorphometric parameter, means and standard deviations were calculated for the overall group of patients. Comparisons between GSH/OSH ratios computed immediately post-surgery and 3 months post-surgery were performed by Wilcoxon signed-rank test. A level of significance of 5% ($p \leq .05$) was used.

To assess the size of the differences between the two GSH/OSH ratios (immediately post-surgery and 3 months post-surgery), the Cohen's *d* test was applied.

RESULTS

During surgical procedures, no perforation of the schneiderian membrane and related complications were observed in the analyzed 12 patients. Primary stability was reached for all implants. The putty formulation used in the current study demonstrated an ideal consistency facilitating a rapid and simple packing of the graft into the sinus cavity, as reported by the oral surgeon.

After a mean healing period of 2.8 ± 0.3 months, all 36 implants were clinically stable, without signs of infection. No patient complications were reported. Abutment connection was performed after an average healing time of 3.5 months and fixed prosthetic restorations were fabricated in all patients. All implants were followed up for 1 year and there were no patient drop out. Peri-implant pocket depth did not change significantly during the follow-up period. At 1-year clinical assessment, no implant was lost.

TABLE 2 Radiographic and Histomorphometric Measurements in the Operated Sites

Patient	Sinus	Maxilla Side	GSH/OSH t0	GSH/OSH t1	New Bone %	Connective Tissue/Bone Marrow %	Residual Graft %
F1	1	Right	2.6	2.4	41.7	22.8	35.6
F1	2	Left	2.4	2.3	41.6	24.5	33.9
F2	3	Left	2.5	2.3	24.8	29.3	45.9
F3	4	Right	3.2	3.1	16.6	32.5	50.9
F4	5	Right	2.9	2.7	20.6	51.2	28.2
F4	6	Left	2.7	2.7	27.8	42.7	29.6
F5	7	Right	2.1	1.9	37.5	38.2	24.3
F6	8	Right	2.8	2.6	33.3	45.0	21.7
M1	9	Left	2.6	2.5	35.4	19.3	45.3
M2	10	Left	2.5	2.4	25.4	48.8	25.8
M3	11	Right	2.4	2.3	40.2	30.2	29.6
M4	12	Right	2.6	2.3	42.6	24.6	32.8
M5	13	Right	2.4	2.4	37.6	23.1	39.3
M6	14	Right	2.3	2.2	40.7	29.2	30.1
M6	15	Left	4.5	4.2	41.6	26.8	31.6
Mean			2.7	2.6	33.8	32.3	33.7
SD			0.6	0.5	8.6	10.3	8.4

GHS, grafted sinus height; OSH, original sinus height; t0, immediately after surgery; t1, about 3 months after surgery.

In the panoramic radiography performed 3 months post-surgery, no linear lucencies (fractures and subsequent displacement), changes in position, radiolucency at the graft-host junction, and dissociation between the graft and the native bone were observed.

All maxillary sinuses demonstrated a GSH/OSH ratio higher than 1.0 at both radiographic measurements. In the immediate postoperative panoramic radiography, the GSH/OSH mean ratio was 2.7 ± 0.6; about 3 months after surgery, the GSH/OSH mean ratio was 2.6 ± 0.5 (see Table 2; Wilcoxon signed-rank test, $p = .01$; see Figure 1). A small size effect (Cohen's $d = 0.18$) was found.

Upon histological examination, no inflammatory cells or foreign body reactions were observed within the 15 bone biopsies. In all augmented sites, newly formed bone appeared to have incorporated the putty, mostly in proximity of the reforming buccal cortex (see Figure 2A). In several specimens, the bone showed a woven bone structure with typical large and scattered osteocyte lacunae (Figure 2B); in some areas, the new bone resembled a mature lamellar structure composed of large trabeculae and osteons interconnecting and surrounding the DBM particles. Four biopsies contained a few calcium sulfate carrier remnants. A well-vascularized intertrabecular bone marrow penetrated the grafted biocomposite with subsequent new bone in-growth (Figure 2C). Several areas of bone remodeling, with scalloped appearance and cement lines were noticed next to the residual grafted particles (Figure 2D).

Table 2 reports the percentage area occupied by new bone, connective tissue/bone marrow, and residual grafted particles in all specimens. Regenerated bone, connective tissue/marrow spaces, and residual graft occupied each about 1/3 of the bioptical volume. Similar histomorphometric and radiographic results were obtained independently from patient age or sex.

DISCUSSION

Bone grafting is a dynamic phenomenon implying application, healing, incorporation, revascularization, and adaptation of the graft within the biologic structures. The healing time principally depends on the graft capability to enhance bone regeneration. Previous studies demonstrated that allogenic grafts may be successful in oral and maxillofacial surgery.[5,11] The major advantages of the use of demineralized bone implants are the shortened operative time compared with autogenous bone graft, the potentially unlimited supply of

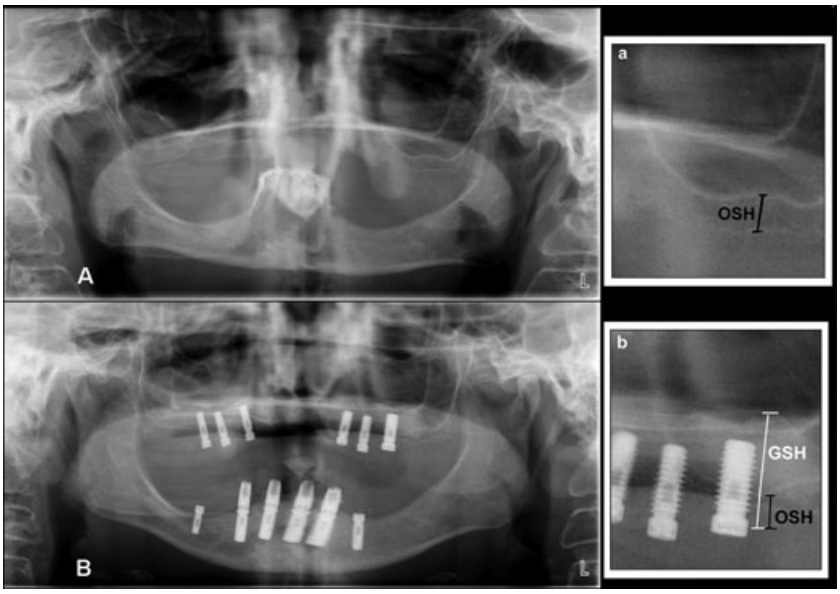

Figure 1 Presurgery (A) and immediately postoperative (B) panoramic radiography in a patient. Particular radiographic measurements are reported for exemplification in the presurgery (a) and in the immediate post-surgery (b) panoramic radiography. OSH: original sinus height; GSH: grafted sinus height. In the maxillary arch six implants were positioned; only one implant was placed in the maxillary sinus grafted area (left side).

banked material, the rapidity of osteoinductive process, and the potential avoidance of late graft resorption.[27] Aside from this, the actual potential of inducing new bone formation is still debated upon.[12] In addition, the allografts are easy to use and stimulate healing within 3 to 6 months, thus providing stability in maxillofacial regions within weeks.[5,11] Processing and formulation changes are continuously proposed to improve DBM activity and clinical handling by the adjunctive use of specific biocompatible carriers.[28]

In the present report, the effect of a calcium sulfate-based bone allograft containing DBM was tested in the maxillary sinus augmentation. To better assess the osteogenic potential of the allograft, no membrane was used to close up the buccal window of the maxillary sinus. Resorbable membranes are frequently placed over the window to prevent graft from soft tissue invasion, thus improving the bone quality of regenerated bone.[29]

Clinically, a good handling of the biomaterial during the packing into the subantral spaces and a reduced uneventful period of healing were observed in all patients, independently from age. The fast-resorbing carrier permitted a simple localization of the grafted particles, a hard physical binding, and a rapid consolidation of the DBM particles which precluded the wash out as a consequence of surgical irrigation and bleeding. The quantity of the carrier in the Allomatrix putty was minimal, thus allowing the insertion of a large volume of DBM particles. The high density of grafting material, together with the placement of a large amount of grafted particles, allowed space maintenance and bone regeneration in all surgical sites in accordance with the previous studies in long bone defects repair.[20–22] Indeed, previous investigations have studied and proved the efficacy and biocompatibility of Allomatrix putty in bone restoration of large critical size defects in canine and human long bones.[20–22] Few studies concerning the use of Allomatrix graft in craniofacial surgery have been published,[19,28] but in no occasion has sinus lift been considered. Nevertheless, the basic principles of bone grafting are the same in orthopedic, maxillofacial, and plastic surgery.

Assessments of outcome of bone grafts are usually performed using radiographic qualitative and quantitative analyses.[4,5,24] In the current study, radiographic images showed no signs of complications. The morphometric analysis showed significant differences in the maxillary sinus floor height, immediately post-grafting (GSH/OSH: 2.7 ± 0.6) and 3 months later (GSH/OSH: 2.6 ± 0.5). Although these differences reached the statistical significance, their clinical relevance is limited, as demonstrated by a small effect size (Cohen's $d = 0.18$). The present data are comparable with those reported by Hatano and colleagues[24] in the first 6 months, following

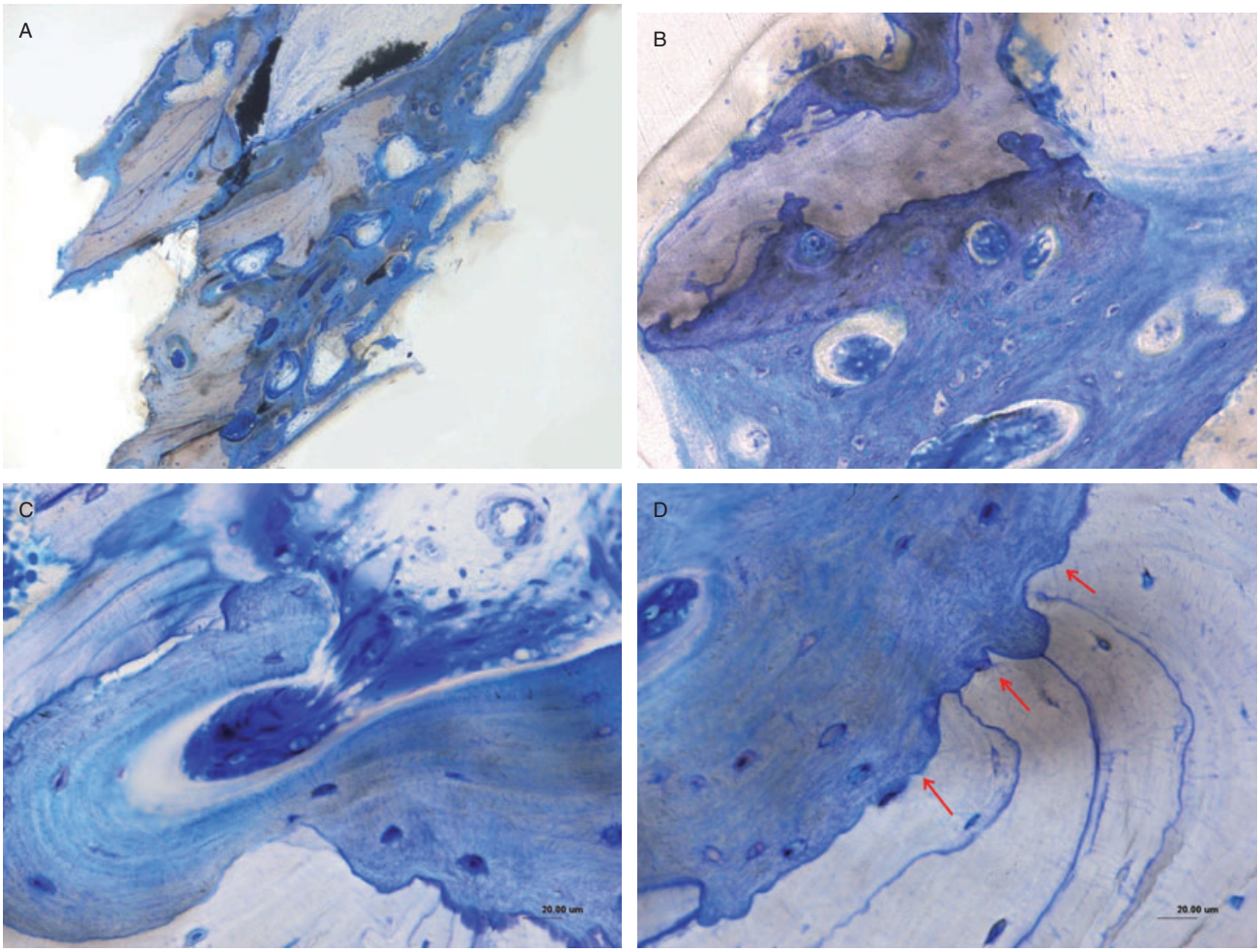

Figure 2 *A*, Overview of one histologic specimen. Newly formed bone (in blue) is invading the grafted particles (in purple). Toluidine blue/pyronine G, original magnification ×40. *B*, The grafted particles (in purple) are incorporated into the regenerated bone with a prevalent woven bone structure (in blue). Toluidine blue/pyronine G, original magnification ×100. *C*, An ongoing bone formation is visible in the grafted areas exposed to bone marrow. Original magnification ×400. *D*, Interface between the new bone (in blue) and the grafted material (in purple) as indicated by red arrows. Original magnification ×400.

a sinus lift augmentation with an autologous bone/xenograft mixture (GSH/OSH: 3.5 ± 1.7). Within the limits of a two-dimensional assessment, the variations of the bone-grafted height provide an estimate of total bone volume resorption, because height represents the principal direction of bone reduction with time.[30] Nevertheless, this shows the limited clinical information that can be obtained from conventional radiographic examinations.

After 3 months of healing, the present histomorphometric results showed a considerable amount of new bone formation in the specimens treated with the Allomatrix putty. The average regenerated bone volume (about 34%) was larger than new bone fractions obtained at 6 months of healing in specimens treated with either a deproteinized bovine xenograft (Bio-oss, about 21%)[10,15] or β-tricalcium phosphate (β-TCP, 17–19%),[9] thus demonstrating the effectiveness of bone regeneration with Allomatrix putty and a significant advantage in terms of time. In addition, the mean percentage volume of regenerated bone found in the current study is comparable with the new bone volume fractions measured 12 months after sinus floor augmentation using a 100% β-TCP ($36.47 \pm 6.9\%$).[14] Similar values of new bone volume were reported in grafted sinus with autologous bone particles at 6 and 12 months after surgery (32–56%).[9,14]

The higher average regenerated bone volume obtained with the present biocomposite compared with other cited bone substitutes (TCP, Bio-oss, etc.) could be due to the large amount of osteoinductive growth factors, as further discussed. Autogenous bone is always

the gold standard, even if different quantities of new bone have been reported in the literature; donor sites, embryologic origin of the graft, time of healing, time of prosthetic loading, and histomorphometric method are some of the major factors influencing the new bone volume. However, the histomorphometric analyses are based on core biopsies, which might have a limitation, because the core may not be representative of the rest of the regenerated volume in the sinus.[31]

In some areas of the present biopsies, the regenerated bone resembled a mature lamellar structure composed of osteons, as already found by Gotz and colleagues[32] in specimens treated with a nano-structured hydroxyapatite, about 4 months after alveolar bone regeneration.

In a review about bone additives in sinus lift, Merkx and colleagues[13] concluded that 3 to 4 months of healing period after grafting may be adequate, and eventual extension after 6 months can lead to progressive bone resorption. Also, the healing time may depend on the simultaneous placement of implants which can interfere with bone graft healing, because of the osteoinductive and/or osteoconductive properties of the implant surfaces.[13] Aside from this, early prosthetic loading can reduce graft remodeling and subsequent resorption according to functional adaptation principles.[33]

The present outcomes are in accordance with radiographic and histologic data reported by Turner and colleagues[20] in a canine model. At 6, 13, and 26 weeks of healing, the authors found comparable area fractions of new bone when comparing the Allomatrix putty and an autologous cancellous bone graft.[20] Similarly, Wilkins and Kelly[22] referred that Allomatrix putty was as effective as an autologous bone in achieving near complete bony restoration of critical-sized defects in human long bones. At 6 months of healing, Turner and colleagues[21] showed a large area fraction of new bone with no apparent residual calcium sulfate in any of the histological sections. In contrast, in regeneration of calvarial bone defects, Acaturk and Hollinger[28] observed that Allomatrix putty produced less new bone than DBM particles alone, or other bone graft substitutes. The stringency of recipient site and the amount of delivered grafted particles could have altered the findings.[28]

Considering the remnants of bone substitute, the current global amount of residual calcium sulfate (almost completely resorbed) and DBM was comparable with the histometric data by Scarano and colleagues,[11] who found a 34% average volume of DBM particles at 6 months post-grafting. DBM is regarded as a slowly resorbable biomaterial, with areas of different mineralization and new bone with colonizing cells.[27] Indeed, allografts are incorporated into existing bone by a process similar to that of autogenous bone grafts, but proceed more slowly as a result of the absence of living cells.[12]

The current findings are in contrast with the histologic observations by Valentini and Abensur,[8] who found no newly formed bone on the surface of DBM graft in three human maxillary sinus elevations. The different DBM formulation used in the studies could have influenced the graft behavior. Schwartz and colleagues[5] demonstrated that DBM alone, or in combination with other materials, can be used successfully for sinus floor elevation (about 18% of new trabeculated bone), although the association with β-TCP resulted in 50% less bone than with other preparations. The content of a large amount of osteoinductive growth factors (BMP-2, TGF-β1, IGF-1, FGFacidic, VEGF, and PDGF) may explain the behavior of the analyzed putty. These growth factors were detected in several DBM formulations, even if a great variability in their concentration was found between different commercial lots. The effectiveness of the bone substitute might differ depending on age and gender of the donor, residual mineral, particle size, and preparation method.[16] The growth factors found in Allomatrix putty have mitotic, chemotactic, and differentiating effects on cells, and can also stimulate the synthesis of further growth factors, enabling a rapid and reliable bone repair through the process of endochondral ossification.[16] Also, the Allomatrix putty is sterilized with electronic beam radiation without the risks of viral and bacterial transmission.[22]

One of the limitations of the current study may be the reduced sample size when compared with previous radiographic and clinical investigations.[24] Nevertheless, the present number of biopsies is well comparable with that reported in several previous histologic reports.[5,8,9,11,14,15]

Also, there were no control sites in the present study. Therefore, the histomorphometric results were compared with published data, which – notwithstanding some differences in the experimental design (eg, one-step or two-step implant positioning, residual crestal bone height) – were performed with similar methodologies in the quantification of tissue components.[5,8,9,11,14,15]

CONCLUSIONS

Within the limits of the study, our results suggest that Allomatrix putty can be a safe and effective graft material for maxillary sinus floor augmentation by enhancing bone regeneration, as shown by the presence of new bone approximately 3 months after implantation. In addition to that consistent reduction of healing time, this specific formulation demonstrated an ideal consistency facilitating a rapid and simple packing of the graft into the sinus cavity. Further prospective studies with a 5-year follow up should assess long-term implant stability and survival.

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CONFLICTS OF INTEREST STATEMENT

The authors have declared no conflicts of interest. [Correction added after online publication 23 October 2009: Conflicts of Interest Statement added.]

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