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Maxillary sinus floor augmentation using bioactive glass granules and autogenous bone with simultaneous implant placement

Clinical and histological findings

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Abstract: This clinical study was undertaken to: 1) evaluate the use of bioactive glass Biogran™ combined with autogenous bone as grafting material for maxillary sinus augmentation with simultaneous implant placement using radiography and histology; and 2) document the short-term post-loading success of implants inserted in sinus cavities augmented with this material. Unilateral or bilateral sinus augmentation was performed in 12 patients with 3–5 mm of alveolar crestal bone height in the posterior maxilla prior to grafting. The sinuses were grafted with bioactive glass mixed in a 4:1 ratio with autogenous bone. Simultaneously, 2–3 threaded titanium implants were inserted into the augmented sinuses. Second stage surgery was carried out 9 to 12 months post implantation. At abutment connection, 10 core biopsy specimens were taken from different grafted sites and evaluated histologically. All 27 implants were clinically stable at second stage surgery. A mean increase in mineralized tissue height of 7.1 ± 1.6 mm was evident when comparing the pre-surgical CT scans with those performed 9–12 months following the sinus augmentation procedure. Evaluation of the cores yielded a mean of $30.6 \pm 5.7\%$ of bone tissue in the grafted sites. One implant failed during the prosthetic phase while the remaining 26 implants were stable 12 months post loading. This study suggests that Biogran™/autogenous bone graft combination used in one-stage sinus augmentation yields sufficient quality and volume of mineralized tissue for predictable simultaneous implant placement in patients with 3–5 mm of bone height prior to grafting.

Sinus grafting procedures using autogenous bone and other bone substitutes have been shown to be a safe technique with high predictability of success (Hirsch & Ericsson 1991; Misch et al. 1991; Smiler et al. 1992; Raghoebar et al. 1993; Betts & Miloro 1994; Hürzeler et al. 1996). Various bone grafting materials have been used in sinus augmentation including autogenous grafts (Hirsch & Ericsson 1991; Raghoebar et al. 1993; Lundgren et al. 1996), freeze-dried bone allografts (Smiler et al. 1992; Nishibori et al. 1994), hydroxyapatite (Wagner 1991; Moy et al. 1993; Wheeler et al. 1996), and xenografts (Smiler et al. 1992; Valentini & Abensur 1997). Although the results of these investigations indicate that sinus augmentation is clinically successful with various graft materials, it is not established which of these materials, except for autogenous bone, provide better osteogenic potential and biomechanical properties. Autogenous bone remains the material of choice currently available for bone reconstructive procedures (Wood & Moore 1988; Hirsch & Ericsson 1991; Moy et al.

1993). However, its use can be limited for the following problems: a) donor site morbidity; b) limited amounts of graft material that can be harvested intraorally; and c) need for general anesthesia for bone harvesting from extra-oral sites in cases of major augmentation procedures.

Recently, bioactive glass has been subjected to intensive experimental and clinical use as a bone substitute in periodontal and various osseous reconstructive applications (Schepers et al. 1991; Schepers et al. 1993; Wilson et al. 1993; Furusawa & Mizunuma 1997; Low et al. 1997; Schepers & Ducheyne 1997). Biogran™ is a resorbable amorphous bioactive glass of 300–355 μm particle size. It is composed of 45% silicon dioxide (SiO_2), 24.5% calcium oxide (CaO), 24.5% sodium oxide (NaO_2), and 6% phosphorous pentoxide (P_2O_5). It has been shown to enhance bone repair not only by the osteoconductive properties of the particles, but also by their osteostimulative potential defined as bone formation within internal pouches excavated within the bioglass particles away from the pre-existing bony defect walls (Schepers & Ducheyne 1997).

The aim of the present study was to clinically, radiographically and histologically evaluate the use of Biogran™ grafting material in maxillary sinus elevation procedures with simultaneous implant placement in humans. It was also the purpose of this report to document the short-term clinical success of fixtures inserted in the sinus cavities augmented with Biogran™.

Material and methods

Preoperative evaluation
Twelve patients were selected for the sinus elevation and implant placement procedure based on the following inclusion criteria: 1) maxillary total or partial (unilateral or bilateral) edentulism involving the premolar/molar areas; and 2) presence of 3–5 mm of bone from the edentulous crest level to the maxillary sinus floor as evidenced at the baseline preoperative radiographic examination. The following patients were excluded from the study: a) smokers; b) patients with systemic contraindications to oral

surgical procedures and implant therapy; c) patients with recent extractions (less than 1 year) in the involved area; d) patients with thin ridges which may not allow immediate primary stability; and e) patients with ongoing pathology of the maxillary sinus.

At the initial visit, all patients received a radiographic (periapical and panorex), clinical and occlusal examination. Computerized tomographic (CT) scans were carried out in all patients using surgical stents with radiopaque markers in the planned position of the fixtures. The radiographic criteria of thickness (≥ 4 mm) and height (3–5 mm) of the remaining alveolar bone below the sinus floor were re-assessed more accurately on the CT scans.

Surgical technique
Immediately prior to surgery, the patients were asked to rinse with a chlorhexidine digluconate solution 0.2% for 2 min. A horizontal antero-posterior incision was made slightly palatal to the alveolar crest and supplemented by buccal releasing incisions at the anterior and posterior ends of the horizontal incision. Full-thickness flaps were elevated to expose the alveolar crest and the lateral sinus wall. Soft tissue was carefully removed within the implant sites. An oval-shaped osteotomy, with the inferior border about 5 mm superior to the alveolar bone margin, was made on the lateral aspect of the sinus wall using a fissure bur with generous saline irrigation to ensure access to the sinus cavity (Fig. 1a). The bone in the center of the window was then gently infractured with its most superior part left intact creating a trapdoor effect. The sinus membrane was carefully elevated and the trapdoor including the elevated sinus membrane was rotated inward and upward. With curettes of different shapes, the sinus membrane was gradually detached along the inferior wall of the sinus and as far as the medial wall. The vertical height of the alveolar bone below the sinus floor was measured. Perforations in the anterior wall of the sinus were made when possible. Preparation of the threaded fixture sites (3i, Implant Innovations Inc., Palm Beach Gardens, FL, USA) was undertaken using surgical guides and according to the standard

clinical procedures for the implant system. The quality of bone present at the implant sites was specified according to Lekholm & Zarb (1985). If perforation of the sinus membrane occurred during the procedure, a collagen membrane was used to seal it and ensure confinement of the graft material.

Two intraoral donor sites, the mandibular symphysis or the maxillary tuberosity, were used to harvest the autogenous bone grafts. For the mandibular grafts, the mandibular symphysis was exposed through a two-layer incision made between the deepest part of the vestibule and the lip. Multiple circular unicortical cuts were made through the buccal cortex using a 5 mm diameter trephine under abundant saline irrigation. The lingual cortical plate was left intact. The cuts were made at least 5 mm inferior to the root apices of the mandibular anterior teeth and 4 mm superior to the mandibular inferior border. The corticocancellous bone cores were stored in saline solution until particulated with a surgical bone mill (Biomix, Geistlich Söhne AG, Wolhusen, Switzerland). The residual symphyseal cavity was packed with a hemostatic agent (Spongostan, Johnson & Johnson Medical, Skipton, UK). The periosteum and muscle attachments were carefully sutured in one layer, and the mucosa closed as a second layer using resorbable sutures. In cases where a smaller quantity of grafting material was needed, bone cores were harvested from the posterior tuberosity area using a 2 mm diameter trephine and particulated using a bone rongeur.

A composite graft of about 70–80% Biogran™ (Orthovita, Malvern, PA, USA) and approximately 20–30% of particulate autogenous bone mixed with blood coagulum was then introduced and carefully packed without excessive pressure into the posterior part of the sinus cavity and thereafter into the anterior part (Fig. 1b). Following graft placement, implants were inserted and the remaining sinus space was completely packed with the Biogran™-bone mixture. Care was taken to pack the Biogran™-bone composite graft around the implant contours and 3 mm superiorly to the apices of the fixtures. In case adequate primary stability was not
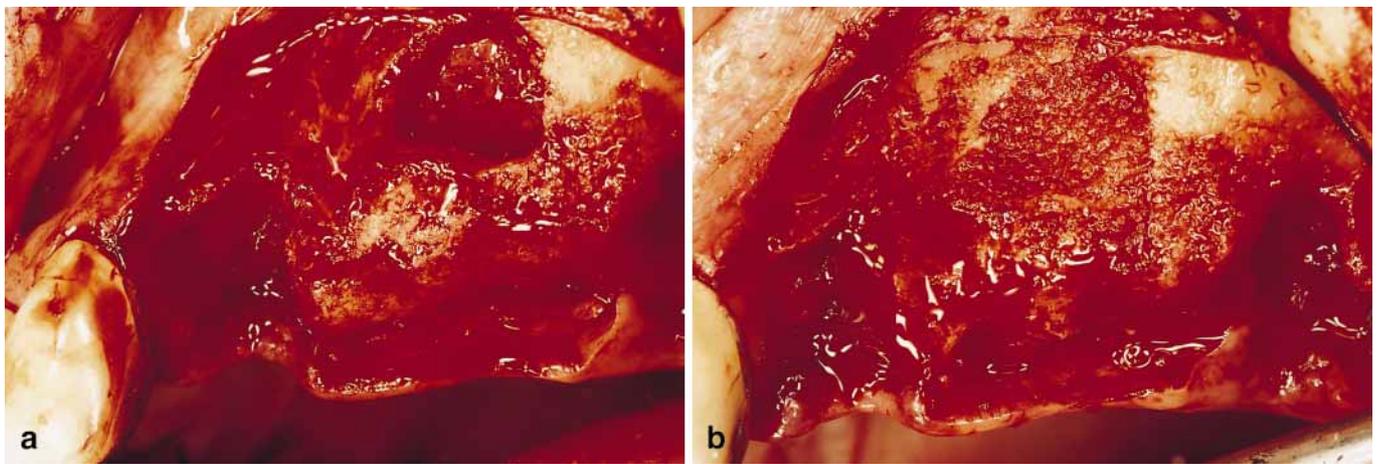
Fig. 1. a. Surgical view showing sinus access window. b. Initial packing of the sinus cavity with Biogran™.

achieved, the implant was removed. Staging of the graft and implant placement procedures were considered if more than one implant was not stable at the time of insertion. The lateral wall of the sinus was then covered with a collagen sheet to prevent migration of the graft particles and the flaps sutured with 4–0 monofilament sutures.

Postoperative care
The patients were instructed not to wear their dentures for 2–3 weeks postoperatively until the prosthesis was relined with a soft liner (Sofreliner S, Tokuyama Corp., Tokyo, Japan). Antibiotics (Amoxicillin 500 mg 4 times per day) were prescribed for 10 days and analgesics as required. Sutures were removed 2 weeks following surgery. Patients with sinus membrane perforation evidenced during surgery were given decongestants for 1 week postoperatively. Patients who developed congestion and cold symptoms were advised against air travel until the symptoms had subsided. Post-surgical visits were scheduled at monthly intervals to check the course of healing.

Second stage surgery
After a healing period of 9–12 months, CT scans were repeated using the original surgical stents. Second stage surgery was carried out, stability of the fixtures verified, and healing abutments connected to the implants. When possible, horizontal bone cores were harvested from the lateral window area using a 2 mm diameter trephine under abundant saline irrigation. This was done only

when the harvesting did not compromise the implants or the natural dentition. The biopsies were retrieved from coronal sites located between the fixtures about 7 mm from the margin of the alveolar ridge ($n=7$) and apical locations between the fixtures about 10 mm from the crestal bone ($n=3$). The cores were obtained to a mean depth of 8 mm.

Block specimens and histological processing
The bone cores were immediately fixed in a solution consisting of 1 part formaldehyde neutralized with $CaCO_3$ (50 g/l) and 2 parts of ethanol 80%. The specimens were subsequently dehydrated in graded alcohol series and embedded in methylmethacrylate. Serial sections of 80–100 μm were obtained using a sawing microtome (Leitz, Wetzlar, Germany) and further ground to yield undecalcified sections of 20–40 μm in thickness (Minimet, Buehler Inc., Lake Bluff, IL, USA). The polished sections were stained using Giemsa, Paragon and a combination of Stevenel's blue with Von Gieson picrofuchsin. With this method, the osteoid tissue stained green and the bone tissue red. Morphometric analysis of the sections was performed as a real measurement using a standard light microscope at ×40 magnification interfaced with a computerized morphometric system (Image-Pro Plus, Media Cybernetics, Silver Spring, MD, USA).

Prosthetic loading
All patients received provisional fixed implant-supported acrylic bridges 3 weeks following second stage procedure

and over an initial phase of 4 months. Subsequently, the patients underwent definitive prosthetic rehabilitation by fixed bridges with gold occlusal surfaces.

Clinical and radiographical follow-up
The 1 year post-prosthetic loading success rate was evaluated using the success criteria of Albrektsson et al. (1986) for early assessment. Periapical radiographs were taken and evaluated for the presence of peri-implant radiolucency, and the radiographic distance from the implant shoulder to the alveolar bone crest was measured in mm at the mesial and distal aspects of the implants using the distance between the implant threads for reference. The changes in bone height were calculated and rounded to the nearest 0.5 mm. The fixed prosthetic reconstructions were removed to check individual implant mobility.

Comparison of the baseline CT scans and those obtained at 9–12 months postoperatively provided a quantitative assessment of the newly formed mineralized tissues in the sinus cavity. Comparison of the CT scan images was performed on the pre- and postoperative cuts located at the level of the same radiopaque markers of the surgical guides. The distance between a point located at the center of the implant shoulder (1 mm below the top of the cover screw) and the new sinus floor was measured along the central longitudinal axis of the implant on the postoperative CT scan cut. The corresponding preoperative cut was then superimposed upon the postoperative cut using the
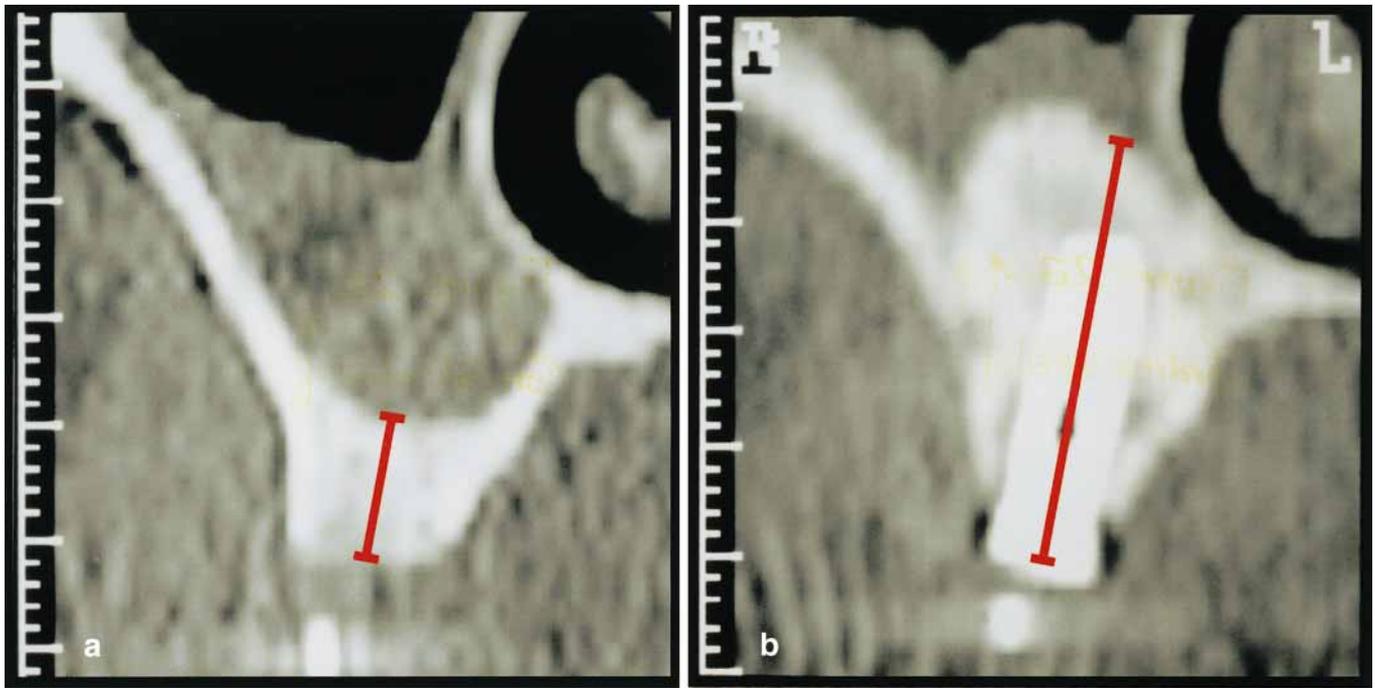
Fig. 2. a. Representative pre-surgical CT scan section from the right maxillary area of patient CS. Note the minimal height of bone below the sinus floor prior to sinus augmentation. b. Post-treat- ment CT scan section obtained at the same site using the cut located at the level of the same radiopaque marker of the surgical guide. Note the substantial increase in bone height at the site of the implant inserted in the augmented sinus cavity. The red lines in both figures measure the amount of pre- and postoperative mineralized tissues in the sinus cavity.

outer outline of the crest and the radiopaque marker for references. The distance between the center of the crest to the original sinus floor was then measured along the line previously drawn on the postoperative cut (Fig. 2a, b).

Histological evaluation

The following qualitative assessments were carried out: 1) nature of the newly formed tissues in the sinus cavity; 2) resorption pattern of the Biogran™ particles; and 3) bone relationship to the residual grafting material. The central section in each specimen was selected for quantitative assessment of different tissue components: mineralized bone, glass particles, osteoid, and fibrous tissue. These measurements were expressed as a percentage of the total surface area of the bone core section.

Results

Clinical observations

The 12 patients in this study included 8 women and 4 men ranging in age between 35 and 63 years with a mean of 48±10 years. A total of 27 implants were inserted simultaneously with sinus augmentation with a subsinus bone height ≤5 mm and a bone quality of mainly Type 2 and Type 3. None of the patients had postoperative complications besides normal swelling and inflammation at the surgical sites. Perforation of the sinus mucosa was recorded in 2 procedures and resulted only in minor postoperative nasal bleeding. All implants were stable at the time of abutment connection which was performed after a mean healing period of 10.8±1.1 months. One implant was lost during the prosthetic phase. All implants maintained stability at 12 months after loading, as tested after removal of the prosthetic reconstruction and on periapical

Table 1. **Data on the patient population, length of the healing period, changes of bone height in the augmented sinuses observed on CT scans, and radiographic peri-implant marginal bone levels at 1 year post-loading**

	Age (years)	Healing period (months)	Bone height pre-operatively on CT scan (mm)	Mineralized tissue height postoperatively on CT scan (mm)	Increase in mineralized tissue height on CT scan (mm)	Marginal bone level at 12 months (mm)
Mean	48.08	10.83	4.40	11.51	7.11	0.85
SD	9.94	1.11	0.63	1.62	1.57	0.33
Max	63	12	5	15	11	1.5
Min	35	9	3	10	5	0.5

Table 2. Means and standard deviations (SD) of bone, osteoid, fibrous tissue, and transformed glass particles in percentages found in the bone cores retrieved from the augmented sinus cavities in coronal and apical locations. Fibrous tissue refers to bone marrow, vascular elements and fibrous tissue *per se*

	Bone (%)	Osteoid (%)	Fibrous tissue (%)	Transformed glass (%)
Apical location (n=3) (mean±SD)	14.2±9.2%	1.3±0.1%	69.8±12.9%	15±13.6%
Coronal location (n=7) (mean±SD)	30.6±5.7%	1.1±0.8%	58.9±10.4%	9.4±10.3%

radiographs. Marginal bone resorption at 12 months after loading did not exceed 1.5 mm from the level measured at abutment connection (Table 1).

CT scan results (Table 1)

The CT scans carried out 9–12 months post-insertion showed a dense mineralized material in the sinus cavities surrounding the implants. In many cases it was difficult to delineate the borderline between the original sinus floor and the newly formed tissues. The original bone height below the sinus floor as measured on the original CT scans ranged between 3 and 5 mm with a mean of 4.40±0.63 mm. At the second CT scan evaluation 9–12 months post-surgery, the height of radiopaque tissues increased to 10–15 mm with a mean increase of 7.1±1.6 mm (Fig. 2a, b).

### Histological and histomorphometrical results (Table 2)

Ten bone biopsies were procured from 7 grafted sites in 6 patients. The biopsy co-

res contained a mean of 30.6% of bone, 1.1% of osteoid, 58.9% of fibrous tissue, and 9.4% of transformed bioglass particles in the coronal locations (n=7). The corresponding figures in the apical locations (n=3) were 14.2% of bone, 1.3% of osteoid, 69.8% of fibrous tissue, and 15% of transformed glass. The newly formed bone was predominantly of the woven type. In the vicinity of the preexisting osseous wall, dense trabecular bone was evidenced with lacunae containing cells indicating viable bone. Marrow spaces were predominantly filled with a well-vascularized connective tissue with no signs of inflammation or foreign body reaction. In some specimens, layers of osteoid tissue covered with active osteoblasts were observed at the outer surface of the bone trabeculae. Less mineralized tissue was evidenced in the biopsy cores retrieved from the deeper portions of the sinus (apical locations). Remnants of the glass particles were well integrated within the bone tissue in most specimens, although

some of them appeared to be surrounded by fibrous tissue in the deeper locations (Fig. 3). Many transformed glass particles showed bone and/or osteoid tissue in their excavated center and on their outer surface (Figs 3, 4). Only scarce remnants of the autogenous graft particles were visible in the grafted areas.

Discussion

This study evaluated the performance of Biogran™-autogenous bone graft combination in one-stage sinus augmentation with simultaneous implant placement in patients with 3–5 mm of bone height prior to grafting. While numerous studies have recommended the 2-step procedure in patients with less than 5 mm of alveolar bone height in the posterior maxilla (Jensen et al. 1990; Smiler et al. 1992; Raghoebar et al. 1993; Marx 1994), the results of this investigation suggest that Biogran™-autogenous bone graft yields adequate bone quality and volume for predictable simultaneous implant placement in such patients. Similarly, Peleg et al. (1999) reported that the single-step procedure is feasible for patients with as little as 3 mm of alveolar bone height prior to augmentation grafting, using hydroxyapatite-coated implants and autogenous bone. The 1-step procedure offers the advantages of reducing the number of surgical procedures
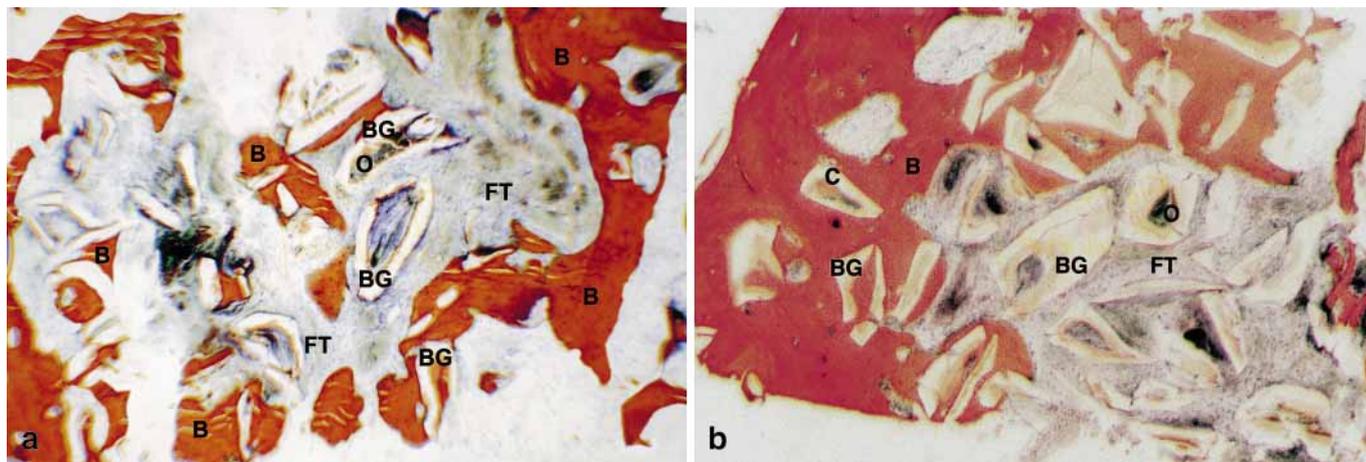
Fig. 3. a. Sinus end of the trephined bone core retrieved from an apical location at 9 months postoperatively. A number of eroded glass particles (BG) are surrounded by fibrous tissue (FT) while others are partially embedded in bone (B). Note the presence of osteoid (O) along with mineralized bone in the excavated center of a glass particle (original magnification ×40; stain Stevenel's blue with Von Gieson picro-fuchsin). b. Sinus end of a bone core harvested from a coronal site. Note the higher percentage bone volume present in this section when compared to that found in the apical area (original magnification ×40; stain Stevenel's blue with Von Gieson picrofuchsin). C=crack connecting the internal excavation within the bioglass particle with the surrounding bone.
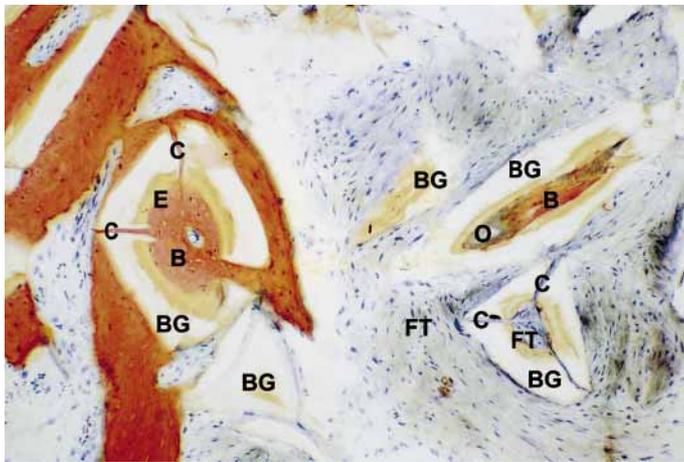
Fig. 4. Higher magnification of eroded glass particles (BG). Note bone formation within the central excavation (E) communicating with the surrounding tissue via small cracks (C). There is a continuity between the internally and externally formed bone tissue. The other 2 particles are encapsulated with fibrous tissue (FT). One of these particles shows bone (B) and osteoid (O) formation in its inner pouch while the other particle is filled with fibrous tissue (FT) (original magnification ×100; stain Stevenel's blue with Von Gieson picro-fuchsin).

and the time needed to complete implant-supported prosthesis.

The need to perform sinus augmentation procedures was questioned by Ellegaard et al. (1997). The authors reported a good success rate with 38 implants inserted in premolar/molar areas with vertical bone height as low as 3 mm using a sinus lift procedure without grafting material. However, the low number of implants in this study along with the relatively short follow-up period (3–4 years) do not provide strong evidence of the superiority of this technique. The authors themselves in their conclusions pointed out that this technique should only be performed in patients with high standards of oral hygiene since "the relatively short implants increase the risk of early implant failure due to inflammation and loss of marginal bone". Furthermore, animal studies (Wetzel et al. 1995; Haas et al. 1998) demonstrated a minor bone apposition along the base of the implant surface projecting into nonaugmented sinus cavities. The relatively high bone-to-implant contact demonstrated in animal sinus grafting reports (Wetzel et al. 1995; Quiñones et al. 1997; Hürzeler et al. 1997; Haas et al. 1998; Terheyden et al. 1999) justifies the use of sinus augmentation procedures in humans and the lack of a control group in the present study.

Various clinical investigations and case reports (Moy et al. 1993; Lundgren et al. 1996; Hürzeler et al. 1997; Lorenzetti et al. 1998; Valentini et al. 1998) have indicated that, although sinus augmentation can be clinically successful with various grafting materials, autogenous bone still provides the best osteogenic potential and biomechanical properties of the regenerated bone. However, the quantitative limitations of autogenous bone harvested from intraoral sites often constrain the clinician to combine the autograft with other types of grafts in order to obtain adequate amount of grafting material. Allografts used as an alternative to autografts have several problems mainly related to delayed resorption of demineralized freeze-dried bone particles, variable inductive properties, and the potential for disease transmission. Alternatives to autogenous and allogeneic bone grafts are anorganic bone mineral and biologically active glass. The osteoconductive properties of Biogran™, a bioactive glass with a narrow size range of particles, have been documented in a series of animal (Schepers et al. 1991; Schepers & Ducheyne 1993; Schepers & Ducheyne 1997) and clinical studies (Schepers et al. 1993; Furusawa & Mizunuma 1997). Schepers & Ducheyne (1997) demonstrated bone formation in protective pouches created within the glass particles through gelation and corrosion phenomena arising from the interfacial ion exchange between the glass particles and the surrounding tissue fluids. This ion exchange reaction would lead, with time, to a partial resorption of the bioactive glass particles resulting in smaller transformed particles and a higher proportion of living tissues in the repaired area. New bone formation in the central excavations of the particles was often seen without a connection with the externally located bone tissue. The authors reported that these islands of newly formed bone function as nuclei for further bone repair. The histological examination of the biopsy specimens in the present study confirmed the osteoconductive properties of Biogran™, as documented by the close contact between this material and the newly formed bone and bone growth along the scaffold of the particles.

The use of autogenous bone in combination with Biogran™ is dictated by the fact that this material is designed to replace the inorganic components required for bone formation. The organic components must be procured from the host vascular elements, from the added autogenous bone, or from added growth factors (Froum et al. 1998). Autogenous bone when used as a graft has an osteogenic potential related to the number of surviving osteoblasts and a potential osteoinductive effect brought about by the release of bone morphogenic proteins and other growth factors. Several authors have reported that addition of autogenous bone to porous hydroxyapatite alloplasts or xenografts significantly increases the amount of vital bone in biopsy cores retrieved from augmented sinus cavities (Quiñones et al. 1997; Hürzeler et al. 1997; Froum et al. 1998).

When comparing percentage bone volume within biopsies retrieved from sinus cavities augmented with different particulated grafting materials, the results reported by various authors have shown large variations (Moy et al. 1993; Lundgren et al. 1996; Hürzeler et al. 1997; Lorenzetti et al. 1998; Valentini et al. 1998). The differences in percentage bone volume among the various aforementioned reports can be attributed to the bone healing pattern in different animal species and in humans, length of the postoperative healing period, sites of

bone biopsies, architecture, conformation and composition of the grafting material, ratio of autogenous bone in composite grafts, and potentially implant loading. Wheeler et al. (1996) found an increase in bone volume from 16.38% after 4–10 months of healing to 45.30% after 36 months in sinus augmented with porous hydroxyapatite alone. In a clinical case report, Wallace et al. (1996) documented the sequential healing process of a sinus graft in the same patient at 4, 8, 12, and 20 months. The authors observed slow bone formation in the sinus cavity augmented with a composite 80% anorganic bovine matrix (OsteoGraf) and 20% autogenous bone harvested from the tuberosities. A 12- to 20-month period was required to convert this composite graft into vital bone. Similar conclusions were reported by Lundgren et al. (1996) with sinus grafting with particulated mandible and by Froum et al. (1998) with anorganic bovine bone matrix. In the present investigation, the presence of bands of osteoid tissue in the biopsy cores indicated that bone formation was still taking place after a healing period of 9–12 months. The transformed bioactive glass particles present at this stage are smaller than those present originally at the implantation procedure because of their partial dissolution resulting from the ion exchange reaction (Schepers & Ducheyne 1997). As reported with other composite grafts (Wheeler et al. 1996; Wallace et al. 1996; Lorenzetti et al. 1998), prolonged healing periods may be required to allow bone maturation and complete resorption and substitution by bone of all Biogran™ particles.

In the present study, less new bone formation was evident in the apical areas (mean of 14.2%) while a greater percentage of new bone was found in the coronal locations (mean of 30.6%) of the augmented sinus cavities. Although the number of biospies is far too small to make a statistically significant comparison between bone biopsy sites, it appears from this histological trend and the findings of previous reports (Boyne & James 1980; Hürzeler et al. 1997) that the osteoprogenitor cells repopulating grafts are mainly derived from cells residing in the residual maxillary alveolar ridge and lateral bony walls of the maxilla and not from the sinus membrane which does not possess an osteogenic potential.

In conclusion, the results of the present investigation indicate that Biogran™/autogenous bone graft combination used for maxillary sinus augmentation with simultaneous implant placement in patients with less than 5 mm of crestal bone height in the posterior maxilla provided stable and predictable results in terms of implant success.

Résumé

Cette étude a été entreprise pour 1) évaluer l'utilisation du Biogran™ de verre bioactif combiné avec de l'os autogène comme matériel de greffe pour l'épaississement du plancher sinusal avec le placement simultané d'implants en utilisant la radiologie et l'histologie, 2) de documenter le succès à court terme après la charge des implants insérés dans des cavités sinusales épaissies avec ce matériel. Une augmentation tant unilatérale que bilatérale a été effectuée chez douze patients avec une hauteur osseuse alvéolaire de 3 à 5 mm dans la région maxillaire postérieure avant la greffe. Les sinus ont été greffés avec du verre bioactif mélangé avec une portion 4:1 de l'os autogène. Simultanément deux à trois implants en titane filetés ont été insérés dans ces sinus épaissis. Une seconde chirurgie a été effectuée neuf à douze mois après la mise en place des implants. Lors de la connexion des piliers, dix biopsies complètes ont été prélevées de différentes sites greffés et évaluées histologiquement. Les 27 implants étaient cliniquement stables lors de la seconde étape. Une augmentation moyenne de la hauteur tissulaire minéralisée de 7.1 ± 1.6 mm était mise en évidence en comparant les images de scanner CT préchirurgicaux avec ceux pris 9 à 12 mois après l'épaississement du plancher sinusal. L'évaluation histologique a mis en évidence une moyenne de $30.6 \pm 5.7\%$ de tissu osseux dans les sites greffés. Un implant a échoué durant la phase prothétique tandis que les 26 autres sont restés stables pendant douze mois après la mise en charge. Cette étude suggère que la combinaison de la greffe osseuse autogène avec le Biogran™ utilisée dans un processus d'épaississement du plancher sinusal en une étape apporte un tissu minéralisé de qualité et une quantité suffisante pour le placement simultané d'implants chez des patients qui n'avaient au départ qu'une hauteur osseuse de 3 à 5 mm au niveau du plancher sinusal.

Zusammenfassung

Diese klinische Studie wurde unternommen um: 1) mit Hilfe von Röntgenaufnahmen und Histologie den Einsatz von bioaktiven Glas (Biogran®) in Kombination mit autologem Knochen als Transplantatmaterial bei der Sinusbodenelevation und gleichzeitiger Implantation zu untersuchen; und 2) um Angaben über die Kurzzeitprognose von Implantaten, die in mit diesem Material aufgefüllte Kieferhöhlen eingesetzt worden waren, zu erhalten. Bei 12 Patienten die vor der Augmentation in der hinteren Oberkieferregion eine alveolare Knochenkammhöhe von 3–5 mm hatten, wurde einseitig oder beidseits eine Sinusbodenelevation durchgeführt. Die Kieferhöhlen wurden mit einem 4:1-Gemisch von bioaktivem Glas und autologem Knochen aufgefüllt. Gleichzeitig implantierte man 2 bis 3 Titanschraubenimplantate in die aufgefüllten Kieferhöhlen ein. Die Zweitoperation erfolgte 9 bis 12 Monate nach der Erstoperation. Während dem Aufsetzen der Sekundärteile entnahm man aus verschiedenen augmentierten Stellen insgesamt 10 Stanzbiopsien und untersuchte sie histologisch. Alle 27 Implantate waren bei der Zweitoperation klinisch stabil. Verglich man praeoperative CT mit solchen, die 9–12 Monate nach der Sinusbodenelevation hergestellt worden waren stellte man eine mittlere Zunahme der mineralisierten Gewebehöhe von 7.1 ± 1.6 mm fest. Die Auswertung der Resultate zeigte eine mittlere Zunahme der Knochengewebe in den aufgebauten Regionen von $30.6 \pm 5.7\%$. Ein Implantat erlitt während der prothetischen Phase einen Misserfolg, die übrigen 26 Implantate waren 12 Monate nach Belastung immer noch stabil. Diese Studie lässt vermuten, dass die Kombination von Biogran® und autologem Knochen als Transplantat bei der Sinusbodenelevation, eine ausreichende Menge und Qualität an mineralisiertem Gewebe bringt, um bei Patienten mit einer alveolären Ausgangsknochenhöhe von 3–5 mm voraussagbar eine gleichzeitige Implantation zu ermöglichen.

Resumen

Este estudio clínico se llevó a cabo para: 1) evaluar el uso cristal bioactivo Biogran™ combinado con hueso autógeno como material de injerto para elevación del seno maxilar con colocación simultánea del implante usando radiografías e histología; y 2) documentar el éxito a corto plazo tras la carga de implantes insertados en las cavidades de los senos elevados con este material. Se llevó a cabo la elevación del seno unilateral o bilateral en doce pacientes con una altura de la cresta alveolar de 3 a 5 mm en el maxilar posterior antes de injertarse. Los senos se injertaron con cristal bioactivo mezclado en una relación 4:1 con hueso autógeno. Simultáneamente, se insertaron de 2 a 3 implantes roscados de titanio en los senos elevados. Se llevó a cabo la cirugía de segunda fase 9 a 12 meses tras la implantación. En el momento de la conexión del pilar se tomaron diez biopsias de diferentes lugares del injerto y se evaluaron histológicamente. Todos los 27 implantes estaban estables en el momento de la segunda cirugía. Se evidenció un incremento medio de la altura del tejido de 7.1 ± 1.6 mm cuando se comparó con los escáneres CT prequirúrgicos con aquellos realizados 9 a 12 meses tras el procedimiento de elevación del seno. La evaluación de las biopsias tuvo un rendimiento medio de $30.6 \pm 6.7\%$ de tejido óseo en los lugares injertados. Un implante fracasó durante la fase protésica mientras que los 26 implantes restantes estaban estables doce meses tras la carga. Este estudio sugiere que la combinación de injerto de Biogran™/hueso autógeno usado en elevaciones de seno produce suficiente calidad y volumen de tejido mineralizado para una colocación simultánea predecible de implantes en pacientes con una altura ósea de 3 a 6 mm antes del injerto.

要旨

　本臨床研究は、１）インプラントの同時埋入をする上顎洞増多術のための移植材料として用いる生体活性ガラス Biogran™と自家骨の混合物を放射線学及び組織学的に評価すること、及び２）同材料によって増多した上顎洞に埋入したインプラントの荷重後の短期成績を記録することを目的に行った。移植前に上顎臼歯部の歯槽頂の高さが３－５ｍｍであった１２名の患者において、片側あるいは両側の上顎洞増多術を行った。上顎洞には

生体活性ガラスと自家骨を４対１の割合で混合した材料を移植した。同時にチタン製スクリュー・インプラント２－３本を増多した上顎洞に埋入した。二次手術は埋入後９ヶ月から１２ヶ月後に行い、アバットメント連結時に１０個のコア生検標本を異なる移植部位から採取し、組織学的に評価した。二次手術時に、２７本のインプラントは全て臨床的に安定していた。上顎洞増多術後９－１２ヶ月後に撮影したＣＴ像と術前の像を比較すると、明らかに石灰化組織の高径が平均７．１±１.

６ｍｍ増加していた。コア標本の評価は移植部位において平均３０．６±５．７％の骨組織を示した。１本のインプラントは補綴治療の段階で失敗したが、残りの２６本は荷重後１２ヶ月後に安定していた。本研究は、１回法の上顎洞増多術に用いられる Biogran™／自家骨の混合物は、移植前の骨高径が３－５ｍｍである患者において、予知性の高い同時インプラント埋入法のために十分な量と質の骨組織をもたらすことを示唆している。

References

Albrektsson, T., Zarb, G.A., Worthington, P. & Eriksson, A.R. (1986) The long-term efficacy of currently used dental implants: a review and proposed criteria for success. *International Journal of Oral and Maxillofacial Implants* **1**: 11–25.

Betts, N.J. & Miloro, M. (1994) Modification of the sinus lift procedure for septa in the maxillary antrum. *International Journal of Oral and Maxillofacial Implants* **52**: 332–333.

Boyne, P.J. & James, R.A. (1980) Grafting of the maxillary sinus floor with autogenous marrow and bone. *Journal of Oral Surgery* **38**: 613–616.

Ellegaard, B., Kølsen-Peterson, J. & Baelum, V. (1997) Implant therapy involving maxillary sinus lift in periodontally compromised patients. *Clinical Oral Implants Research* **8**: 305–315.

Froum, S.J., Tarnow, D.P., Wallace, S.S., Rohrer, M.D. & Cho, S.-C. (1998) Sinus floor elevation using anorganic bovine bone matrix (OsteoGraf/N) with and without autogenous bone: a clinical, histologic, radiographic, and histomorphometric analysis. Part 2 of an ongoing prospective study. *International Journal of Periodontics and Restorative Dentistry* **18**: 529–543.

Furusawa, T. & Mizunuma, K. (1997) Osteoconductive properties and efficacy of resorbable bioactive glass as a bone-grafting material. *Implant Dentistry* **6**: 93–101.

Haas, R., Donath, K., Födinger, M. & Watzek, G. (1998) Bovine hydroxyapatite for maxillary sinus grafting: comparative histomorphometric findings in sheep. *Clinical Oral Implants Research* **9**: 107–116.

Hirsch, J.M. & Ericsson, I. (1991) Maxillary sinus augmentation using mandibular bone grafts and simultaneous installation of implants. A surgical technique. *Clinical Oral Implants Research* **2**: 91–96.

Hürzeler, M.B., Kirsch, A., Ackermann, K.-L. & Quiñones, C.R. (1996) Reconstruction of the severely resorbed maxilla with dental implants in the augmented maxillary sinus: A 5-year clinical investigation. *International Journal of Oral and Maxillofacial Implants* **11**: 466–475.

Hürzeler, M.B., Quiñones, C.R., Kirsch, A., Schüpbach, P., Krauße, A., Strub, J.R. & Caffesse, R.G. (1997) Maxillary sinus augmentation using different grafting materials and dental implants in monkeys. Part III. Evaluation of autogenous bone combined with porous hydroxyapatite. *Clinical Oral Implants Research* **8**: 401–411.

Jensen, J., Simonsen, E.K. & Sindet-Pedersen, S. (1990) Reconstruction of the severely resorbed maxilla with bone grafting and osseointegrated implants: a preliminary report. *Journal of Oral and Maxillofacial Surgery* **48**: 27–32.

Lekholm, U. & Zarb, G.A. (1985) Patient selection and preparation. In: Brånemark, P.-I., Zarb, G.A. & Albrektsson, T., eds. *Tissue-integrated prostheses. Osseointegration in clinical dentistry*, 1st edition, 199–209. Chicago, Illinois: Quintessence Publishing Co. Inc.

Lorenzetti, M., Mozzati, M., Campanino, P.P. & Valente, G. (1998) Bone augmentation of the inferior floor of the maxillary sinus with autogenous bone or composite bone grafts: a histologic-histomorphometric preliminary report. *International Journal of Oral and Maxillofacial Implants* **13**: 69–76.

Low, S.B., King, C.J. & Krieger, J. (1997) An evaluation of bioactive ceramic in the treatment of periodontal osseous defects. *International Journal of Periodontics and Restorative Dentistry* **17**: 359–367.

Lundgren, S., Moy, P., Johansson, C. & Nilsson, H. (1996) Augmentation of the maxillary sinus floor with particulated mandible: a histologic and histomorphometric study. *International Journal of Oral and Maxillofacial Implants* **11**: 760–766.

Marx, R.E. (1994) Clinical application of bone biology to mandibular and maxillary reconstruction. *Clinics of Plastic Surgery* **21**: 377–392.

Misch, C.M., Misch, C.E., Resnik, R.R., Ismail, Y.H. & Appel, B. (1991) Post-operative maxillary cyst associated with a maxillary sinus elevation procedure: a case report. *Journal of Oral Implantology* **17**: 432–437.

Moy, P.K., Lundgren, S. & Holmes, R.E. (1993) Maxillary sinus augmentation: histomorphometric analysis of graft materials for maxillary sinus floor augmentation. *Journal of Oral Maxillofacial Surgery* **51**: 857–862.

Nishibori, M., Betts, N.J., Salama, H. & Listgarten, M.A. (1994) Short-term healing of autogenous and allogeneic bone grafts after sinus augmentation: a report of 2 cases. *Journal of Periodontology* **65**: 958–966.

Peleg, M., Mazor, Z. & Garg, A.K. (1999) Augmentation grafting of the maxillary sinus and simultaneous implant placement in patients with 3 to 5 mm of residual alveolar bone height. *International Journal of Oral and Maxillofacial Implants* **14**: 549–556.

Quiñones, C.R., Hürzeler, M.B., Kirsch, A., Schüpbach, P., Blum, P., Strub, J.R. & Caffesse, R.G. (1997) Maxillary sinus augmentation using different grafting materials and osseointegrated dental implants in monkeys. Part II. Evaluation of porous hydroxyapatite as a grafting material. *Clinical Oral Implants Research* **8**: 487–496.

Raghoebar, G.M., Brouwer, T.J., Reintsema, H. & Van Oort, R.P. (1993) Augmentation of the maxillary sinus floor with autogenous bone for the placement of endosseous implants: A preliminary report.

Journal of Oral and Maxillofacial Surgery **51**: 1198–1203.

Schepers, E.J.G. & Ducheyne, P. (1993) The application of bioactive glass particles of narrow size range as a filler material for bone lesions: a 24-month animal experiment. In: *Bioceramics*, Vol. 6: 401–404. Proceedings of the 6th International Symposium on Ceramics in Medicine. Philadelphia: Butterworth-Heinemann Ltd.

Schepers, E.J.G. & Ducheyne, P. (1997) Bioactive glass particles of narrow size range for the treatment of oral bone defects: a 1–24 month experiment with several materials and particle sizes and size ranges. *Journal of Oral Rehabilitation* **24**: 171–181.

Schepers, E., De Clercq, M. & Ducheyne, P. (1991) Bioactive glass particulate material as a filler for bone lesions. *Journal of Oral Rehabilitation* **18**: 439–452.

Schepers, E.J.G., Ducheyne, P., Barbier, L. & Schepers, S. (1993) Bioactive glass particles of narrow size range: a new material for the repair of bone defects. *Implant Dentistry* **2**: 151–156.

Smiler, D.G., Johnson, P.W., Lozada, J.L., Misch, C., Rosenlicht, J.L., Tatum, O.H. & Wagner, J.R. (1992) Sinus lift grafts and endosseous implants. Treatment of the atrophic posterior maxilla. *Dental Clinics of North America* **36**: 151–186.

Terheyden, H., Jepsen, S., Möller, B., Tucker, M.M. & Rueger, D.C. (1999) Sinus floor augmentation with simultaneous placement of dental implants using a combination of deproteinized bone xenografts and recombinant human osteogenic protein-1. A histometric study in miniature pigs. *Clinical Oral Implants Research* **10**: 510–521.

Valentini, P. & Abensur, D. (1997) Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): a clinical study of 20 patients. *International Journal of Periodontics and Restorative Dentistry* **17**: 233–241.

Valentini, P., Abensur, D., Densari, D., Graziani, J.N. & Hämmerle, C.H.F. (1998) Histological evaluation of Bio-Oss® in a 2-stage sinus floor elevation and implantation procedure. A human case report. *Clinical Oral Implants Research* **9**: 59–64.

Wagner, J.R. (1991) A $3^1/_2$-year clinical evaluation of resorbable hydroxyapatite Osteogen HA used for sinus augmentation in conjunction with the insertion of endosseous implants. *Journal of Oral Implantology* **17**: 152–164.

Wallace, S.S., Froum, S.J. & Tarnow, D.P. (1996) Histologic evaluation of sinus elevation procedure: a clinical report. *International Journal of Periodontics and Restorative Dentistry* **16**: 47–51.

Wetzel, A.C., Stich, H. & Caffesse, R.G. (1995) Bone apposition onto oral implants in the sinus area filled with different grafting materials. A histological

study in beagle dogs. *Clinical Oral Implants Research* **6**: 155–163.

Wheeler, S.L., Holmes, R.E. & Calhoun, C.J. (1996) Six-year clinical and histologic study of sinus-lift grafts. *International Journal of Oral and Maxillofacial Implants* **11**: 26–34.

Wilson, J., Clark, A.E., Hall, M. & Hench, L.L. (1993) Tissue response to Bioglass endosseous ridge maintenance implants. *Journal of Oral Implantology* **19**: 295–302.

Wood, R.M. & Moore, D.L. (1988) Grafting of the maxillary sinus with intraorally harvested autogen-
ous bone prior to implant placement. *International Journal of Oral and Maxillofacial Implants* **3**: 209–214.