A comparison of two techniques to augment maxillary sinuses using the lateral window approach: rigid synthetic resorbable barriers versus anorganic bovine bone. Five-month post-loading clinical and histological results of a pilot randomised controlled clinical trial

Key words: anorganic bovine bone, resorbable barrier, sinus lift

Purpose: To compare the efficacy of two different techniques to augment maxillary sinuses using a lateral window approach: rigid synthetic resorbable barriers (Inion) versus granular anorganic bovine bone (Bio-Oss).

Materials and methods: Ten partially edentulous patients having bilaterally 1 to 5 mm of residual bone height and at least 5 mm bone width below the maxillary sinuses, as measured on computed tomography (CT) scans, were randomised to receive two different 2-stage sinus lift procedures using the lateral window approach. In one side, the sinus lining was raised by placing a resorbable rigid Inion barrier without any bone substitute whereas the contralateral side was loosely packed with 100% granular Bio-Oss. After 6 months, 2 to 3 implants were inserted at each side and submerged for 4 months. Implants were loaded with provisional acrylic prostheses and replaced after 4 months, by definitive screwretained metal-ceramic prostheses. Outcome measures were: time necessary to complete the augmentation procedure, bone gain on CT scans, histomorphometry, any complication, implant and prosthetic failures, and clinician and patient preference assessed by a blinded outcome assessor. All patients were followed up to 5 months after loading.

Results: No patient dropped out. There was no significant difference in time to complete the augmentation procedure (19.8 minutes for Inion versus 20.5 for Bio-Oss). After 6 months, both interventions gained bone in a highly statistically significant way (14.4 mm for Inion versus 14.1 mm for Bio-Oss) with no significant differences between the procedures. Histologically, more new bone formed at Bio-Oss treated sites (36.1% versus 24.2%), the difference being highly statistically significant ($P = 0.002$). There were no differences in complications between groups (2 perforations of the maxillary lining at Inion treated sites versus 1 at a Bio-Oss site), however, in one of the patients where a perforation occurred at the Inion site, at implant placement, the sinus was two-thirds filled with soft tissue and the site was successfully retreated with Bio-Oss. No implant failed. The clinician preferred Bio-Oss because it was simpler to handle. There were no statistically significant differences in patient preference 1 month after surgery and 1 month after delivery of definitive prostheses: 8 patients had no preference while 2 preferred the Bio-Oss treated side.

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Introduction

A common clinical problem encountered in the rehabilitation of an edentulous posterior maxilla is the presence of large pneumatised maxillary sinuses preventing the placement of implants due to the lack of sufficient bone volume. To overcome this problem, various sinus lifting techniques have been proposed ranging from using autogenous bone grafts (particulated or in blocks) or combinations of various types of allografts or biomaterials. Sinus lift techniques are among of the most commonly performed augmentation procedures and are considered very reliable particularly when autogenous bone is used. The original technique was described during the late 1970s. A lateral window is opened into the maxillary sinus, the sinus membrane is carefully lifted up, autogenous bone or bone substitutes are placed into the sinus and are allowed to heal for about 6 months or more before placing the implants. This technique, with some minor modifications, is now widely used.

Some authors suggested that bone augmentation can also be obtained without using any grafting material simply by maintaining free space, filled with blood, between the basal bone and the sinus lining keeping the membrane in a higher position than the apex of the implants. While some bone regeneration clearly occurred, it is difficult to evaluate whether these procedures could be a feasible clinical alternative to bone grafting since no control groups were used. In those studies, implants were simultaneously inserted in residual basal bone with mean heights ranging from 2 to 9 mm. Preliminary findings suggest that 5-mm-long implants with a diameter of 6 mm can be successfully loaded when placed in residual bone height of 4 to 6 mm without using any sinus lift procedure. Therefore, it would be interesting to evaluate whether major sinus lift procedures could be successfully implemented using the principle of guided bone regeneration in pneumatised sinuses having a residual bone height ranging from 1 to 5 mm without using any grafting material. To allow space maintenance, a resorbable rigid barrier would be needed. One barrier having the characteristics required (rigidity and resorbability) is the Inion GTR™ biodegradable membrane system (Inion, Tampere, Finland). This membrane is rigid but becomes malleable after being immersed in a plasticiser. The barrier stiffens in contact with water. There is scarce published scientific evidence on the clinical use of this barrier. It would also be useful to compare this technique with a sinus lift procedure using a bone substitute to clinically evaluate which of the procedures could be more successful and simpler to use in clinical practice.

The aim of this pilot randomised controlled clinical trial was to compare the efficacy of two different techniques for augmenting maxillary sinuses using a lateral window approach: rigid synthetic resorbable barriers (Inion, GTR Biodegradable Membrane System) without any grafting material versus 100% granular anorganic bovine bone (Bio-Oss®, Geistlich Pharmaceutical, Wolhusen, Switzerland). The present investigation is a preliminary report focusing on outcomes up to 5 months after loading. It was planned

Conclusions: Although bone grafting is not needed to augment atrophic maxillary sinuses since it is sufficient to keep space with a rigid barrier, bone was histologically more mature and appeared to be clinically harder when using Bio-Oss. Moreover, it was judged simpler to fill sinuses with a bone substitute than to position a rigid barrier for maintaining space.

Conflict-of-interest statement: This trial was partly supported by Geass srl (Pozzuolo del Friuli, UD, Italy), the manufacturer of the dental implants used in the present study, however the data belonged to the authors and the implants were not the object of the hypothesis tested in this investigation.
to follow-up the patients to the fifth year of function in order to evaluate the success of the procedures over time. This article is reported according the CONSORT statement for improving the quality of reports of parallel-group randomised trials (http://www.consort-statement.org/).

## Materials and methods

Any patient bilaterally edentulous in the posterior maxilla (Fig 1), having residual bone heights under the maxillary sinus between 1 to 5 mm and a width of at least 5 mm, as measured on CT scans, requiring 2 to 3 adjacent implants, who was 18 years or older and able to sign an informed consent form, was eligible for inclusion in this trial. A preoperative computer tomography (CT) scan was used to quantify the amount of available bone under the maxillary sinus to decide whether the patient could be included in the study (Fig 2).

Patients were not eligible for the study if any of the following exclusion criteria were present:
- general contraindications to implant surgery
- subjected to irradiation in the head and neck area
- immunosuppressed or immunocompromised
- treated or under treatment with intravenous amino-bisphosphonates
- active periodontitis, poor oral hygiene and motivation
- uncontrolled diabetes
- pregnant or nursing
- substance abuse
- psychiatric problems or unrealistic expectations
- lack of opposite occluding dentition/prosthesis in the area intended for implant placement
- acute chronic infection/inflammation (sinusitis) in the area intended for implant placement
- patients participating in other trials, if the present protocol could not be properly followed
- referred only for implant placement or unable to attend a 5-year follow-up.

After patients were enrolled in the study, the surgeon indicated a side of his choice as site number 1 and the contralateral as site number 2. Patients were placed into 3 groups according to what they declared: non-smokers, light smokers (up to 10 cigarettes per day), and heavy smokers (more than 10 cigarettes per day). Patients were recruited in three university clinics/hospitals (University of Bologna, University of Chieti and San Filippo Neri Hospital in Rome) and were treated by the same operator (PF performed all of the surgical procedures), using similar and standardised procedures.

The principles outlined in the Declaration of Helsinki on clinical research involving human subjects were adhered to. All patients received thorough explanations and signed a written informed consent form prior to being enrolled in the trial. All patients received prophylactic antibiotic therapy: 2 g of amoxicillin (or clindamycin 600 mg if allergic to penicillin) 1 hour before the intervention and continued the take the antibiotics post-operatively, 1 g amoxicillin or 300 mg clindamycin twice a day, for 7 days. Prior to the intervention, patients rinsed with chlorhexidine mouthwash 0.2% for 1 minute. All patients were treated under local anaesthesia using articaine with adrenaline.
A crestal incision was performed starting from site number 1 and a flap was elevated. After internal displacement of a lateral bony window prepared with a piezosurgery device (Mectron Piezosurgery™ device, Mectron, Carasco, Genoa, Italy), the maxillary membrane was carefully elevated and its integrity was assessed visually and with a blunt instrument. Any laceration or perforation was noted. At this point, site number 1 was randomised by opening a sequentially numbered opaque sealed envelope to receive either a rigid Inion resorbable barrier (Fig 3) or 100% granular Bio-Oss (Fig 4). After the procedure at site number 1 was completed, the contralateral side was treated with the other technique during the same surgical session.

The Inion membrane was softened before application in a biocompatible plasticising solution for 30 seconds and a curing solution for 10 minutes as suggested by the manufacturer, which allowed the membrane to be cut and moulded to exactly fit the space. The barrier was cut into two identical parts and one part trimmed into the proper form, placed into the sinus in contact with the bony walls and moulded into the desired shape (Fig 5). These synthetic barriers stiffened on contact with water, acquiring a rigid fixed shape allowing the maintenance of the space beneath (Fig 6). Physiological solution was spayed onto the barrier to accelerate the stiffening process. No augmentation material was placed beneath the barrier. On the contralateral site, Bio-Oss was inserted and loosely packed into the space between the sinus alveolar bone and the lifted sinus lining (Fig 7). In case of perforation of the sinus membrane, an Inion barrier was used to contain the graft. The lateral window was then covered with resorbable Inion barrier using what was left of the same barrier employed for keeping the sinus lining lifted. Flaps were sutured with vicryl 4.0. Ibuprofen 400 mg was prescribed as an analgesic to be taken 2 to 4 times a day during meals, as long as required. Patients were instructed to use 0.2% chlorhexidine mouthwash for 1 minute twice a day for 2 weeks; to have a soft diet for 1 week; to avoid blowing the nose and using drinking straws; in the case of sneezing, to try to keep the mouth open in order to decrease intra-sinus pressure; and to avoid brushing and trauma on the surgical sites. Patients were seen after 1 week for suture removal and after 1 month when their preference for the surgical intervention was evaluated.

Six months after the augmentation procedure, a CT scan of the sinuses was made to estimate the amount of vertical bone available for implant placement (Fig 8). All patients received 2 g of amoxicillin (or clindamycin 600 mg if allergic to penicillin) 1 hour before the intervention and rinsed with a chlorhexidine mouthwash 0.2% for 1 minute and were treated under local anaesthesia using articaine with adrenaline.
1:100,000. After flap elevation, 2 bone core biopsies were retrieved with a trephine (Biomet 3i, Palm Beach, FL, USA) having an external diameter of 3 mm with the aid of a surgical template. Two or 3 implants were then placed at each side of the patient (Fig 9) directly in the sites prepared by the trephine, and when 3 implants were used, in the additional implant site that was under-prepared using a drill of one size smaller that the actual implant diameter. Implants were inserted with the neck flush to the bone using the motor set with a torque of 25 Ncm. Conical Way (Geass, Pozzuolo del Friuli, UD, Italy) titanium grade 4 self-tapping implants, of 3.8 mm diameter, with conical internal hexagonal connection, designed for...
platform-switching, with micro-threading at the neck and microtextured surface treated with laser (Synthegra®) were used (Fig 10). The implant lengths used were 11 and 13 mm. Implants were submerged and flaps were sutured with vicryl 4.0. Intraoral radiographs (baseline) were made with the paralleling technique. In the case that the peri-implant bone levels around the study implants were hidden or difficult to read, a second radiograph was taken.

Ibuprofen 400 mg was prescribed to be taken as an analgesic 2 to 4 times a day during meals, as long as required and patients were instructed to use 0.2% chlorhexidine mouthwash for 1 minute twice a day for 2 weeks. Patients were seen after 1 week for suture removal.

The bone core biopsies were immediately stored in 10% buffered formalin and were subsequently processed using a Precise 1 automated system (Assing, Rome, Italy) to obtain thin ground sections. The specimens were dehydrated in an ascending series of alcohol rinses and embedded in Technovit 7200 VLC glycolmethacrylate resin (Kulzer, Wehrheim, Germany). After polymerisation, the specimens were sectioned longitudinally at about 150 μm along the major axis with a high-precision diamond disc and ground down to about 30 μm. Three slides were obtained and stained with acid fuchsin and toluidine blue.

After 4 months of submerged healing, implants were exposed via a crestal incision and flap elevation. No soft tissue augmentation procedures were performed. Implants were manually tested for stability by loosening the cover screws and impressions were taken with pick-up impression copings using a polyether material (Impregum™, 3M ESPE, Neuss, Germany) with customised resin impression trays. The vertical dimension was registered and models were made with class 4 precision plaster and mounted in a standard articulator. Healing abutments were placed and flaps were sutured. Patients were instructed to use 0.2% chlorhexidine mouthwash for 1 minute twice a day.
day for 2 weeks and ibuprofen 400 mg was prescribed as an analgesic 2 to 4 times a day during meals, as long as required. Within 1 month, provisional screw-retained reinforced acrylic restorations rigidly joining the implants were delivered. Occlusal surfaces were in slight contact with the opposite dentition with no contacts in lateral movements. Oral hygiene instructions were given and periapical radiographs of the study implants were taken.

Four months after delivery of the provisional prostheses, definitive screw-retained metal-ceramic restorations rigidly joining the implants were delivered (Fig 11). Implant stability was manually checked by tightening the abutment screws with a 20 Ncm torque. At 1 week, the prostheses were checked and patients were given additional oral hygiene instructions. At 1 month, patient preference was assessed. Patients were enrolled in an oral hygiene program with recall visits every 6 months. Follow-ups were conducted by an independent and blind outcome assessor (GP) together with the operator (PF). The present study tested the null hypothesis that there were no differences between the two procedures against the alternative hypothesis of a difference.

Outcome measures were:

- Prosthesis failure: planned prosthesis which could not be placed due to implant failure(s) and loss of the prosthesis secondary to implant failure(s).
- Implant failure: implant mobility and removal of stable implants dictated by progressive marginal bone loss or infection. Stability of individual implants was measured with the prosthesis removed at abutment connection, delivery of the provisional and definitive prostheses. The latter assessment was done when tightening the abutment screw with a torque of 20 Ncm.
- Any biological or prosthetic complications.
- Time necessary to complete the augmentation procedure (expressed in minutes) starting from incision to the end of suturing.

Fig 11 Clinical pictures and radiographs taken at delivery of the final prostheses 4 months after loading: a) periapical radiograph, b) clinical picture of a definitive bridge inserted at the sinus augmented with a synthetic rigid barrier, c) periapical radiograph and d) clinical picture of a definitive bridge inserted at the sinus augmented with granular bovine anorganic bone. The increased radiopacity of Bio-Oss is evident.
Clinician preference after completing the augmentation procedure, expressed as 1) the Inion treated side; 2) the Bio-Oss treated side; 3) none, both treatments were equally good and 4) none, both treatments were equally bad.

Amount of bone augmented in the vertical direction was measured on CT scans in mm (rounded to 1/2 mm) at implant surgery (baseline) and after 6 months. The mean vertical bone height was determined on paraxial 1 mm thin slices at 6, 12 and 18 mm posterior to the more distal portion of the last tooth, measuring the distance between the lower and the upper border of the crestal bone using Autocad-Autodesk® software (San Rafael, CA, USA).

Histological and histomorphometric evaluation of the augmented bone retrieved with a trephine bur at implant placement. Histomorphometry was carried out using a light microscope (Laborlux S, Leitz, Wetzlar, Germany) connected to a high resolution video camera (3CCD, JVC KY-F55B, JVC, Yokohama, Japan) and interfaced to a monitor and PC (Intel Pentium III 1200 MMX, Intel, Santa Clara, CA, USA). This optical system was associated with a digitising pad (Matrix Vision, Oppenweiler, Germany) and a histometry software package with image capturing capabilities (Image-Pro Plus 4.5, Media Cybernetics, Immagini & Computer, Milano, Italy). The values for marrow spaces, residual graft material and newly-formed bone were recorded exactly 1 mm from the pre-existing bone, and the mean percentage values were calculated at patient level and then at group level.

Patient preference was assessed 1 month after the augmentation procedure and 1 month after delivery of the final prostheses by an independent assessor asking the patients which treatment they preferred. The answers could be: 1) the Inion treated side; 2) the Bio-Oss treated side; 3) none, both treatments were equally good; 4) none, both treatments were equally bad.

Peri-implant marginal bone levels evaluated on intraoral radiographs taken with the paralleling technique at implant placement, at delivery of the provisional prosthesis, 1 and 5 years after loading. Data on this outcome will be reported in future publications.

One dentist (GP) not involved in the treatment of the patients, made all the clinical assessments without knowing group allocation, therefore the outcome assessor was blind. However, Bio-Oss augmented sites could be identified on radiographs because they appeared more radiopaque, while Inion treated sites appeared rather radiolucent (Figs 8, 9 and 12).

No sample size was calculated since this was a pilot study. A computer generated restricted randomisation list was created. Only one of the investigators (ME), not involved in the selection and treatment of the patients, was aware of the randomisation sequence and could have access to the randomisation list stored in his password protected portable computer. The randomised codes were enclosed in sequentially numbered, identical, opaque and sealed envelopes. Envelopes were opened sequentially after the sinus lining epithelium of site number 1 was lifted, therefore, treatment allocation was concealed to the investigators in charge of enrolling and treating the patients.

All data analysis was carried out according to a pre-established analysis plan. A biostatistician with expertise in dentistry analysed the data, without knowing the group codes. The patient was the statistical unit of the analyses. Differences of means at patient level for continuous outcomes (operation time and histomorphometry) between groups were compared by paired t tests. Differences in the proportion of patients for dichotomous outcomes (prosthesis and implant failures, complications and patient preference) were compared between the groups using the McNemar chi-square test (one implant failure or complication counted as a failure for that group within that patient). All statistical comparisons were conducted at the 0.05 level of significance.
Results

Sixteen patients were screened for eligibility, but 6 patients could not be enrolled in the trial for the following reasons: 4 patients had more than 5 mm of residual bone height at the maxillary sinuses and 2 patients because of sinusitis. Ten patients were considered eligible and were consecutively enrolled in the trial. All patients were treated according to the allocated interventions, no patient dropped out up to 5 months after loading, and the data of all patients was evaluated in the statistical analyses. No deviations from the original research protocol occurred apart from the fact that the prostheses were not supported exclusively by the study implants.

Patients were recruited and subjected to the sinus lift procedures from October to November 2008. The last final prosthesis was inserted in September 2009. The follow-up of all patients was 5 months after prosthetic loading.

The mean age of treated patients was 50 years, ranging from 35 to 60 years. There were 8 females and 2 males, and 5 patients smoked up to 10 cigarettes per day. The main baseline intervention characteristics are presented in Table 1. Forty-eight implants were placed, 24 in each group. There were no apparent baseline imbalances between the 2 groups (Table 1).

The main results are summarised in Table 2. Two complications occurred in 2 patients of the Inion group versus one complication in the Bio-Oss group. The difference was not statistically significant \((P = 0.57, \text{ odds ratio} = 0.444, 95\% \text{ CI} = 0.03 \text{ to } 7.17)\). All complications occurred during the sinus augmentation procedure and consisted of rupture of the sinus membrane. In particular, one rupture of the lining was induced by incorrect handling of the Inion barrier. The Schneider membrane was perforated during the positioning of the Inion barrier by one cutting edge not properly reduced by the operator. The perforation at the Bio-Oss site was sealed with an Inion barrier.

There was no statistically significant difference in surgical time required to complete the augmentation procedures: 19.8 minutes ± 3.4 for Inion treated sites versus 20.5 ± 3.1 minutes for Bio-Oss treated sites \((0.7 ± 3.2 \text{ minutes}; 95\% \text{ CI} -2.99 \text{ to } 1.59; P = 0.506)\).

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**Table 1.** Intervention characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Inion</th>
<th>Bio-Oss</th>
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<tbody>
<tr>
<td>Mean residual bone height (SD) in mm</td>
<td>3.4 (0.7)</td>
<td>2.8 (1.2)</td>
</tr>
<tr>
<td>Mean bone height 6 months after augmentation</td>
<td>17.8 (1.9)</td>
<td>16.9 (2.8)</td>
</tr>
<tr>
<td>Total number of inserted implants</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>11-mm-long implants</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>13-mm-long implants</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Patients receiving 2 implants</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Patients receiving 3 implants</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Implants placed with less than 25 Ncm torque</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Mean (range) of minutes needed to augment</td>
<td>19.8 (15–25)</td>
<td>20.5 (15–27)</td>
</tr>
</tbody>
</table>

**Table 2.** Summary of the main results presented at patient level.

<table>
<thead>
<tr>
<th></th>
<th>Inion</th>
<th>Bio-Oss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmentation procedure failures</td>
<td>1 (retreated with Bio-Oss)</td>
<td>0</td>
</tr>
<tr>
<td>Implant failures</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Complications*</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Patients’ preference 1 month after augmentation</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Patients’ preference 1 month after delivery of definitive prostheses</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

*All complications occurred intra-operatively and consisted of perforation of the sinus epithelium*
The surgeon preferred to augment with a bone substitute because he found it simpler than cutting and adapting the synthetic barrier.

One month after the augmentation procedure, 8 patients had no preference and 2 patients preferred the augmentation procedure with Bio-Oss because of less post-operative swelling. This difference was not statistically significant (McNemar test $P = 0.5$). Seven of the patients expressing no preference found the intervention equally acceptable at both sides, whereas one patient described both interventions as equally unpleasant due to post-operative swelling.

After 6 months, the radiographic appearance on CT scans of the augmented sites was qualitatively quite different between the 2 groups. While the Bio-Oss treated sites were more radiopaque than the
nearby bone, Inion treated sites were more radiolucent and resembled the ‘cloudy’ appearance of chronic sinusitis (Figs 8 and 9). Direct measurements on CT scans revealed that a highly statistically \( (P < 0.001) \) and clinically significant bone gain was obtained at both sites: 14.4 mm for Inion versus 14.1 mm for Bio-Oss, with no significant differences between the procedures (mean difference 0.3 mm; \( P = 0.672 \); Table 3).

At implant placement, 6 months after augmentation, the remnants of the Inion barrier could still be seen (Fig 13). At implant placement, the window of one Inion treated side was found filled about two-thirds with fibrotic tissue (Fig 14). This patient experienced rupture of the sinus lining at the time of the augmentation procedure. The fibrous tissue was partially removed, leaving a layer forming a sort of pseudo-membrane to allow the containment of Bio-Oss (Fig 15). 3 implants were placed and a new augmentation was done using Bio-Oss.

Representative examples of the histological sections are illustrated in Figures 16 a to b. The paired histomorphometric data (Table 4) showed that there was statistically more new bone formation at Bio-Oss treated sites (36.1% versus 24.2%; mean difference -11.8% \ ([8.3]; 95% CI -17.78 to -5.86; \( P = 0.002 \)) and roughly double bone marrow spaces (61.8% versus 31.3%) at Inion treated sites (mean difference 30.5% \ ([15.2]; 95% CI 19.56 to 41.38; \( P < 0.001 \)). If all the bone tissue is counted (newly formed bone and Bio-Oss granules, when applicable), there were statistically significantly more hard tissues at Bio-Oss treated sites (69.5% versus 24.2%; mean difference -45.2% \ ([9.3];
In the Inion group, newly formed bone (24.2%) with wide osteocyte lacunae and large marrow spaces (61.8%) were present with newly formed vessels and no inflammatory cell infiltrates. In the Bio-Oss group, most of the Bio-Oss particles (33.4%) were surrounded by newly formed mature, compact bone with well-organised osteons (36.1%). Only in a few areas were the material particles near the marrow spaces (31.3%). No inflammatory cell infiltrates or foreign body reactions were present. No osteoblasts were present. No gaps were present at the bone-Bio-Oss interface, and the bone was always in close contact with the particles. Bio-Oss particles presented marked staining differences from the host bone and had a lower affinity for the stains. Only in a few areas was it possible to see multinucleated giant cells.

Only 2 implant lengths, 11 and 13 mm, were used. This was done to minimise the implant stock. In 8 sides (18 implants) of the Inion group, implants were inserted with a torque <25 Ncm versus 4 sides (9 implants) of the Bio-Oss group. Four patients had an implant inserted with less than 25 Ncm torque at both sides. This difference was not statistically significant (McNemar test \( P = 0.125 \)). All patients received the same implant lengths and numbers at both sides. No implant failed and all prostheses were successfully loaded.

One month after delivery of the definitive prostheses (5 months after loading), 8 patients had no preference and 2 patients preferred the augmentation procedure with Bio-Oss, one patient because the intervention had to be repeated due to failure of the augmentation procedure at the Inion side. This difference was not statistically significant (McNemar test \( P = 0.5 \)). Seven of the patients expressing no preference found the intervention equally acceptable at both sides, whereas 1 patient described both interventions as equally unpleasant due to post-operative swelling.

### Discussion

The present pilot trial was conducted to evaluate the feasibility and efficacy of sinus lift procedures without using any bone grafts to allow the placement of dental implants in an atrophic sinus with a residual bone height of 1 to 5 mm. Previous studies\textsuperscript{6-11} have shown that new bone can be regenerated by simply keeping space between the maxillary sinus lining and the residual bone. However, no studies used suitable controls. In the present study, the control intervention may be considered the gold standard of sinus lift procedures: a bone substitute (anorganic bovine bone) placed via a lateral window into the sinus cavity\textsuperscript{1,14,15}. Both techniques were able to achieve the planned goals, however, some useful indications could be gained from this pilot trial despite its small sample size. Only one procedure out of 20 failed to obtain sufficient bone, though implants could be successfully placed anyway performing a simultaneous augmentation with Bio-Oss. The reason for this failure at the Inion treated side can only be speculated upon. The sinus lining was perforated during the lifting procedures but it is unclear whether there is any association between this complication and the insufficient bone regeneration. This problem was easily solved with a second sinus lift procedure concurrent with implant placement, using Bio-Oss. This complication occurred in the first treated patient and was probably coincidental or might be associated with the limited experience of the surgeon.

<table>
<thead>
<tr>
<th></th>
<th>Inion (n = 10)</th>
<th>Bio-Oss (n = 10)</th>
<th>Mean difference (SD)</th>
<th>P value for paired t test</th>
<th>95% CI of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>New bone % (SD)</td>
<td>24.2 (6.5)</td>
<td>36.1 (4.6)</td>
<td>-11.8 (8.33)</td>
<td>0.002**</td>
<td>-17.78 to -5.86</td>
</tr>
<tr>
<td>Bio-Oss % (SD)</td>
<td>N/A</td>
<td>33.4 (5.6)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>All hard tissue* % (SD)</td>
<td>24.2 (6.5)</td>
<td>69.5 (5.1)</td>
<td>-45.2 (9.3)</td>
<td>&lt;0.001**</td>
<td>-51.91 to -38.55</td>
</tr>
<tr>
<td>Marrow space % (SD)</td>
<td>61.8 (11.5)</td>
<td>31.3 (5.6)</td>
<td>30.5 (15.2)</td>
<td>&lt;0.001**</td>
<td>19.56 to 41.38</td>
</tr>
</tbody>
</table>

\* Includes newly formed bone and Bio-Oss when applicable

\** Statistically significant differences
with this new procedure. Nevertheless, if the trial had been stopped at the first encountered problem in the first patient, important information could have been lost.

Both procedures allowed for about 14 mm of vertical bone gain in the sinus, which is a remarkable result. No implant failures occurred and all prostheses could be successfully loaded, therefore both procedures can be considered successful. Nevertheless, some indications suggesting that one procedure could be preferable over the other can be mentioned. The surgeon found it easier to place Bio-Oss than to adapt a rigid barrier, softened in a plasticiser solution. Despite these subjective difficulties, no difference in operation time was found. The importance of eliminating any sharp edges during trimming of the membrane should not be underestimated. In fact, one of the lacerations of the sinus lining at the Inion treated side was provoked during the adaption of the barrier into the sinus cavity by a remaining sharp edge. On the other hand, this synthetic resorbable barrier was effective in becoming rigid and maintaining space. Patient preference assessed 1 month after the augmentation procedure did not display any statistically significant difference, with 8 patients having no definitive preference and 2 patients preferring the side treated with Bio-Oss because it was associated with less post-operative discomfort.

Six months after the augmentation procedure, when evaluating the new CT scan for planning implant placement, the augmented sinuses appeared consistently different: the radiopacity of the sites treated with anorganic bovine bone was remarkably different from the radiolucent appearance of the sites augmented with the synthetic resorbable barriers (Figs 8, 9 and 11). These radiographic findings were substantiated by histomorphometric (Fig 16) and clinical findings at implant placement. There was significantly more newly formed bone at the Bio-Oss treated sites and this, when added to the volume of the Bio-Oss particles, resulted in about 70% ‘new’ bone versus 24% newly regenerated bone at Inion sites. This might explain why there was a tendency for implants to be inserted with higher insertion torques (>25 N cm) at Bio-Oss treated sites (15 implants versus 6). On the other hand, it should be observed that there were no obvious clinical consequences on the success of the implant rehabilitation, since all implants were stable and remained osseointegrated for 4 months after loading. It appears that there is no strong correlation between the amount of newly formed bone and the clinical success of dental implants in augmented bone, which questions the value of the histomorphometric evaluation to predict the clinical success of dental implants.

There are not yet other published RCTs comparing similar sinus lift procedures1, therefore it is difficult to evaluate how the present results fit with other comparable studies. Previous studies lacked suitable controls and used the implant apexes to maintain space6–9, therefore results are not directly comparable with those obtained by the present trial. However, all previous studies showed that bone can be gained by simply lifting the sinus membrane without adding any grafting materials6–9.

The main limitation of the present investigation was the small sample size. Since the augmentation procedure of the maxillary sinus with a synthetic barrier was not tested in any controlled trial, it was decided to run a pilot trial with a limited number of patients. In a previous pilot trial enrolling 10 patients treated according to a split-mouth design, it was possible to detect significant differences and trends between different interventions using similar outcome measures16, therefore the split-mouth design was used again, enrolling just a few patients. The main advantages of a split-mouth trial are the reduced number of patients needed to be enrolled to find possible statistical differences, and the minimisation of biological factors influencing different patient responses to the tested interventions. This design also allowed for the investigation of patient preference, which is an important patient-centred outcome too often neglected in clinical trials. No prosthesis or implant failure occurred, therefore it is likely that hundreds, if not thousands, of patients need to be enrolled to detect a statistically significant difference, if any, between the 2 procedures for these primary outcomes. The strengths of the present study are that all treated patients were accounted for with no exclusions and all assessments were done by an independent and blinded assessor. Both techniques were tested in real clinical conditions and patient inclusion criteria were rather broad, therefore the results of the present trial can be generalised to a larger population with similar characteristics.
In the present trial, implants with a new surface modified with a laser procedure were tested in an unfavourable anatomical condition. The newly formed bone was in fact rather soft considering that 27 implants out of 48 implants were inserted with a torque < 25 Ncm despite under-preparation of the implant sites. These preliminary findings suggest that the new implant performed very well in the initial part of the study. It would be interesting to evaluate whether the new laser-treated implant surface could have played a significant role in the success of the implants in the ‘poor’ quality bone, especially at the Inion treated sites.

Conclusions

Bone grafting is not needed to augment atrophic maxillary sinuses, since it is sufficient to maintain the space with a rigid barrier to obtain substantial bone regeneration. However it is simpler to fill the space with a bone substitute than to maintain the space with a rigid barrier. The use of a bone substitute might be the preferable choice because it is easier to handle and is associated with more newly formed bone.

References