Improvement of Implant Placement after Bone Augmentation of Severely Resorbed Maxillary Sinuses with ‘Tent-Pole’ Grafting Technique in Combination with rhBMP-2

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Objective: To study the clinical effect of short implant placement using osteotome sinus floor elevation technique and tent-pole grafting technique with recombinant human bone morphogenetic protein 2 (rhBMP-2) in severely resorbed maxillary area.

Methods: Eleven patients with insufficient bone height in the posterior maxillary area were included. According to the native bone height and crown height space (CHS), the patients were divided into two groups: immediate placement of short implants with simultaneous bone augmentation (group A, 5 patients) and delayed dental implant placement (4 to 6 months) after bone augmentation. The rhBMP-2 was added into a deproteinised bovine bone mineral (DBBM) bone grafting material to shorten the treatment procedure and enhance the final effect of bone augmentation in both groups. Tent-pole grafting technique was applied for vertical bone augmentation in group B (6 patients).

Results: The success rate of the implants placed was 100% in both groups. In group A, the short implants treatment was successful, with a vertical gain of 1.5 to 6.4 mm in bone height after 4 to 6 months. In group B, the tent-pole grafting procedure in combination with DBBM and rhBMP-2 increased vertical bone height between 3.1 and 8.1 mm, an optimistic and adequate increase for implant placement. This bone increase was maintained following implant placement and final crown placement in the maxillary region (3.5 to 7.3 mm).

Conclusion: The tent-pole grafting technique was a viable alternative choice to lateral sinus floor elevation in cases with excessive CHS. The application of rhBMP-2 with a shortened treatment time demonstrated positive outcomes in sinus floor augmentation procedures.

Key words: sinus floor augmentation, recombinant human bone morphogenetic protein 2, deproteinised bovine bone mineral, tent-pole grafting, crown height space

ing lateral sinus floor elevation (LSFE)\textsuperscript{9}, osteotome sinus floor elevation (OSFE)\textsuperscript{10,11} and modification of either\textsuperscript{12-14}. Investigators have more recently shown that the residual crestal bone beneath the sinus floor is the deciding factor between the two techniques\textsuperscript{15,16}. Traditionally, OSFE technique has been utilised as a less-invasive procedure to the lateral window osteotomy as an option when the residual bone is 4 mm or greater in height (4 mm of intact alveolar bone has been a point of demarcation for simultaneous grafting and implant placement with a typical healing period of 4 to 6 months suggested if the available host bone height is less than 4 mm\textsuperscript{17}. Some studies described a significant difference in the success/failure rates of implants when the residual bone height was less than 4 mm\textsuperscript{9,18}.

Crown height space (CHS), the distance from the crest of the alveolar bone to the plane of occlusion, which is related to lever arm mechanics, is another important factor to consider during implant placement\textsuperscript{19}. It has been shown that each 1 mm increase in CHS is accompanied by a 20% increase in the total cervical load\textsuperscript{20}. Gehrke et al stated that CHS was a more significant factor than the crown/implant (C/I) ratio in influencing the biomechanical outcome and prosthetic failure for CHS > 15 mm\textsuperscript{21}.

Interestingly, in areas where CHS is excessive, tent-pole grafting technique has been a recent grafting technique, with very successful outcomes used in the treatment of severely atrophied mandibles and maxillae\textsuperscript{17,22}. Dental implants\textsuperscript{23,24}, cortical bone\textsuperscript{25}, titanium screws\textsuperscript{24,26,27} or titanium meshes\textsuperscript{28} have all been utilised to create a tenting effect to maintain graft volume and minimise pressure on the grafted area, thereby inducing new bone to grow in the tented space. Xiao et al reported a promising result of bone gain utilising the tent-pole grafting technique with deproteinised bovine bone mineral (DBBM) and porcine collagen membrane (Bio-Oss, Bio-Gide, Geistlich, Wolhusen, Switzerland) after a prolonged treatment period\textsuperscript{24}. But the healing time of the screw tent-pole grafting technique was approximately 10 months, which was a long procedure. Bone grafting materials have also been an important factor in both sinus floor elevation technique and tent-pole grafting techniques. Although autogenous bone has been considered the gold standard of bone grafting\textsuperscript{29,30}, a wide variety of alternative grafts, such as xenografts, allografts and synthetically fabricated bone grafts (hydroxyapatite, tricalcium phosphate, biphasic calcium phosphate and bioactive glasses) have been utilised due to the obvious drawbacks of autogenous bone, including increased patient morbidity, fast turnover rates, increased surgical time and lack of supply\textsuperscript{31}.

Ideal bone grafts share the features of osteoconductivity, osteoinduction, and osteogenesis\textsuperscript{32}. The use of rhBMP-2/ACS (absorbable collagen sponge carrier) appeared to be a realistic alternative for augmentation of atrophic anterior maxilla\textsuperscript{33}. In order to increase the osteoinductive potential of various xenografts and alloplasts, recombinant human bone morphogenetic protein 2 (rhBMP-2) has been combined with bone grafts to improve new bone formation\textsuperscript{29,34-36}. While some studies have investigated the use of rhBMP-2 maxillary sinus floor elevation procedures using a LSFE\textsuperscript{4,37-40}, few studies have investigated the use of rhBMP-2 in other techniques for sinus elevation. Furthermore, rhBMP-2 has been reported to improve and accelerate the bone maturation process\textsuperscript{36,38}. Therefore, the purpose of this study was two-fold. Firstly, to evaluate the short-term outcomes of the tent-pole grafting technique in the minimal edentulous posterior maxilla with inadequate RBH. Secondly, to investigate the effect of rhBMP-2 to shorten the treatment procedure in severely resorbed maxillae.

**Materials and methods**

**Patient selection**

The requirements of the Declaration of Helsinki were used for this study, with all patients giving the informed written consents for all surgical procedures. Patients were included in the study if no systemic or local contraindications were encountered. Inclusion criteria were severe atrophy (> 7 mm) of the alveolar process in the sinus area, bi- or unilaterally, and the presence of a Misch type 3 or 4 sinus situation. All patients received oral hygiene instructions before entering the study. The indications for the procedure and possible complications were reviewed with the patients and all patients agreed to proceed and signed a consent form. A total of 11 patients (3 women and 8 men; aged 20 to 69 years old) were included in this study and provided with a total of 14 implants (Table 1). Data related to age, sex, implant location, intraoperative or postoperative complications, implant stability and implant success, and radiographic bone changes were recorded for all patients.

**Preoperative work-up**

Preoperative work-ups included an assessment of the edentulous alveolar ridges using casts and a diagnostic wax-up. All patients were evaluated preoperatively for the need for sinus augmentation via cone beam...
tomography (CBCT) scans. On the basis of information obtained from the preoperation work-up, surgical plans were drawn up. Considering the minimum of bone height from the crest of the ridge to the floor of the sinus and the final prosthesis from the wax-up, planning was done using immediate implant placement with a surgical procedure, including maxillary sinus augmentation (simultaneous approach) (group A), or with sinus floor elevations procedures followed by delayed implant placement (group B).

The surgical procedure of this study is described in Figure 1. There were four situations according to original sinus height (OSH) and CHS: 1) OSH < 4 mm, CHS to be proper; 2) OSH ≥ 4 mm, CHS to be proper; 3) OSH < 4 mm, CHS to be excessive; 4) OSH ≥ 4 mm, CHS to be excessive. Patients in situation 1 would receive regular sinus-lifting procedure and have the dental implant placed after the healing time. In this study, we focus on the other three situations (2 to 4), in which 2 is Group A, and 3 and 4 are Group B.

Recombinant human bone morphogenetic protein-2 (rhBMP-2) (Hangzhou Jiuyuan Gene Engineering, Hangzhou, China) was combined with porous absorbable sponge fabricated from pharmaceutical gelatin, soy lecithin and hydroxyapatite. All surgical procedures were completed by the same surgeon (YZ). In six cases, the sinus height was less than 4 mm (group B), and therefore implants were placed after bone augmentation (two-stage surgery). In the remaining five cases with more than 4 mm of original sinus height (group A), the implants were immediately placed. A total of 16 titanium implants were inserted: five implants using Straumann (Straumann, Switzerland) with 10 mm (3) or 8 mm (2) in length and 4.1 mm in diameter; and 11 implants using Bicon (Bicon, Boston, MA, USA) with 6 mm in length and 5 mm in diameter. All patients received 2 g of amoxicillin 1 h before the surgery. Immediately before the surgical procedure, all patients were instructed to rinse with a 0.2% chlorhexidine solution for 2 min.

In group A, dental implants were placed (surgery 2) immediately after the osteotome sinus floor elevation. The recipient site was prepared using an appropriate calibrated trephine bur of the same diameter as the implant installed. The trephine ended approximately 1 mm below the sinus floor calculated from the presurgical CBCT. After removal of the trephine bur, the alveolar bone core was confirmed. Next, a calibrated hand osteotome was selected to correspond to the diameter of the trephine preparation. A gentle malleting force was used to cause initial fracture of the sinus floor. The sinus floor was then elevated to displace the Schneiderian membrane apically. This step was performed manually by an experienced surgeon, with special attention paid to avoid perforation of the membrane. Two methods were used to ascertain the integrity of the Schneiderian membrane. The elasticity of the membrane was felt when manually inserting the depth gauge and the Valsalva manoeuvre was confirmed negative. Grafting

![Fig 1](https://example.com/fig1.png)

**Fig 1** Treatment procedure of this study.
material (Bio-Oss collagen, Geistlich Pharma, AG, Wolhusen, Switzerland) rehydrated in blood and 1 mg of rhBMP-2 was added apically. Implants were placed immediately after the elevation. Concerning the healing outcome, the submerged approach was generally preferred for all implants being inserted into less than 8 mm of the initial alveolar bone height. Consequently, a precise tension-free, interrupted suture of the margins was necessary, allowing for primary wound closure (Fig 2). Postoperatively, all patients received 2 g of amoxicillin twice daily for 3 to 5 days after surgery and non-steroid analgesic as needed. All patients were also instructed to maintain good oral hygiene as normal and were instructed to rinse twice daily with 0.12% chlorhexidine gluconate solution over a period of 2 weeks. Patients were also instructed not to blow their nose for 15 days following sinus elevation procedures. The sutures were removed 14 days after surgery. After a healing period of 4 to 6 months, abutment connections were placed. After 6 to 8 weeks, impressions were taken at the level of the implant shoulder. Two weeks later, the prosthetic reconstructions were inserted. All patients were rehabilitated with fixed implant-supported prostheses.

In the delayed implant group (group B), the bone augmentation procedure was performed (surgery 1) in the edentulous area with severe bone loss (ridge less than 4 mm). Where necessary, inflammatory tissue was carefully removed from the defect area. Then the ridge was prepared with a specific drill for the placement of titanium screws (Straumann, Switzerland), with 1 mg of rhBMP2, with its carrier being gently placed in the defect area (Fig 3). DBBM and with a resorbable porcine-derived collagen membrane covering the defect (Fig 4) flap closure.
Table 1  Variables and results of the 16 implants during the study period

<table>
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OSH: Original sinus height
SH1: The sinus height after the bone augmentation process (surgery 1)
VI1: Vertical increase of the sinus between SH1 and OSH (the increase in ridge height)
SH2: The sinus height after the implant placement (surgery 2) and before the final restoration
VI2: Vertical increase of the sinus between SH2 and OSH (a combination of the increase in ridge height as well as bone gain on the sinus floor)

defect area and fixed with titanium screws. A bone grafting material (DBBM) rehydrated in blood was filled up to the level of the mesiodistal bone plate. Then the bone-grafted area was completely covered with a resorbable porcine-derived collagen membrane (Bio-Gides, Geistlich Pharma) to prevent bone graft spreading and soft tissue invasion. The incision was repositioned and sutured using 4/0 resorbable suture material (Trofilorc, LorcaMarin, SA, Murcia, Spain) to achieve tension-free closure. Following a 4 to 6-month healing period, after standard preoperative anaesthesia, the tenting screws were removed and implant placement surgery (surgery 2) was then carried out. The regular dental implant placement surgery was taken when the alveolar bone height was sufficient for 5 patients. In the other patient, the bone was still insufficient for regular implant placement despite the bone augmentation procedure. Thus, the implants were placed simultaneously with osteotome sinus floor elevation in the same way as group A. The ostoperative instruction of group B for surgeries 1 and 2 was the same as described for group A.

After a healing period of 3 to 4 months for five of the patients and 5 months for the sixth, abutment connections were placed. After 6 to 8 weeks, impressions were taken at the level of the implant shoulder. Two weeks later, the prosthetic reconstructions were inserted. All patients were rehabilitated with fixed implant-supported prostheses.

Radiographic examinations
We used flat panel detector (FPD)-based CBCT (New Tom FP, Quantitative Radiology, Verona, Italy) for imaging from within our department in the Wuhan University Dental School (China). CBCT scans were obtained before the surgery, immediately after the sinus augmen-
tation (group B only), before the implant placement and before restoration. All measurements were made twice by one blinded investigator. The height was analysed and measured by NNT-Viewer software.

Results

The success rate of implants in this study was 100% in both groups A and B. All the implants were clinically stable and loaded without pain or any subjective sensation. No sinus membrane perforations were reported. The radiographic results (Table 1) demonstrated that the mean sinus increase was 5.8 mm after surgery 1, and 4.7 mm after surgery 2. All cases presented satisfactory results. Figures 2 to 4 present a typical case from Group A and Figures 5 to 9 from Group B.

Discussion

Alveolar bone insufficiency in the posterior maxilla with ridge resorption and sinus pneumatisation is a commonly reported challenge in implant dentistry. Traditionally, the choice of procedure to correct this anatomic deficiency is via maxillary sinus floor elevation. Lateral sinus floor elevation (LSFE) and osteotome sinus floor elevation (OSFE) are two main approaches well documented in the literature. LSFE permits a better effect of bone augmentation to the atrophic maxilla, but requires a much more invasive and longer surgical procedure. With appropriate case selection according to native vertical bone height, reports have now demonstrated no difference in final implant outcomes when case selection be appropriately applied. Initial sinus bone height of less than 4 mm reduced the success rates of implants inserted in combination with osteotome sinus floor elevation. When the native bone height is > 4 mm, implants can routinely be placed simultaneously with OSFE. In this study, patients (group A, from case 1 to case 5) with native bone height > 4 mm (except 3.6 mm at tooth 17 in case 4) were treated with the OSFE technique with short implants (Table 1). All implants osseointegrated accordingly with satisfactory final restoration results (Figs 7 to 9).

In sites with < 4 mm bone height, and especially with excessive CHS, LSFE technique would result in a long crown, associated with a longer and increased morbidity treatment period. Screw tent-pole grafting technique has therefore been described as a potential alternative method. Xiao et al reported a successful case report of applying this method for bone augmentation, but in their protocol, they used a long healing period of 10 months prior to implant placement.

While autogenous bone is considered the gold standard of bone grafting, obvious disadvantages, including a limited harvesting supply, unpredictable resorption rates and additional surgical time, have made bone substitution materials necessary in implant dentistry. DBBM is considered one of the most widely used bone graft materials.
Zhang et al. substitute materials in oral and maxillofacial surgery due to its low substitution rate, and numerous articles describe its successful use over long healing periods. Despite this, DBBM is not considered osteoinductive and its additional combination with rhBMP-2 is considered a safe and promising alternative for alveolar ridge augmentation procedure. Chen et al. have also recently shown that the combination of inlay osteotome sinus floor elevation, concentrated growth factor application and simultaneous short implant placement was a reliable surgical procedure in severely atrophic maxillae. The use of rhBMP-2/ACS appeared to be a realistic alternative for augmentation of atrophic anterior maxillae. Moreover, rhBMP-2 has been reported to improve and accelerate the bone maturation process. It therefore became of interest to our group to apply rhBMP-2 in combination with a screw tent-pole grafting technique to better augment atrophic maxillary sinuses with shorter healing periods.

Interestingly, in our case series, group B (patients with < 4 mm alveolar bone height) received a bone augmentation procedure with screw tent-pole grafting technique, and the graft utilised comprised DBBM and rhBMP-2. After a 4 to 6-month (instead of the suggested 10-month) healing period, the acquired bone height increased from 3.1 to 8.1 mm – an optimistic and adequate outcome for implant placement. Following this healing period, stage-two surgery was carried out and final prostheses were adequately fixed (Figs 5 to 9). In this study, the combination of DBBM with rhBMP-2 using the tent-pole grafting technique further corrected the excessive CHS.

In our study, the tent-pole grafting technique with rhBMP-2 in severely atrophic maxillae was utilised successfully to augment vertical bone with little observed resorption. Other authors using the inlay osteotome protocol also reported obvious resorption of their bone core. Chen et al. indicated less dynamic bone remodelling during the late stage after surgery. The vertical bone height was relatively stable after surgery using the traditional osteotome technique.

In our study, short implants were often utilised (< 10 mm). CHS was a more significant factor than the C/I ratio in influencing biomechanical outcome and prosthetic failure occurred at CHS > 15 mm. Short implants are obvious alternative choices in such cases where maxillary sinus resorption has previously
occurred with documented success rates similar to conventional dental implants.48-50

In conclusion, the present study reports that:

- With careful planning, tent-pole grafting technique achieved excellent results, especially in clinical situations where the CHS was excessive.
- The cases treated with rhBMP-2 appeared to enhance bone augmentation in both OSEF and tent-pole grafting technique groups.

It may therefore be suggested that both protocols led to adequate results in the severely atrophic maxillary region. Future large randomised comparative studies are needed to fully characterise the influence and necessity of rhBMP-2 during such procedures.

Conflicts of interest

The authors reported no conflicts of interest relating to this study.

Author contribution

Dr Qiao Zhang and Dr Li Li Zhang carried out the data collection, interpretation and statistical analysis, as well as preparing the manuscript; Dr Richard J. Miron prepared and revised the manuscript, Dr Yu Feng Zhang directed the study, performed the surgery, and revised and finally approved the manuscript. All the authors participated in the design of the study.

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