Three-Dimensional Vertical Alveolar Ridge Augmentation in the Posterior Maxilla: A 10-year Clinical Study

Fouad Khoury, PhD, DMD[1]/Thomas Hanser, DMD[2]

Purpose: *The aim of this clinical study was to evaluate the long-term outcome of the split bone block (SBB) technique for vertical bone augmentation in the posterior maxilla in combination with sinus floor elevation using a tunneling approach.* ***Materials and Methods:*** *Patients were treated for extensive vertical and horizontal alveolar bone defects without simultaneous implant placement and followed up for at least 10 years postoperatively. Autogenous bone blocks were harvested from the mandibular retromolar area following the MicroSaw protocol. The harvested bone blocks were split longitudinally according to the SBB technique. Implants were inserted and exposed after every 3 months, and prosthetic restoration was performed.* ***Results:*** *One hundred forty-two consecutively treated patients, 154 grafted sites, and 356 inserted implants were documented. Minimal graft exposure (1 to 3 mm) 4 to 8 weeks postoperatively was documented in two sites; infection of the grafted area occurred in one other case. The mean preoperative clinical vertical defect was 7.8 ± 3.9 mm, and the mean horizontal width was 3.1 ± 2.2 mm. Postoperatively, the mean vertical gained dimension was 7.6 ± 3.4 mm (maximum: 13 mm), and the mean width was 8.3 ± 1.8 mm. Implants could be inserted in all sites, with additional local small augmentation in 21 cases. The amount of maximum vertical bone resorption was 0.21 ± 0.18 mm after 1 year, 0.26 ± 0.21 mm after 3 years, 0.32 ± 0.19 mm after 5 years, and 0.63 ± 0.32 mm after 10 years. As part of a total patient dropout of 16.9%, four implants were lost within 10 years. The mean vertically gained bone was stable at 6.82 ± 0.28 mm (maximum: 12 mm). The resorption rate after 10 years was 8.3%.* ***Conclusion:*** *The described tunneling flap approach allows a hermetic soft tissue closure, characterized by a reduction of dehiscence and a secure bone graft healing. The combination of thin autogenous bone blocks and bone particles according to the SBB technique allows an acceleration of transplant revascularization, and thus, of graft regeneration, allowing a shortening of the patient treatment time as well as long-term three-dimensional volumetric bone stability.* Int J Oral Maxillofac Implants 2019;34:471–480. doi: 10.11607/jomi.6869

Keywords: *3D bone augmentation, MicroSaw protocol, posterior maxilla, sinus floor elevation, split bone block technique, tunnel technique, vertical alveolar ridge augmentation*

An appropriate bony situation is essential for dental implant placement and bony support of soft tissues. For some patients, implant treatment would not be an option without horizontal and vertical bone augmentation. While there are different established and predictable methods for horizontal augmentation,[1,2] combined horizontal and vertical so-called three-dimensional (3D) alveolar ridge augmentations are challenging procedures in dental implantology. The approach should provide an adequate site for the osseointegration of titanium implants with an intense revascularization and revitalization of the reconstructed area for long-term tissue stability.[1,3–5]

Guided bone regeneration is described as a surgical technique to increase limited alveolar bone for implant placement. To overcome vertical deficiencies in the atrophied crest, bioabsorbable membranes[6] and reinforced nonresorbable barriers[7–9] are used to cover autologous bone grafts,[6–8] a mixture of autologous and anorganic bovine bone grafts,[10] or an allogeneic bone matrix.[8,9,11] In the context of vertical guided bone regeneration, the use of nonresorbable membranes is described as the most effective.[3,7] However, with their use, a long time of graft healing up to 1 year is required, and an increased risk of dehiscences and infections is

[1]Professor, Department of Oral and Maxillofacial Surgery, University of Münster, Germany; Chairman, Private Clinic Schloss Schellenstein, International Dental Implant Center, Olsberg, Germany.
[2]Senior Surgeon, Private Clinic Schloss Schellenstein, International Dental Implant Center, Olsberg, Germany.

Correspondence to: Prof Dr Fouad Khoury, Am Schellenstein 1, 59939 Olsberg, Germany. Fax: +49-2962-9719-22. Email: prof.khoury@t-online.de

Submitted December 22, 2017; accepted October 29, 2018.

observed, which is found to have a detrimental effect on the regenerative outcome of the graft.[1,3,12,13]

Allograft blocks are used as an alternative to autogenous grafts in a variety of different scaffolds to avoid donor site morbidity.[9,14–17] Conclusions in published work concerning vertical alveolar ridge augmentation are based on a few trials including a low number of patients, sometimes having a short follow-up, and often being judged to be at high risk of bias.[3,4]

Autogenous bone grafts are still considered to be the gold standard, especially for vertical alveolar ridge augmentation.[1,18–22] In this context, harvesting autogenous bone grafts intraorally became a common, predictable, and safe surgical technique within the last 15 years.[1,18,23,24] Autogenous bone grafts are utilized in different consistency and shapes, with or without membranes, using different techniques and approaches to reconstruct the missing vertical alveolar volume.[1,18,20,21,25] However, some risks related to these surgeries are still present, for example, soft tissue necrosis with graft exposure as well as poor revascularization of the mandibular cortical graft leading in many cases to an increased resorption of the grafted area.[1,15,23,26–31] The split bone block (SBB) technique,[1,23] using a combination of autogenous thin bone blocks and small pieces of bone (bone chips), was described as a biologic modification of the grafting procedure that accelerates the regeneration of the graft through improvement of the osteoconductive properties, especially in vertical bone reconstructions. The stable box thus created with thin bone blocks and the resulting stable biologic space filled with autogenous bone chips increases the amount of vital osteocytes in the grafted area and intensifies the quality of revascularization and regeneration of the graft.[1,23] Postoperative complications in the form of tissue necrosis and graft exposure can be reduced through a tunnel approach.[30–33]

The aim of this prospective study was to evaluate the long-term outcome of the SBB technique[1,23] for vertical bone augmentation in the posterior maxilla in combination with sinus floor elevation using a tunneling approach.

This study was performed following the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology, http://www.strobe-statement.org) guidelines.[5]

MATERIALS AND METHODS

Patients who were treated between 2003 and 2007 for a vertical bony defect in the posterior maxilla without simultaneous implant placement were included in this study and followed up for at least 10 years postoperatively. All the patients were older than 18 years of age and gave their informed consent to the surgery. The study was approved by the ethical commission of the hospital.

The study inclusion criteria were:

- Edentulous posterior maxilla with crestal vertical bony defects as well as insufficient bone height to the sinus area
- Edentulous posterior maxilla with three-dimensional (3D) (vertical and horizontal) bony defects as well as insufficient bone height to the sinus area

The exclusion criteria were:

- Untreated severe periodontitis with poor oral hygiene
- General contraindication to implant surgery
- Uncontrolled diabetes
- Treatment with intravenous (i.v.) bisphosphonate
- Pregnant or nursing

Visual examination and digital palpation allowed for a preliminary estimation of the morphologic contours and dimensions of the alveolar crest. This clinical examination also provided information about the quality of the soft tissue. Panoramic radiographs were used to get additional information. Cone beam computed tomographic (CBCT) scans (Galileos, Sirona) were only performed in the case of patients receiving multiple bone augmentations for the reconstruction of additional severe bony defects.

All the surgeries were performed as a combination of 3D vertical bone augmentation with sinus floor elevation through a tunnel approach.

Surgical Procedure

All patients underwent at least one session of oral hygiene instruction as well as ultrasonic debridement and rinsing 2 minutes directly preoperatively with chlorhexidine mouthwashes 0.2%.

Preoperative antibiotic administration was performed, with amoxicillin 1 g i.v. directly before local anesthesia was injected (before vasoconstriction occurred). Antibiotics were to be continued for 10 days postoperatively at 2 × 1 g/day. In the case of an amoxicillin allergy, clindamycin 300/600 mg was administered at 1.2 g/day. The surgery was generally performed under local anesthesia in conjunction with intravenous sedation. Local vestibular and palatinal/lingual infiltration with 4% articaine and 1:100,000 epinephrine (Ultracain DS forte, Sanofi Aventis) was administered at the bone donor site in the mandibular retromolar area as well at the recipient site in the posterior maxilla. General anesthesia was indicated for large reconstructions involving multiple donor sites, as well as surgery exceeding 3 to 4 hours.

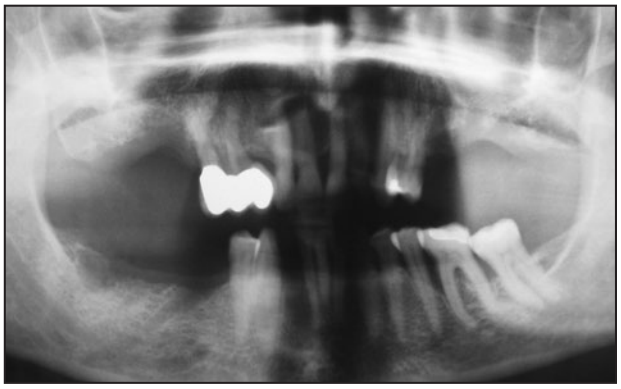

Fig 1 Bilateral free end situation with vertical bone defects.

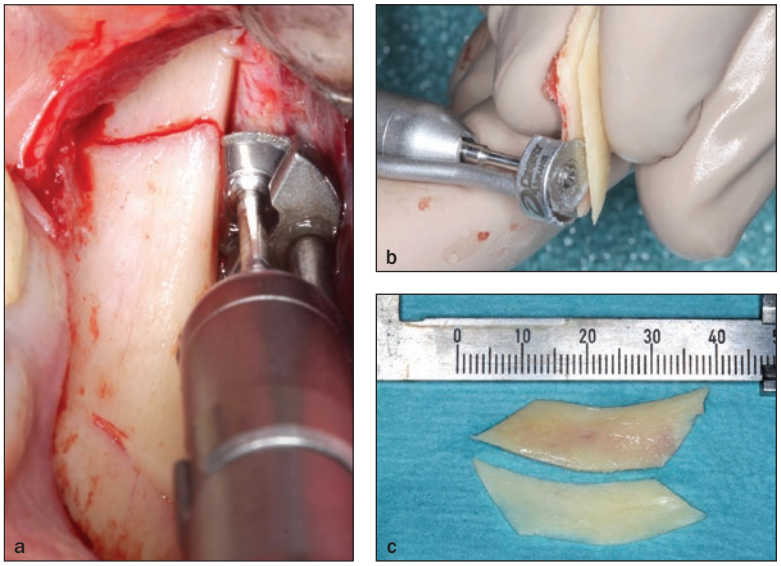

Fig 2a Bone harvesting according to the MicroSaw protocol from the retromolar area.

Fig 2b Longitudinal cutting of the harvested bone blocks into two thin blocks.

Fig 2c The two thin bone blocks after scraping some bone chips from the surface.

Bone blocks were harvested from the mandibular retromolar area following the MicroSaw protocol.[1,23,24] The bone blocks were generally harvested from the same side of the grafted area, eg, left mandibular retromolar area for augmentation of the left posterior maxilla. The dimension of the harvested block was determined by measuring the length of the area of reconstruction (Fig 1). The width had a minimum of 1 cm. The harvesting protocol included three osteotomies performed with the diamond disk: two proximovertical made with the MicroSaw handpiece (Fig 2a) and one baso-horizontal with the contra-angle handpiece. The final osteotomy, on the occlusal crestal site parallel to the external oblique ridge, was achieved with a thin 1-mm drill bur. Small perforations of 3 to 4 mm in depth, parallel to the buccal bone wall, were made with the drill bur at the level of the crestal platform of the external oblique ridge, at a distance approximately 4 mm from the external border of the external oblique line and between the two vertical incisions. These perforations were interconnected using a fine chisel producing tension in the cortical bone, creating a kind of "explosive effect" in the area of the crestal perforations, leading to an easy lateral dislocation of the bone block.[24] The donor site was usually sealed with collagen fleece.

The harvested bone blocks were split longitudinally into two bone blocks with the diamond disk according to the SBB technique of the biologic concept of grafting procedures (Fig 2b). The two blocks were scraped with a bone scraper until a thickness of approximately 1 mm, receiving at the same time a good amount of bone chips (Fig 2c).

The grafting procedure in the posterior maxilla was performed through a tunnel approach. Only a single vertical incision, starting on the mesial third of the last tooth before the edentulous area and going down in the vestibular gingival mucosa in a mesial direction, was necessary for such a technique and was followed by the elevation of a mucoperiosteal flap. This elevation of the flap has to be done very carefully to reach all the buccal and palatal sites around the bony defects, creating an elastic mucoperiosteal tunnel and exposing the alveolar crest until the tuber area (Fig 3a). The bony defect was measured with the PCPNC periodontal probe (Stoma) and documented.

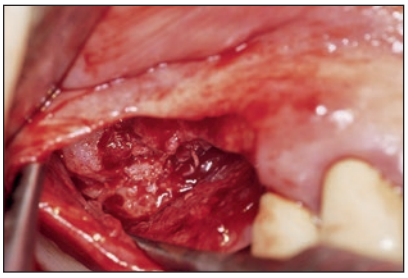

Fig 3a Tunnel preparation with exposure of the vertical bony defect in the right posterior maxilla.

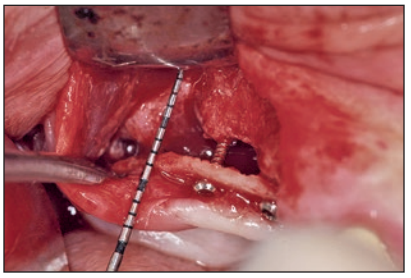

Fig 3b Stabilization of the first bone block under the elevated flap with microscrews.

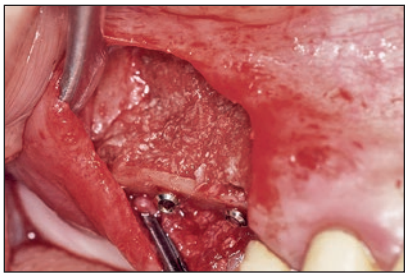

Fig 3c The gap between the bone block and the remaining crest is filled with autogenous bone chips.

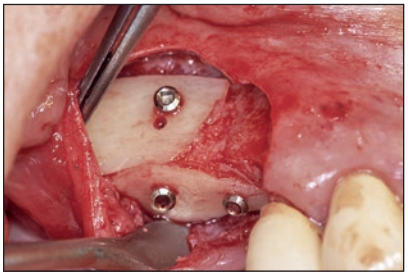

Fig 3d The second bone block is stabilized with microscrews on the vestibular site forming the 3D reconstruction of the bony defect.

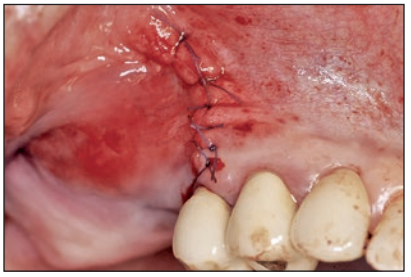

Fig 3e Wound closure of the vertical incision with 6-0 resorbable monofile sutures; no disturbing of the blood circulation over the grafted area.

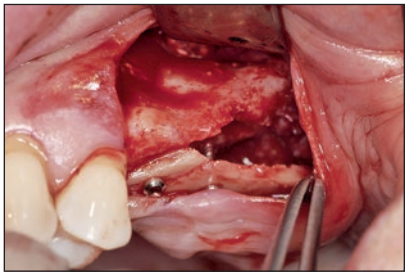

Fig 3f Similar situation in the left maxilla with tunnel preparation and fixation of the first bone block.

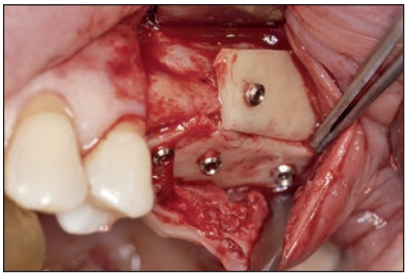

Fig 3g The second bone block covering the bone chips on the vestibular site.

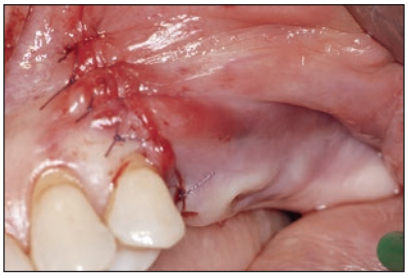

Fig 3h Similar situation as in the right maxilla.

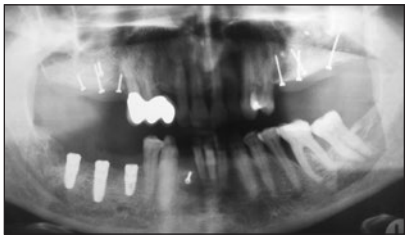

Fig 3i Postoperative radiograph.

The bone scraper was used to harvest bone chips from the lateral vestibular sinus bone wall until the exposure of the sinus membrane, followed by an osteotomy with a small round diamond bur to have an approximately 1-cm oval bony window. The access for the elevation of the sinus mucosa was difficult since the surgery was done through a single vertical incision, making the view very limited. After the careful elevation of the sinus membrane, the area was grafted with autogenous bone chips and a phycogenic hydroxyapatite (Algipore, Dentsply Sirona Implants) according to the layer technique.[1,34] Possible perforation of the sinus membrane was closed with 7-0 resorbable sutures or fibrin glue.[34]

The crestal 3D bone reconstruction was started by introducing one of the thin bone laminae through the vertical incision under the tunnel and placed in a crestal position supported either by the anterior and posterior piers of the defect, or in some cases, only by the anterior pier where no posterior pier was present (Fig 3b). This crestal block was stabilized in the planned position on the distance to the native alveolar crest with at least two microscrews (Stoma). The space between the thin block and the alveolar crest was filled with autogenous bone chips and particulate bone (Fig 3c). The second bone lamina was placed in a vestibular position over the bone chips in such a way as to create a box closing the door on the vestibular site and completing the reconstruction of the defect (Figs 3d and 3e). In many cases, one microscrew was enough to stabilize the vestibular block since this was blocked by the crestal one (Figs 3f to 3i). At the end, the vertical incision was closed in a single layer with 6-0 resorbable monofile sutures (Glycolone 6.0, Resorba).

Three months after the grafting surgery, the screws were removed and the implants were inserted as planned. During this reentry, the width of the augmented crest was measured with the periodontal probe (PCPNC, Stoma Instruments) and documented

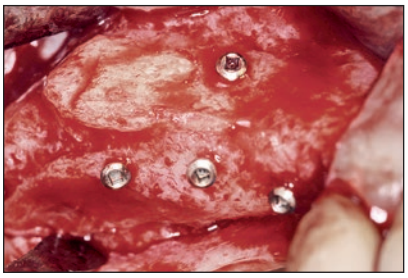

Fig 4a Clinical situation of the regenerated graft in the right maxilla 3 months postoperatively: good macroscopic vascularization with volume stability of the grafted area.

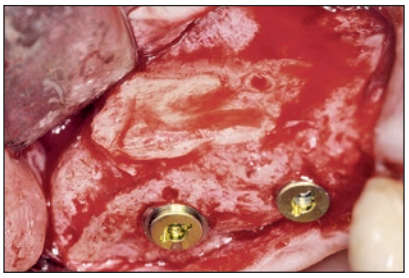

Fig 4b Insertion of two XiVE Implants (diameter 3.8 and 4.5 mm/length 13 mm) in the regenerated area.

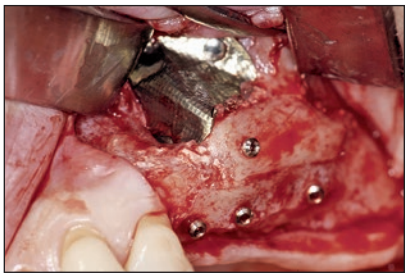

Fig 4c Clinical situation in the left maxilla 3 months postoperatively. The titanium membrane was used to close the sinus window after the sinus floor elevation.

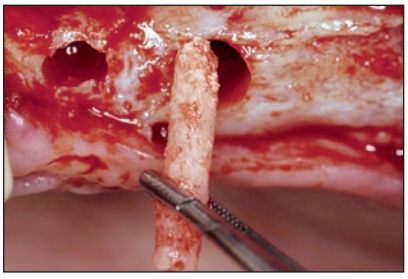

Fig 4d Bone core harvested from the grafted area macroscopically demonstrates the healing quality: the apical third contains the integrated biomaterial of the sinus floor grafting.

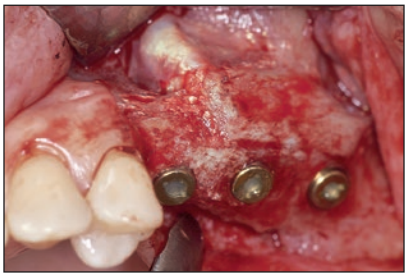

Fig 4e Insertion of three XiVE Implants (length 13 mm/diameter 3.8 and 4.5 mm) on the same level as the bone of the neighboring tooth.

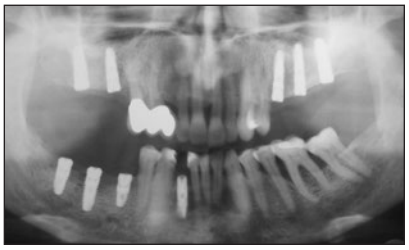

Fig 4f Postoperative radiograph.

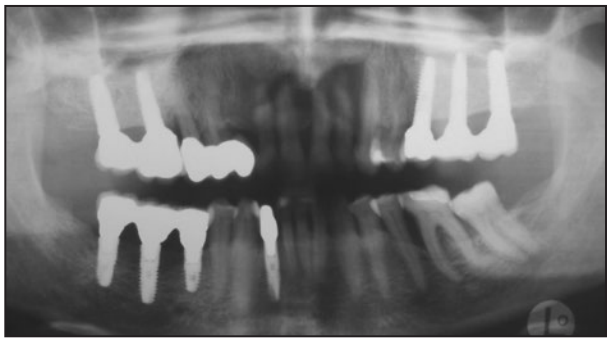

Fig 5a Panoramic radiograph 5 years postoperatively.

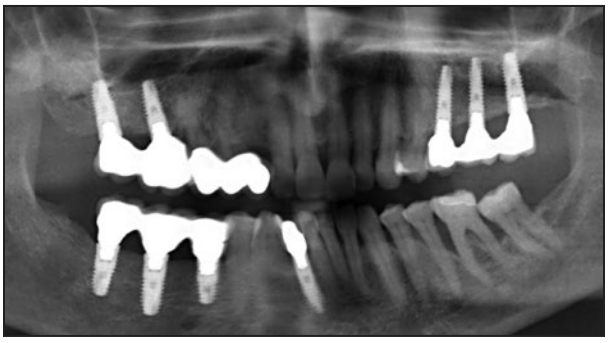

Fig 5b Panoramic radiograph 11 years postoperatively demonstrating bone stability at the grafted areas.

as well as the healing quality (Figs 4a to 4f). Bone cores and chips were gained during implant bed preparation and were used for some local augmentation in case of intensive bone remodeling with some bone resorption. The implants were exposed 3 months later with an apical reposition flap to improve the soft tissue situation through the movement of keratinized tissue from the palate to the vestibule. The prosthetic restoration was started 4 weeks later.

Postoperative Management

The sutures were removed in all the surgeries after 2 weeks. In case of complications related to primary healing as implants or bone exposure, the area was treated with H_2O_2 rinsing, photodynamic decontamination (Helbo, Bredent), and the application of chlorhexidine gel on the exposed areas. Four weeks later, the remaining exposed bone and the exposed microscrew were removed. The results were evaluated by repeated clinical and radiographic examinations according to a standard protocol: clinical postoperative examinations were made after 2, 4, and 12 weeks; then, following completion of the definitive prosthetic treatment, the patients were seen twice a year for evaluation and hygiene maintenance. All examinations included assessment of the peri-implant status, dental hygiene, and functional relationships. Panoramic radiographs were taken preoperatively, postoperatively, after implant exposure, after definitive prosthetic treatment, and then annually (Figs 5a and 5b). In some patients,

CBCT was performed because of other augmentation procedures.

Outcome Measures

This study tested the outcome of 3D vertical bone augmentation in the posterior maxilla.

The outcome measures were:

- Good healing of the surgical site: This was determined clinically by the primary healing of the soft tissue over the grafted area without any tissue necrosis, suppuration, or bone exposure. The soft tissue had to show normal color without any inflammation 2 weeks after the surgery (removal of the sutures) as well as at the reentry.
- Postoperative pain was classified into three groups: heavy pain with the patient taking a total of more than eight analgesics (ibuprofen 400 mg); moderate pain when the patient took between four and eight analgesics; and little pain when the patient needed less than four analgesics.
- Good healing of the grafted bone: This was determined clinically 3 months after the surgery by the normal color of the soft tissue without any pathology as a fistula, abscess, or exposed bone. The reentry had to show a good integrated bone graft with good macroscopic revascularization.
- Volume of the gained bone and its stability after the healing time of 3 months: This was determined by measuring the amount of missing bone on the preoperative panoramic radiograph. The radiologic vertical bone defect was determined by measuring the difference between the crestal bone level of the last tooth close to the defect and the deepest area of the bony defect. Additional measurements were performed intraoperatively by measuring the clinical vertical defect similarly as on the radiograph as well as the clinical horizontal width of the alveolar ridge with the PCPNC periodontal probe. After the grafting procedure, the distance between the crestal bone block and the basal border of the augmented area was measured, documenting the amount of vertical augmentation, as well as the width of the crestal bone block, documenting the width of the new alveolar crest. These measurements were repeated during the reentry for the implant insertion as well as the amount of primary resorption (PR) by measuring the distance from the head of the crestal screw to the surface of the regenerated crest.
- Stability of the grafted area: This was determined through regularly measuring the distance between the implant shoulder and the augmented crestal bone level on the panoramic radiograph and compared with the initial bone level at the time of implant insertion (amount of maximum bone resorption after 1 year [BR1], 3 years [BR3], 5 years [BR5], and 10 years [BR10]). The magnification of the panoramic radiograph was taken into consideration, and the measurements were corrected by comparing the original implant length with its projection on the panoramic radiograph. CBCT was not a requirement for measurement because of unnecessary radiation, but in cases where CBCT was done for other therapeutic reasons, the CBCT data were analyzed for additional information.
- Implant failure: implant mobility, removal of stable implants because of infection, or progressive marginal bone loss.
- Prosthetic failures: Planned prosthetic restoration could not be performed due to implant failure (wrong localization/angulation) or any other reason.

All the data that were saved in a database were updated regularly. The outcome assessment was not conducted by the operator, and therefore, it was independent.

RESULTS

From 2003 to 2007, 142 consecutively treated patients (90 [63.4%] women and 52 [36.6%] men) underwent a vertical 3D bone augmentation in the posterior maxilla in combination with sinus floor elevation through a tunnel approach. The youngest patient was 34 years of age, the oldest was 71 years of age, and the mean age was 58.4 years. There were 35 (24.65%) smokers and 107 (75.35%) nonsmokers or previous smokers (had stopped smoking at least 4 weeks before the surgery); most of the smokers (82.6%) consumed more than 10 cigarettes per day. Twelve patients underwent bilateral 3D reconstruction during the treatment period, so a total of 154 grafted sites were documented. Eighty-six of the surgeries were performed in the left and 68 in the right posterior maxilla. The surgery was performed in 113 patients under local anesthesia and conscious intravenous sedation and in 29, because of multiple bone augmentations and additional surgeries, under general anesthesia. In 149 surgical sites, flap elevation during the tunnel preparation was possible until the required exposure of the bony defect without additional incisions or periosteal dissection, and thus, offering the possibility to perform the 3D reconstruction and the sinus floor elevation. In two cases, a small crestal rupture (up to 8 mm) of the tunnel flap occurred without influencing the outcome of the surgery. In three other cases, dissection of the periosteum was necessary because of the presence of a large amount of scar tissue.

The following intraoperative complications occurred. In three sites, there was heavy bleeding during sinus floor elevation, which was stopped by using a bipolar device. In another 24 sites, a rupture of the sinus membrane up to a diameter of 10 mm was documented. The perforation was closed with 7-0 resorbable sutures and fibrin glue. The primary healing in most of the patients was uneventful without any tissue necrosis or bone exposure, but in six patients (all smokers), small dehiscences occurred on the mesial vertical incision without bone exposure and were treated locally with H_2O_2 rinsing until the wound closed completely within 2 weeks. Little postoperative pain was observed in 57 patients (40.14%), 82 patients (57.75%) had moderate pain, and only three patients (2.11%) had heavy pain.

Late bone exposure 4 to 8 weeks postoperatively due to sharp bone borders was documented in two sites (1 to 3 mm). After rinsing with H_2O_2 and application of chlorhexidine gel, the exposed part of the bone block was removed without any other complications. Infection of the grafted area with abscess and pus occurred in one case, and the origin of the infection was in the grafted sinus. After local treatment with H_2O_2 and saline rinsing, it was possible to control the infection and to continue the treatment as planned.

Soft tissue retraction on the neighboring tooth at the place of the vertical incision was detected in two cases and corrected during implant exposure through connective tissue grafting. Early exposure of screws was documented on 31 augmented sites (20.13%) without influencing the results.

The reentry surgery with the insertion of the implants was performed after 3 months. A total of 356 XiVE Implants (Dentsply Sirona Implants) were inserted into the grafted area with the following diameters: 302 with a diameter of 3.8 mm and 54 implants with a diameter of 4.5 mm. The implant lengths were as follows: 32 implants with a length of approximately 11 mm, 141 with a length of 13 mm, and the remaining 183 implants had a length of 15 mm.

The mean preoperative clinical vertical defect was 7.8 ± 3.9 mm, and the mean clinical horizontal width was 3.1 ± 2.2 mm. Postoperatively, the mean vertical gained area was 7.6 ± 3.4 mm (maximum: 13 mm), and the mean alveolar crestal width reached 8.3 ± 1.8 mm. At reentry, the mean PR was 0.28 ± 0.27 mm; thus, the vertical gained bone was 7.3 ± 2.6 mm (maximum: 13 mm), and the alveolar crestal width was 7.7 ± 1.7 mm. In all patients, it was possible to insert the number of implants as planned without any complication. In 21 sites, an additional small augmentation was performed with local harvested bone. All the implants were successfully restored as planned.

All the patients came to the regular recall in the first 3 years; the mean BR1 was 0.21 ± 0.18 mm, and the mean BR3 was 0.26 ± 0.21 mm. One implant was lost during this time due to nonosseointegration. After this time, one patient died, and eight other patients did not continue to come to the regular recall; thus, after 5 years, only 133 patients were still under regular control (dropout: 6.34%). The mean BR5 was 0.32 ± 0.19 mm with the same survival rate; no additional implants were lost during this time. After 10 years, 118 patients with 127 augmented sites and 306 implants were still under control: 4 patients died, 12 patients moved to another region or outside the country, and 8 patients did not answer the recall letter (total dropout: 16.9%). Three implants were lost during this time due to periimplantitis (0.98%). The mean BR10 was 0.63 ± 0.32 mm; thus, after 10 years, the mean vertically gained bone was stable at 6.82 ± 0.28 mm (maximum: 12 mm). The resorption rate after 10 years was approximately 8.3%.

DISCUSSION

In the context of augmentative measures, there is always a consensus to be reached between a minimally invasive approach, a maximum of predictability, and long-term tissue stability.[3,4]

Within the sinus, as demonstrated in this and other studies, bone substitute material has been shown to be an adequate space-maintaining grafting material due to the favorable and protected defect morphology and allows a reduction of autogenous bone harvesting.[1,34,35]

In terms of alveolar crest reconstruction, there are several augmentative approaches, but many techniques that provide reliable results for lateral augmentation, for example, with resorbable membranes and bone replacement materials such as xenografts or allografts, seem to find their limits in vertical tissue retrieval.[1–4]

The challenge in the context of vertical augmentation is, above all, the creation of a 3D space, which at the same time protects the transplant for a secure integration and stabilizes it sufficiently. For promising vertical reconstructions, distraction osteogenesis[36–38] or augmentation techniques with nonresorbable membranes[7–10] or bone blocks[1,21,22] are currently available.

Techniques such as distraction osteogenesis, appropriate for vertical tissue volume gain, fail in the posterior maxilla because they are only suitable for certain anatomical regions.[36–38]

For vertical bone augmentation procedures, the most appropriate membranes are the nonresorbable in combination with membrane-enhancing measures. The most common complication of nonresorbable membranes is exposure, which has a detrimental effect on the final outcome with both types

of membranes.[12,13] To achieve vertical alveolar dimension, screwable, xenogenous deproteinized blocks,[14,15] allogeneic block bone grafts,[39,40] screw fixation of 3D printed monetite blocks,[16] and three-dimensional printed calcium phosphate porous structures[17] were used as scaffolds. However, available studies are based on case reports or short clinical trials.[3,4,8,39–42] In addition, these techniques are characterized by a long treatment time with a graft healing time of 9 to 12 months before implant placement.[3,4,7,39,40]

The SBB technique used in this study is independent of the defect morphology and can be adapted by an appropriate preparation of autogenous bone block graft. Furthermore, a very low primary as well as late complication rate can be determined, especially with respect to tissue necrosis and dehiscence as well as in patients who are smokers. One reason for this could, of course, be the protective effect of the tunneling soft tissue approach, keeping the flap vascularization over the grafted bone intact,[28–31] but additionally, it could be the fact that artificial membranes were kept off. Thus, the soft tissue flap was in touch with its natural surface, namely, the bone. This seems to favor a faster and more stable reattachment over the entire length of the flap with the underlying surface compared to an underlying artificial membrane.[1,2,12,13]

From today's perspective, the clinical use of autogenous bone block grafts seems to be indispensable for a predictable augmentation result within the scope of vertical reconstructions.[1,3,4,19,21,23,25,31] This is due to the osteoconductive, above all, osteoinductive, and osteogenetic potential of autogenous transplants.[1,3,4] The potential of osteoinduction and ostegenesis also accelerates the formation of new bone and thus leads to a reduction of the treatment time compared to augmentation techniques with bone substitute material. In addition, due to the stiffness of the autogenous bone blocks, an absolute stability of the created 3D space is obtained, which ensures the integration of the transplant and leads to less irritation during the healing phase compared with guided bone regeneration techniques using membranes.[1,23,26–28]

Besides the stability of a graft, sufficient graft volume is desirable. For extensive defects, transplants from the hip or the calvaria were often unavoidable.

In the present study, mandibular grafts were split longitudinally and additionally thinned with a bone scraper.[1] This not only increased the number of bone blocks available for augmenting, but also increased the overall graft surface and volume exponentially. This often makes it possible to dispense with extraoral transplants, even with extensive vertical reconstructions. In addition to increasing the volume of the graft, the thinning of the mandibular blocks also causes a surface enlargement of the graft by creating small pieces of bone. This, in turn, causes an improvement of the graft's osteoconductive potential and thus its accelerated revascularization and regeneration.[25,27]

One reason for the controversial volume stability of autogenous bone transplants discussed in the literature, therefore, appears to be the different processing of the bone block transplants.[1,15,16] The described resorption of autogenous bone block grafts is usually attributable to the use of mandibular full-thickness bone block grafts, which, due to their low surface area, are exposed to many remodeling effects such as osteoclast activity in nonrevitalized transplant areas and ultimately end in volume loss.[1] In further studies, biopsy specimens from the newly formed alveolar crest reconstructed with the presented technique of 3D augmentation showed an intensive revascularization and a large proportion of newly formed bone within only 3 months, on the day of implant placement.[1] This, in turn, explains the volumetric long-term bone stability of the reconstructed alveolar crest over the period of 10 years with BR10 of 0.63 ± 0.32 mm, stable vertically gained bone up to 12 mm, with a mean of 6.82 ± 0.28 mm, and a 98.1% survival rate.

The measurement of the gained bone height was performed clinically during the entry with the PCPNC periodontal probe in relation to the bone level of the neighboring teeth. These measurements are not very precise as with the use of a template, but are enough to document the difference compared with the preoperative situation. The stability of the grafted bone was measured on panoramic radiographs, which are also not very precise due to distortion. The use of CBCT and CT can give more precise details about the bone volume, but their use for study reasons is not ethical due to the high radiation. However, in cases where CBCT was done for other therapeutic reasons, the CBCT data confirmed these measurements. This was the case in 24 patients.

As a disadvantage of the technique described in this study, the necessity of autogenous bone graft harvesting can be considered. However, clinical studies show that autogenous bone graft harvesting is reproducible and safe to perform.[1,23,24] With regard to 97.89% of patients shown in this study with low or moderate pain perception as well as the low complication rate during the process of bone harvesting,[24] the use of autogenous transplants seems to be justified considering the treatment safety, predictability, and long-term tissue stability achieved.

One of the key factors for successful vertical augmentation is soft tissue management.[1,23–31] Depending on the defect size and defect localization, different flap designs and approaches are to be selected. The tunnel approach seems to be an adequate solution, especially in the cases of vertical reconstructions, since a crestal cut above the transplant is avoided, thus reducing the

risk of postoperative dehiscence.[1,28–31] Also, in this study, early complications could be completely avoided, even in the case of smoker patients, by the applied tunnel technique. The disadvantages of the described tunnel technique are the reduced access and the restricted view to the augmentation field. However, all challenges arising during the augmentation, such as perforations of the sinus membrane or bleeding occurring, could be solved without compromise. In this respect, the advantage of tunneling technology has been predominant, especially in view of the fact that the periosteum is retained during the preparation, and thus, the bone graft remains directly in contact with it. In addition to hermetic wound closure, intensive transplant regeneration is initiated.[1] This might be another reason that in all cases involved in this study, implants could be inserted in a proper implant-prosthetic position after 3 months of transplant healing.

In clinical comparison to results of guided bone regeneration techniques described in the literature with the SBB technique described in the present study for the reconstruction of the posterior maxilla, the same vertical alveolar ridge regeneration can be achieved with both techniques. However, the SBB technique seems to be associated with fewer complications such as dehiscence and infections and allows a significant reduction in patient treatment time.[1,3,4,7–9,39,40]

With an implant survival rate of 98.7% after 10 years in this study, the probability of the success of implants inserted in vertically reconstructed alveolar ridges in the posterior area of the maxilla is that of implants in nonaugmented bone.[43]

CONCLUSIONS

The described vertical augmentation technique in the posterior maxilla performed according to the SBB technique using a tunneling flap approach is a predictable and safe method. Compared with open-flap techniques, tunneling allows hermetic soft tissue closure, which is characterized by a reduction of dehiscence, and secure bone graft healing as well in smoker patients. The combination of thin autogenous bone blocks and bone particles according to the SBB technique allows an acceleration of transplant revascularization and thus of graft regeneration, allowing a shortening of the patient treatment time as well as long-term 3D volumetric bone stability in the area of the vertically reconstructed posterior maxilla.

ACKNOWLEDGMENTS

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

REFERENCES

1. Khoury F, Khoury Ch. Mandibular bone block grafts: Diagnosis, instrumentation, harvesting techniques and surgical procedures. In: Khoury F, Antoun H, Missika P (eds). Bone Augmentation in Oral Implantology. Berlin, London: Quintessence, 2006:115–212.
2. Hämmerle CH, Jung RE, Feloutzis A. A systematic review of the survival of implants in bone sites augmented with barrier membranes (guided bone regeneration) in partially edentulous patients. J Clin Periodontol 2002;29(suppl 3):226–231; discussion 232–233.
3. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P. The efficacy of horizontal and vertical bone augmentation procedures for dental implants - a Cochrane systematic review. Eur J Oral Implantol 2009;2:167–184.
4. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P. Interventions for replacing missing teeth: Horizontal and vertical bone augmentation techniques for dental implant treatment. Cochrane Database Syst Rev 2009;CD003607.
5. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. J Clin Epidemiol 2008;61:344–349.
6. Llambés F, Silvestre FJ, Caffesse R. Vertical guided bone regeneration with bioabsorbable barriers. J Periodontol 2007;78:2036–2042.
7. Urban IA, Jovanovic SA, Lozada JL. Vertical ridge augmentation using guided bone regeneration (GBR) in three clinical scenarios prior to implant placement: A retrospective study of 35 patients 12 to 72 months after loading. Int J Oral Maxillofac Implants 2009;24:502–510.
8. Fontana F, Santoro F, Maiorana C, Iezzi G, Piattelli A, Simion M. Clinical and histologic evaluation of allogeneic bone matrix versus autogenous bone chips associated with titanium-reinforced e-PTFE membrane for vertical ridge augmentation: A prospective pilot study. Int J Oral Maxillofac Implants 2008;23:1003–1012.
9. Misch CM, Jensen OT, Pikos MA, Malmquist JP. Vertical bone augmentation using recombinant bone morphogenetic protein, mineralized bone allograft, and titanium mesh: A retrospective cone beam computed tomography study. Int J Oral Maxillofac Implants 2015;30:202–207.
10. Urban IA, Monje A, Wang HL. Vertical ridge augmentation and soft tissue reconstruction of the anterior atrophic maxillae: A case series. Int J Periodontics Restorative Dent 2015;35:613–623.
11. Dahlin C, Johansson A. Iliac crest autogenous bone graft versus alloplastic graft and guided bone regeneration in the reconstruction of atrophic maxillae: A 5-year retrospective study on cost-effectiveness and clinical outcome. Clin Implant Dent Relat Res 2011;13:305–310.
12. Cucchi A, Vignudelli E, Napolitano A, Marchetti C, Corinaldesi G. Evaluation of complication rates and vertical bone gain after guided bone regeneration with non-resorbable membranes versus titanium meshes and resorbable membranes. A randomized clinical trial. Clin Implant Dent Relat Res 2017;19:821–832.
13. Soldatos NK, Stylianou P, Koidou VP, Angelov N, Yukna R, Romanos GE. Limitations and options using resorbable versus nonresorbable membranes for successful guided bone regeneration. Quintessence Int 2017;48:131–147.
14. Felice P, Marchetti C, Piattelli A, et al. Vertical ridge augmentation of the atrophic posterior mandible with interpositional block grafts: Bone from the iliac crest versus bovine anorganic bone. Eur J Oral Implantol 2008;1:183–198.
15. Rothamel D, Schwarz F, Herten M, et al. Vertical ridge augmentation using xenogenous bone blocks: A histomorphometric study in dogs. Int J Oral Maxillofac Implants 2009;24:243–250.
16. Tamimi F, Torres J, Gbureck U, et al. Craniofacial vertical bone augmentation: A comparison between 3D printed monolithic monetite blocks and autologous onlay grafts in the rabbit. Biomaterials 2009;30:6318–6326.
17. Carrel JP, Wiskott A, Scherrer S, Durual S. Large bone vertical augmentation using a three-dimensional printed TCP/HA bone graft: A pilot study in dog mandible. Clin Implant Dent Relat Res 2016;18:1183–1192.

18. Sakkas A, Ioannis K, Winter K, Schramm A, Wilde F. Clinical results of autologous bone augmentation harvested from the mandibular ramus prior to implant placement. An analysis of 104 cases. GMS Interdiscip Plast Reconstr Surg DGPW 2016;5:Doc21.
19. Marianetti TM, Leuzzi F, Pelo S, Gasparini G, Moro A. J-graft for correction of vertical and horizontal maxillary bone defects. Implant Dent 2016;25:293–301.
20. Miyamoto I, Funaki K, Yamauchi K, Kodama T, Takahashi T. Alveolar ridge reconstruction with titanium mesh and autogenous particulate bone graft: Computed tomography-based evaluations of augmented bone quality and quantity. Clin Implant Dent Relat Res 2012;14:304–311.
21. Gultekin BA, Cansiz E, Borahan MO. Clinical and 3-dimensional radiographic evaluation of autogenous iliac block bone grafting and guided bone regeneration in patients with atrophic maxilla. J Oral Maxillofac Surg 2017;75:709–722.
22. Restoy-Lozano A, Dominguez-Mompell JL, Infante-Cossio P, Lara-Chao J, Lopez-Pizarro V. Calvarial bone grafting for three-dimensional reconstruction of severe maxillary defects: A case series. Int J Oral Maxillofac Implants 2015;30:880–890.
23. Khoury F, Khoury C. Mandibular bone block grafts: Instrumentation, harvesting technique and application. Journal de Parodontologie & d´Implantologie Orale 2006;25:15–34.
24. Khoury F, Hanser T. Mandibular bone block harvesting from the retromolar region: A ten years prospective clinical study. Int J Oral Maxillofac Implants 2015;30:688–697.
25. Stimmelmayr M, Beuer F, Schlee M, Edelhoff D, Güth JF. Vertical ridge augmentation using the modified shell technique—a case series. Br J Oral Maxillofac Surg 2014;52:945–950.
26. Khoury F, Happe A. Soft tissue management in oral implantology: A review of surgical techniques for shaping an esthetic and functional peri-implant soft tissue structure. Quintessence Int 2000;31:483–499.
27. Khoury F. Augmentation osseuse et chirurgie implantaire: Facteurs de prognostic [article in French]. Implant 1999;5:221–237.
28. Ponte A, Khoury F. The tunnel technique in bone grafting procedures: A clinical study [abstract]. Int J Oral Maxillofac Implants 2004;19:766.
29. Mazzocco C, Buda S, De Paoli S. The tunnel technique: A different approach to block grafting procedures. Int J Periodontics Restorative Dent 2008;28:45–53.
30. De Stavola L, Tunkel J. Results of vertical bone augmentation with autogenous bone block grafts and the tunnel technique: A clinical prospective study of 10 consecutively treated patients. Int J Periodontics Restorative Dent 2013;33:651–659.
31. Restoy-Lozano A, Dominguez-Mompell JL, Infante-Cossio P, Lara-Chao J, Espin-Galvez F, Lopez-Pizarro V. Reconstruction of mandibular vertical defects for dental implants with autogenous bone block grafts using a tunnel approach: Clinical study of 50 cases. Int J Oral Maxillofac Surg 2015;44:1416–1422.
32. Joos U, Kleinheinz J. Reconstruction of the severely resorbed (Class VI) jaw: Routine or exception? J Craniomaxillofac Surg 2000;28:1–4.
33. Khoury F, Tunkel J. Bone augmentation and soft tissue management. In: Khoury F, Antoun H, Missika P (eds). Bone Augmentation in Oral Implantology. Berlin, London: Quintessence, 2006:75–114.
34. Khoury F, Keller P, Keeve PL. Stability of grafted implant placement sites after sinus floor elevation using a layering technique: 10-year clinical and radiographic results. Int J Oral Maxillofac Implants 2017;32:1086–1096.
35. Esposito M, Grusovin MG, Rees J, et al. Effectiveness of sinus lift procedures for dental implant rehabilitation: A Cochrane systematic review. Eur J Oral Implantol 2010;3:7–26.
36. Cheung LK, Chua HD, Hariri F, Pow EH, Zheng L. Alveolar distraction osteogenesis for dental implant rehabilitation following fibular reconstruction: A case series. J Oral Maxillofac Surg 2013;71:255–271.
37. Wolvius EB, Scholtemeijer M, Weijland M, Hop WC, van der Wal KG. Complications and relapse in alveolar distraction osteogenesis in partially dentulous patients. Int J Oral Maxillofac Surg 2007;36:700–705.
38. Chiapasco M, Romeo E, Casentini P, Rimondini L. Alveolar distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: A 1-3-year prospective study on humans. Clin Oral Implants Res 2004;15:82–95.
39. Lee EY, Kim ES, Kim KW. Vertical augmentation of maxillary posterior alveolar ridge using allogenic block bone graft and simultaneous maxillary sinus graft. Maxillofac Plast Reconstr Surg 2014;36:224–229.
40. Schlee M, Rothamel D. Ridge augmentation using customized allogenic bone blocks: Proof of concept and histological findings. Implant Dent 2013;22:212–218.
41. Potres Z, Deshpande S, Klöeppel H, Voss K, Klineberg I. Assisted wound healing and vertical bone regeneration with simultaneous implant placement: A histologic pilot study. Int J Oral Maxillofac Implants 2016;31:45–54.
42. Zigdon-Giladi H, Bick T, Lewinson D, Machtei EE. Mesenchymal stem cells and endothelial progenitor cells stimulate bone regeneration and mineral density. J Periodontol 2014;85:984–990.
43. Javed F, Romanos GE. Role of implant diameter on long-term survival of dental implants placed in posterior maxilla: A systematic review. Clin Oral Investig 2015;19:1–10.