The Ti-Mesh Technique: Guided Bone Regeneration for Three-Dimensional Augmentations. Clinical Aspects: A Case Series

Piotr Majewski, DDS, PhD

This article presents the surgical aspects of, and evaluates bone dimensional changes following, the application of the guided bone regeneration (GBR) technique using individualized titanium mesh on atrophied alveolar ridges to achieve an optimal crest volume for implant placement. Six patients were included and evaluated clinically and radiologically for at least 3 years. Every patient presented bone resorption affecting implant placement in a proper prosthetic position. During the regenerative procedure, customized titanium mesh was used to secure the contour of the augmented site and the stability of xenograft particles deposited on the atrophied crest. After 6 months of healing, the mesh was removed, and implants were placed in planned, prosthetic positions. CBCT scans were taken before the regenerative procedures and after 6 months, before the second-stage surgeries. This allowed for assessment of the postaugmentation vertical and horizontal bone tissue gain. The average volumetric gain of the augmented sites was 5.2 mm horizontally and 2.75 mm vertically. In 50% of cases, minor soft tissue perforation was observed after a few weeks. This complication did not influence the implant placement procedure and was treated during the second-stage procedure with the GBR technique, using a resorbable membrane and xenograft particles to compensate the localized bone defect. No implant failed during the control period. Panoramic radiographs were taken 1 to 3 years after completion of definitive prosthetic treatment to assess potential bone resorption around implants. No crestal bone resorption was observed within this period. It can be concluded that the use of customized titanium mesh is a predictable technique for bone regeneration in advanced, three-dimensional defects. Int J Periodontics Restorative Dent 2022;42:145–153. doi: 10.11607/prd.5692

Tooth loss results in bone resorption that makes implant placement difficult or impossible. There are many regenerative techniques and bone substitutes used to augment atrophic bone. Some of them utilize autogenous or allogenic bone blocks, while others, like guided bone regeneration (GBR) procedures, use bone-substitute particles with barrier membranes.1–4 Selecting the appropriate augmentation technique is one of the most important factors for success.5 It has an impact on biologic regeneration and implant osseointegration. Independently from the surgical technique, several clinical and biologic rules must be followed to achieve optimum results.6 Stabilization of grafted material in the bone defect is the prerequisite that allows for vascularization of the transplanted material and initialization of the biologic response, leading to new vital bone formation.7 It also prevents fibrous tissue ingrowth, which is regarded as the “unwanted” component in the regenerated area. GBR procedures utilize particulate bone substitutes, such as bone chips, allogen, xenografts, or alloplast granules, together with the barrier membranes.8–10 Thus, several techniques have been developed to stabilize the grafted material and to maintain the contour of the augmented space. These surgical procedures include
The present article describes the GBR technique with customized titanium mesh, which acts as a stable “cage” that protects the stability of deposited bone substitute granules. The individualized meshes are prepared prior to surgery on the basis of the images derived from CBCT scans, and these meshes facilitate the surgical procedure. They present passive fit on the bone, allowing precise contouring of the augmented site. Due to special design, they are easy to remove during the second-stage surgery.

Materials and Methods

A total of six patients (three men, three women) were treated between 2015 and 2017 for three-dimensional bone resorption. All patients were older than 18 years. Prior to treatment, informed consent was obtained from patients regarding the treatment protocol. The inclusion criteria were as follows: general contraindications for implant therapy that might influence bone tissue turnover or exclude the patient from surgical procedure; systemic diseases (such as uncontrolled diabetes), intravenous bisphosphonate use, or chemotherapy treatment; and untreated local oral pathology, poor oral hygiene, smoking, pregnancy, and nursing. The treatment plan was made based on CBCT scans taken prior to treatment (PAX-i3D Green 16, Vatech). The width and height of the resorbed crest was measured in the area of interest. All meshes used in the augmentation procedures were planned and produced on the basis of CBCT scans. Each individualized titanium mesh was designed and prepared prior to the surgery using CAD/CAM technology (Re-Oss). The shape of the mesh corresponded with the bone defect and the previously planned contour of the augmentation region. The special design of the meshes facilitated their fragmentation and removal during second-stage surgery (see Case 1). Rigid titanium meshes were used for advanced/multiple tooth defects in cases of extensive vertical and horizontal ridge defects. The graft particles were placed and packed inside the titanium mesh. The meshes were filled with the mixture of xenograft granules (Bio-Oss, Geistlich) and autogenous bone particles (1:1 ratio). The autogenous material was harvested using a bone scraper (Micross, Meta) at the area adjacent to the augmented region or by means of a trephine drill (ACM, NeoBiotech) at the retromolar region in the mandible. The meshes were then stabilized on the host bone with two mini screws (Ergo-plant Bone Fixation, Aesculap Dental Instruments). After 6 months of healing, the second-stage procedure/implant placement was performed. The alveolar ridge was assessed with intraoral examination (shape, volume, soft tissue status). CBCT scans were performed to measure the bone dimensions and estimate volume gain following the reconstructive surgery. The measurements were performed in two sections for each patient: before regenerative surgery and after 6 months, prior to second-stage surgery. The new created tissue was recognized on the radiographs as the more radiopaque zone, whereas the native residual crest was more radiolucent. The horizontal dimension was measured 4 mm apically from the top of the residual crest, before and after regenerative surgery. The vertical gain was measured from the top of the residual crest to the most apical point of the newly created ridge shape. The follow-up was at least 3 years postoperative. One year after completion of prosthetic treatment, the orthopantomographs were taken to estimate the bone level around implants situated in regenerated tissue.

Surgical Procedure

All surgeries were done by the same surgeon (P.M.) under local anesthetic (Ubistesin 4%, 3M ESPE; 4 to 6 mL, 1:2000,000) with antibiotic prophylaxis (600 mg clindamycinum 1 hour before surgery, and 600 mg
twice daily beginning the day before surgery and continuing until 5 days postsurgery. Patients were advised to rinse their mouths twice a day with 0.2% chlorhexidine fluid (Eludril, Pierre Fabre Oral Care), beginning 2 days before surgery and continued 10 days postsurgery.

In all cases, one horizontal midcrestal incision and two vertical releasing incisions were performed, and a full-thickness mucoperiosteal flap was elevated to access the bone defect. The flap was extended at least 5 mm away from the defect so that the prepared mesh could be seated on the bone surface surrounding the defect. The flap was then elongated by a horizontal periosteum incision to facilitate tension-free wound closure after bone augmentation. The cortical wall of the recipient bed was perforated into the marrow space to enhance bleeding, which supplies osseointductive factors from the host bed, and to promote graft revascularization.19 The graft material was in direct contact with the recipient bone bed. The wounds achieved primary closure with both horizontal mattress sutures and single interrupted sutures. Additionally, analgesics were prescribed (500 mg paracetamol or 50 mg ketoprofen up to three times a day, according to individual needs). Sutures were removed 10 to 14 days after surgery. Patients were not allowed to wear dentures for a minimum of 1 to 2 weeks; after that period, dentures were adjusted and relined with soft material.

Case 1
Case 1 illustrates the reconstruction of an alveolar ridge in the maxillary left lateral incisor and canine region. The implant position was planned in native bone, but due to a narrow ridge (Fig 1), it was decided to perform the bone augmentation procedure with autogenous bone particles mixed with xenograft, utilizing titanium mesh. The autogenous bone particles were collected from the outer aspect of maxillary sinus wall, distal to regenerated area (apically to teeth 25 and 26; FDI tooth-numbering system). Prior to placing the biomaterial, the mesh was checked for precise fit and stability (Figs 2 and 3). The autogenous bone and xenograft particles were mixed together and packed inside the mesh (Fig 4). The titanium mesh was stable due to the precise shape, but two mini screws were used to prevent unintentional mesh movement during the regenerative period (Fig 5). Prior to second-stage surgery, another CBCT scan was performed (Fig 6). The second surgery was performed with the same recommendations for patients and with the same antibiotic and rinsing fluid coverage as during the first procedure. After flap elevation, the titanium mesh was divided into two parts due to a special design (described in the Discussion) and easily removed (Fig 7). The tissue underneath the mesh was stable, and vital (bleeding) bone was identified within the regenerated site (Fig 8). The amount
of tissue created vertically from the palatal and labial sites allowed for optimal implant positioning within the bone housing (Fig 9).

**Case 2**

Case 2 presents alveolar ridge augmentation in the anterior maxilla (Fig 10). The bone and xenograft particles were secured with the individualized titanium mesh, whose design took into account the horizontal (mainly labial aspect) and vertical augmentation (Fig 11). This case encountered the most common complication associated with this procedure. After 6 weeks, tissue fenestration was observed, exposing the central fragment of the mesh. The patient was asked to stop wearing the denture. The tissue fenestration and mesh exposure were left to heal on their own, and control follow-up appointments were advised every week to observe the soft tissue healing. The patient was under a strict regime of oral hygiene (chlorhexidine rinsing twice a day for 2 weeks and continuous Solcoseryl paste (Mylan Healthcare) use in the area of tissue perforation). After 1 week, the soft tissue started to heal
under the fragment of the exposed mesh, relining and closing the wound (Fig 12). The situation was left for the next 7 months, when the second-stage surgery (implant placement) was performed. After flap elevation, the mesh was removed. Fibrous tissue was observed in the area of fenestration, penetrating into the augmented region, and needed to be curetted. The soft tissue only penetrated the superficial layer of the augmented area in the region of the perforation. The implants were placed according to the surgical stent in the optimal prosthetic position with a primary stability of 30 to 35 Ncm. The newly created alveolar ridge was recognized as stable tissue. After implant placement, the implant in site 22 was exposed. The threads were covered (Figs 13 and 14) with a minor additional regenerative procedure (Bio-Oss xenograft particles and Bio-Gide membrane, Geistlich) to overcome the deficient tissue volume at the site of the mesh fenestration. Three tenting screws were used to support the resorbable membrane. The flap achieved primary closure.

Fig 10  Case 2. Horizontal, labial resorption of an anterior maxilla. Cortical perforations were made prior to augmentation.

Fig 11 The titanium mesh was filled with the composite xenograft and autograft particles (1:1 ratio) and fixated at the site using two mini screws.

Fig 12  Mesh exposure 6 weeks after surgery (image taken 2 weeks after exposure). Note the epithelialization under the exposed mesh.

Fig 13  The implants were placed in a preplanned position. The implant at site 22 has exposed threads visible. Three tenting screws were used for additional vertical and horizontal augmentation, which compensated for the volume loss in the region of mesh exposure.

Fig 14  Xenograft particles were deposited in the area of implant exposure, and a resorbable membrane was fixed over the tenting screw.
After 4 months, the implants were uncovered (Fig 15), and the screw-retained prosthetic bridge was fixed on the implants. The tissue architecture was restored with pink porcelain in the prosthetic suprastructure (Fig 16).

Results

The individualized meshes were used for more advanced, three-dimensional bone resorption cases. They defined the required amount of regenerative volume; were easy to mount, place, and fix; and were easy to remove in pieces due to the special framework design. The meshes were removed, revealing stable tissues with xenograft particles incorporated in the native bone. The average crest width before augmentation was 3.75 mm, increasing to 8.9 mm after the healing period. The average horizontal bone tissue augmentation was 5.2 mm. The average vertical augmentation was 2.75 mm. Table 1 reports the results of radiographic evaluations of alveolar bone gain during the study. The newly created dimensions of the augmented alveolar crest allowed for implant placement within the bony housing according to the prosthetic treatment plan.

In three cases (50%), wound dehiscence appeared over the titanium mesh 4 to 6 weeks after surgery; however, during the following 1 to 2 weeks, the dehiscence healed and its bottom was lined with epithelium. Neither suppuration nor granulation tissue was noticed. The titanium meshes did not have to be removed in any of the present cases. During the reentry procedures, in exposed areas, a layer of loose connective tissue with xenograft particles was noticed; however, hard new bone with incorporated xenograft particles was present beneath the tissue.

The soft tissue was removed, and a small, second grafting (with resorbable collagen membrane) was performed during implant placement. The implants were placed with optimal primary stability in the native residual bone and reconstructed alveolar ridge. Follow-ups were performed at 6 months, 1 year, and every year after the completion of prosthetic treatment, during which the implants placed in the reconstructed region were evaluated and showed optimal peri-implant tissue stability. There was no sign of bone resorption or soft tissue dehiscence around implants. The thickness of the alveolar ridge surrounding implants allowed for the preservation of at least a 2-mm zone of keratinized tissue. There was no sign of bleeding on probing, and pocket depths were ≤ 2 mm while checking the peri-implant soft tissue status. The panoramic radiographs taken 24 months after definitive prosthetic treatment showed no
Discussion

The GBR procedures face clinical and biologic challenges, and proper clinical execution must be performed according to the principal rules (PASS rules: primary wound closure, angiogenesis, stability, and space maintenance). Stability of the grafted material is a prerequisite for vascularization and new bone ingrowth from the residual bed. The grafted particles cannot necessarily maintain a stable contour. Thus, GBR procedures utilize membranes or templates that fulfill not only biologic tasks (exclusion of non–bone-forming cells and soft tissue ingrowth) but also mechanical protection of biomaterial granules, sustaining the pressure from the surrounding soft tissues. The membranes/templates should also support and maintain the contour of the reconstructed region during the regeneration process. Different techniques have been developed to achieve desirable results; among them are the tent techniques, Urban’s “sausage technique,” and utilizing resorbable membranes, and titanium-reinforced nonresorbable membranes, titanium meshes, or titanium foils are also used. Procedures with collagen membranes are mostly used in horizontal augmentations and less in vertical and three-dimensional augmentations.

The nonresorbable membranes are used in two- or three-dimensional defects, as these kind of membranes (especially titanium-reinforced membranes) maintain the contours of the area. One should take into account the complications, mostly soft tissue dehiscence that may lead to bone loss rather than the formation of the desired tissue. The use of xenografts and alloplasts in GBR techniques leads to creation of the “bone-like” tissue, in which both the new bone formation and the biomaterial particles and fibrous tissue make the tissue conglomerate. The “gold-standard” autogenous bone graft with its osteoinductive and osteogenetic properties enhances the regenerative capacity. The autogenous material is subject to bone turnover by “creeping substitution” into the new vital bone, with minimal traces of undesired fibrous tissue in the regenerated area. Thus, in the present GBR techniques, a mixture of xenograft granules and autogenous bone particles in a 1:1 ratio was used. The xenograft particles (as the nonresorbable or slowly resorbable materials) remain stable over subsequent years, making a scaffold of the augmented region for long-term stabilization of the grafted site. The use of 100% autogenous bone chips in GBR techniques is not

| Table 1 Radiographic Evaluation of Horizontal and Vertical Alveolar Bone Gain |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|                             | Patient no.                | 1                           | 2                           | 3                           | 4                           | 5                           | 6                           |
| Horizontal dimension        |                             | 1                           | 2                           | 3                           | 4                           | 5                           | 6                           |
| Baseline                    | Horizontal bone gain       | 3.0                         | 5.0                         | 4.0                         | 2.0                         | 3.0                         | 4.0                         | 3.75                        |
| After surgery               | Vertical gain              | 9.0                         | 11.0                        | 8.0                         | 9.0                         | 9.0                         | 9.0                         | 8.9                         |
| Gain after regeneration     | Vertical gain              | 6.0                         | 6.0                         | 4.0                         | 7.0                         | 6.0                         | 5.0                         | 5.2                         |

Measurements are presented in millimeters. Horizontal bone gain is calculated as the difference between the average width before (baseline) and after regeneration. Vertical bone gain was measured 6 months after regeneration, from the original bone level to the top of the new created crest. Measurements were taken across the ridge, 4 mm below the top of the crest and always in two places (hence the two values shown per patient). The distance between the sections was 4 mm. The measurements were performed in the planned implant position, and they helped define the thickness changes in the implant site.
recommended due to the resorption rate of this grafting material.8–10

The standard meshes need to be shaped during surgery, as they are produced for plates of different sizes that must then be adapted according to the clinical situation. The accuracy of the mesh is compromised due to the stiffness of the material while adjusting and trimming the edges according to the shape of the bone defect. The passive, CAD/CAM-prefabricated, patient-specific Re-Oss meshes allow for a precision fit without additional adjustments during surgery. The constructions have smooth edges and are better adapted in the soft tissue under the flap. The special design allows the removal of the device without performing an extensive full-thickness flap during the second-stage surgery. As with other GBR techniques, soft tissue dehiscence is one of the problems that may influence the healing process. It should be taken into consideration that meshes are situated directly under the flap; from this position, they exert pressure and tension on the soft tissue covering the augmented region. In addition, when patients in the present study were using the removable dentures, the soft tissue was squeezed between the mesh and the denture. This problem was observed in 50% of the present cases. These findings are in accordance with other authors who found a similar rate of exposure.21 In three of the present cases, the soft tissue perforation happened after a few weeks (4 to 6 weeks), not during the first stages of wound healing. Thus, this complication should be regarded as a perforation and not as a dehiscence, which happens mostly when using the non-resorbable polytetrafluoroethylene (PTFE) membranes. The soft tissue dehiscence over the Gore-Tex membranes leads to inflammation of the grafted materials under the membrane, which may impair the regenerative process.22,23 Treatment mostly relies on immediate membrane and biomaterial removal. The soft tissue perforation over the mesh was limited in all cases. Only part of the mesh was exposed, and when the patient was under controlled observation with a strict oral hygiene regime, the soft tissue started to heal after a few days, with epithelialization under the exposed part of the mesh. The lack of inflammatory process within the grafted material was confirmed with other studies.24 The porosity of the membranes with regard to nutrient passage is discussed in the literature. Some authors consider this factor important in the biology of bone regeneration.25,26 The titanium mesh with pores in its construction does not block the blood supply from the mucosal side. This may facilitate the nutrition and metabolic exchange that may positively influence bone remodeling.20,21,23,24

Conclusions

The GBR technique with titanium mesh is a predictable procedure for the reconstructions of three-dimensional bone defects. The described technique is recommended in situations where the implant position is planned mainly in the native bone and the augmentation procedure compensates for the loss of alveolar bone contour. The use of customized titanium meshes facilitates the surgery and may positively influence the biologic response of regenerative therapy. Individualized titanium meshes present a more advantageous alternative to PTFE membranes because of easier handling during fixation and removal. They also provide better regenerative outcomes if soft tissue perforation occurs when compared to the same complications with PTFE material.

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References