Horizontal Ridge Augmentation of the Atrophic Maxilla Using Pericardium Membrane Versus Titanium Mesh: A Clinical and Histologic Randomized Comparative Study

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Purpose: To compare the outcomes of maxillary horizontal alveolar ridge augmentation in the esthetic area, using either pericardium membrane or titanium mesh, clinically, radiographically, and histologically. ***Materials and Methods:*** A randomized clinical study was performed on 20 patients with insufficient edentulous ridge width. Subjects were equally allocated into two groups. For both groups, autogenous tenting bone blocks were harvested from the symphysis area. Bone block was covered by an equal mixture (1:1) of particulate graft of inorganic bovine bone and autogenous bone matrix. The barrier membrane used in group 1 (PM) was bovine pericardium membrane, and in group 2 (TM), it was titanium mesh. ***Results:*** Both groups had a clinically statistically significant difference in buccopalatal alveolar ridge dimension between baseline and after 4 months. Radiographically, at both intervals, there was no significant difference in 3D volume between both groups. Within both groups, there was a significant volume increase postoperatively. Histologically, the PM group had a lower area fraction of the mean value of newly formed bone than the TM group, yet the difference was not significant. The PM group had a higher mean osteocyte count than the TM group, but again, the difference was not significant. ***Conclusion:*** Guided bone regeneration using either pericardium membrane or titanium mesh is a reliable treatment for horizontal augmentation of insufficient maxillary alveolar ridge width. No significant differences between both treatment modalities were noticed clinically and histologically. However, percentage change in radiographic volumetric measurements using TM was significantly higher than that of PM. *Int J Oral Maxillofac Implants 2023;38:451–461. doi: 10.11607/jomi.9715*

Keywords: CBCT, guided bone regeneration, inorganic bovine bone matrix, pericardium membrane, titanium mesh, 3D volume

Restoration in the esthetic zone with implant-supported prostheses is one of the most difficult procedures to achieve in maxillofacial surgery. Bone resorption following periodontal disease or traumatic extraction causes a diminution in the alveolar ridge dimension due to bone resorption. This can make implant placement difficult or even impossible. The focus of recent research has shifted from osseointegration to an implant restorative-driven concept that is compatible with the surrounding hard and soft tissue.[1]

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Within 12 months of tooth extraction, the alveolar ridge resorption rate is 40% to 60% of the pre-extraction dimensions of the ridge height and width, which is equal to 5 to 7 mm loss of width, creating a residual knife edge ridge.[2]

Alveolar bone defects can be reconstructed through variable surgical techniques, including guided bone regeneration (GBR), onlay grafting, interpositional inlay grafting, distraction osteogenesis, and ridge splitting, as well as forced orthodontic eruption. In a systematic review, GBR was determined to be the best way to augment the alveolar ridge based on implant survival rates.[3]

GBR is a surgical technique that increases the volume of alveolar ridge for implant placement using barrier membranes with or without bone substitutes. The exclusion of soft tissue cells during bone remodeling by osteoblasts is considered the key success factor for GBR.[4]

The biologic basis for GBR involves building a stable and immovable base that allows for a constant release of growth factors, blood supply access to the defect areas, and space for adequate bone formation, as well as cell occlusion through the use of barrier membranes.[5]

The tenting technique is an alternative surgical technique, based on GBR principles to achieve new bone formation in the atrophic ridge. It involves lifting the periosteum like a tent so the osteoblasts can migrate into the gap to initiate osteogenesis.[6]

There are various types of membranes: resorbable membranes like collagen and polylactide-co-glycolide, nonresorbable membranes like polytetrafluoroethylene (PTFE) and titanium mesh (Ti mesh), and others, like acellular dermal matrix, absorbable gelatin compressed sponge, and cargile and pericardium membranes.[7]

Some studies have shown that even in cases with a large bone cavity, Ti mesh maintains the space with a higher degree of predictability,[8] but with cutting, trimming, and bending. Ti mesh results in sharp edges that can cause mucosal irritation and membrane exposure.[9]

Although collagen membranes exhibit an efficient regeneration profile, their main drawback is their rapid resorption, which leads to an early loss of barrier function, significantly affecting the rate of bone formation.[10]

Compared with collagen membranes, the pericardial membranes showed efficient cross-linking, indicating prolonged resorption time. Various in vitro and in vivo studies have demonstrated the bioeffectiveness of these pericardiam membranes to enhance bone augmentation. However, further clinical studies are needed to prove their effectiveness in GBR.[11]

Radiographic analysis was critical in determining the clinical efficacy of GBR interventions. CBCT has established itself as a reliable 3D imaging method for implant dentistry, providing cross-sectional scans of the bone at a lower radiation dosage than multislice computed tomography (CT).

It is anticipated that the evaluation of grafted bone volume would be improved by using interactive 3D data measurement and visualization technologies.

Some studies have used 3D data from CBCT or CT scans to evaluate volumetric changes in grafted bone following sinus floor augmentation.[12,13,14] However, few studies have used reconstituted 3D models of grafted bone to examine volume changes following GBR operations.

Therefore, the purpose of this randomized controlled study was to compare the use of resorbable bovine pericardium membranes (BPs) for horizontal alveolar ridge augmentation versus titanium mesh in terms of clinical, radiographic volumetric bone changes and histologic outcomes before implant placement.

MATERIALS AND METHODS

Patient Selection

The present study recorded a total of 20 patients who were enrolled from the outpatient clinic of the Oral Medicine, Periodontology, Oral Diagnosis and Radiology Department, Faculty of Dentistry, Ain Shams University, who satisfied the inclusion criteria and were planned to undergo intraoral bone blocks to increase an atrophic maxillary edentulous ridge.

The faculty's Research Ethics Committee reviewed and accepted the research proposal (ethical no. FDASU-REC IM021726; clinicaltrials.gov registration no. NCT04570566).

A power analysis was designed to have adequate power to apply a two-sided statistical test of the null hypothesis that no difference would be found between different groups regarding volumetric changes. By adopting an alpha (α) level of .05, a beta (β) level of 0.2 (ie, power = 80%), and an effect size (d) of 1.51 calculated based on the results of a previous study,[13] the predicted sample size (n) was a total of 16 cases (ie, 8 cases per group). Sample size calculation was performed using G*Power version 3.1.9.7.[15]

The study inclusion criteria specified healthy patients of both sexes, free from systemic disease that might affect healing,[16] aged 20 to 50 years, with partially edentulous areas in the esthetic zone (maxillary incisors to premolar area); residual bone width ≤ 4 mm and minimum alveolar vertical dimension ≥ 8 mm from the alveolar crest to the roof of the nasal cavity or maxillary sinus (Cologne Classification, 2013; H.1.e), class IV,[17] and gingival biotype > 1 mm in thickness.[18] The exclusion criteria were patients with active periodontal disease, subjects who were tobacco or alcohol users,[19] and pregnant and breastfeeding women.

Participants were assigned a number between 1 and 20 and were randomly and equally allocated to group 1 (PM) or group 2 (TM; 10 participants per group) following a simple randomization procedure using IBM SPSS version 23 statistical analysis software (IBM).

For both groups, the particulate graft was an equal mixture (1:1) of autogenous and anorganic bovine bone matrix (ABBM) covering bone block harvested from the symphysis area using a trephine bur. Group 1 (PM) received BP as a barrier membrane, whereas group 2 (TM) received Ti mesh.

Radiographic Examination

A baseline CBCT was performed to evaluate the recipient site dimension and ensure no pathologic lesion (Fig 1a). CBCT was repeated again after 4 months postoperatively.

CBCT scanning was done with the following parameters: field of view 10 × 10 cm; voxel size 200 um; kilovoltage 90 KVp; 6.3 mA, time 12 seconds, and a single 200-degree image rotation.

CBCT scan data were collected in the Digital Imaging and Communications in Medicine (DICOM) file format. The images were processed using the CBCT Materialise

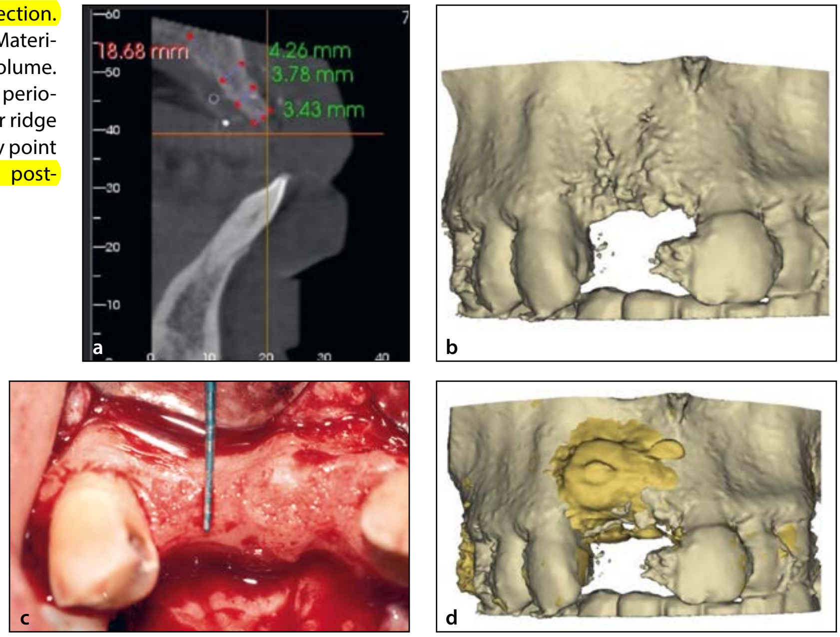
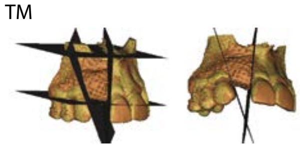
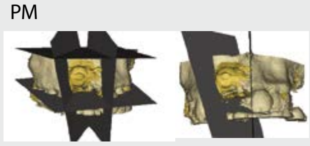


Fig 1 *(a)* Preoperative CBCT sagittal cross section. *(b)* Images were processed using the CBCT Materialise Mimics 21.0 software. 3D preoperative volume. *(c)* Crestal view showing UNC 15 color-coded periodontal probe to measure the horizontal alveolar ridge defect. *(d)* The superimposition of 3D models by point and global registration allowed for pre- and posttreatment scan models.

Table 1 Volumetric Analysis

Groups	Volumetric measurement of pretreatment scan model of defective area (mm^3)	Volumetric measurement of posttreatment scan model of defective area (mm^3)	Difference (bone graft volume)
TM 	1,316.26 mm^3 	1,947.05 mm^3 	630.79 mm^3
PM 	1,501.71 mm^3 	1,781.36 mm^3 	279.65 mm^3

The volumetric analysis was performed on the alveolar bone alone, not including the soft tissue. The six boundaries of the volume of interest were a plane parallel to the crestal bone inferiorly, a plane parallel to the nasal floor superiorly, the most external plane of the facial and palatal bony plates, and an extension in both the mesial and distal directions, used as structures of reference.The volumetric measurements of the pre- and posttreatment scan models of the defective area were subtracted from each other to calculate the difference, which represents the bone graft volume.

Mimics 21.0 software. The 3D volume of preoperative and postoperative augmented area was evaluated (Figs 1b and 1d).

Digital bone segmentation was performed by thresholding of the defective area before and after bone grafting (Table 1). Two 3D models were created from the thresholding segmentation. The superimposition of 3D models by point and global registration allowed for pre- and posttreatment scan models to be overlaid for comparison (Fig 1d). The volumetric analysis was performed on the alveolar bone alone, not including the soft tissue. The six boundaries of the volume of interest (VOI) were a plane parallel to the crestal bone inferiorly, a plane parallel to the nasal floor superiorly, the most external plane of the facial and palatal bony plates, and an extension in both the mesial and distal directions, used as structures of reference. The volumetric measurements of the pre- and posttreatment scan models of the defective area were subtracted from each other to calculate the difference, which represents the bone graft volume[20] (Table 1).

Surgical Procedure

Amoxicillin (Amoxil, GlaxoSmithKline, Medical Union Pharmaceuticals, 500 mg) was administered 1 hour before the surgical procedure.[21] Patients were required to rinse with chlorhexidine HCl (CHX) 0.25% mouthwash immediately prior to surgery as an antiseptic and disinfectant at the surgical site. All procedures were performed under local anesthesia infiltration. Articaine 4% 1:100,000 epinephrine (Artinibsa 40 mg/mL + 0.01 mg/mL, Inibsa Dental) was used.

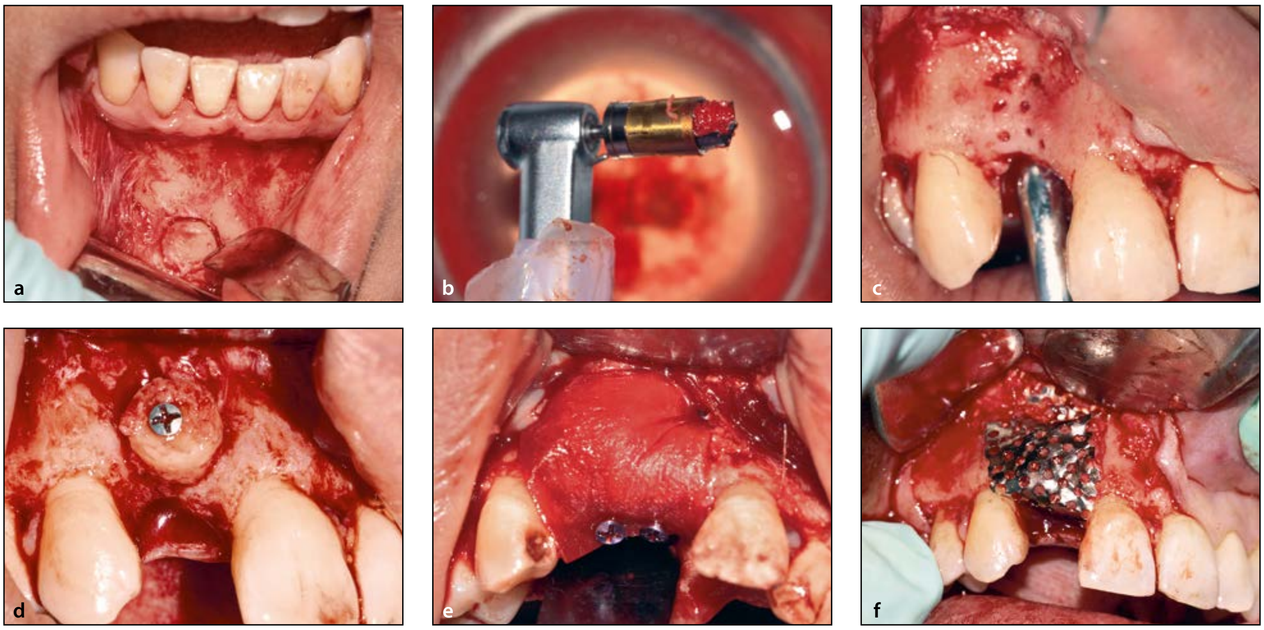


Fig 2 *(a)* Labial view showing a vestibular approach to expose the mandibular symphysis. The block was harvested using a trephine bur of 8 mm diameter. *(b)* Auto-Max trephine bur with autogenous cancellous particulate bone. *(c)* Labial view showing multiple decortications through the buccal cortical bone. *(d)* Labial view showing harvested bone block fixed by 10 mm titanium screw. *(e)* Labial view showing the particulate bone graft placed around supporting tenting screws to the level of the screw head. Fixation of the pericardium membrane was performed using bone tacs. *(f)* Composite graft of ABBM and harvested autogenous bone compacted around the bone block and covering the head of the titanium screw, with fixation of Ti mesh by titanium screw.

A full-thickness paracrestal incision and two diverging vertical incisions were made on each side of at least one surgical site using a no. 15C surgical scalpel.

The full-thickness mucoperiosteal flap was elevated sufficiently to expose the recipient site. All periosteal tissue was removed from the buccal surface of the bone.

Intraoperative examination to identify the largest horizontal defect of the alveolar ridge and narrow alveolar ridge crest with insufficient ridge width for ideal dental implant placement was measured with the UNC 15 color-coded periodontal probe or bone calipers (1-15 Hu-Friedy UNC 15; Fig 1c).[22]

Chin Graft Harvesting

A clinical and radiographic examination of the donor site was done. The site needed to be easily accessible, with no pathologic lesion or anatomical abnormality.

Incision design. After elevation of a full-thickness flap, bone block harvesting was done using a trephine bur with an inner diameter of 8 mm (Mr. Curette [Mr. Currette Dental Instruments]) at a depth of 5 mm (Fig 2a). The surgical drill was used at 2,000 to 2,500 rpm with copious saline irrigation.[23,24]

An Auto-Max trephine bur (Auto-Max bur, Megagen, Basepoint Business and Innovation Centre) was used to harvest autogenous particulate bone from the same site of the harvested block (speed 300 rpm, torque 50 Ncm) without irrigation to avoid scattering of the harvested bone[25] (Fig 2b).

Placement of the graft. The particulate autogenous bone graft was mixed with an equal volume of particulate ABBM (Hard tissue cerabon, botiss biomaterials) to create a 1:1 composite graft. The recipient bone bed was prepared with multiple decortications using a small round bur to facilitate angiogenesis and migration of osteoprogenitor cells from marrow spaces[26] (Fig 2c). An augmentation bone block was fixed using a 1.5-mm–diameter and 10-mm–long titanium reference screw (Titanium screw, BioMaterials Korea). The bone block acted as a tent with a titanium screw (Fig 2d). The particulate graft consisted of a combination of xenograft and particulate autogenous bone and was applied to the recipient site.[27]

Group 1 (PM). Trimming of bovine pericardium membrane (Tutopatch is a collagenous membrane [thickness range 0.5 mm], derived from solvent-preserved irradiated bovine pericardium MED and CARE; BP) was performed extraorally. The membrane was fixed palatally with titanium bone titan pins (titan pins, botiss biomaterials; Fig 2e).

The membrane was pulled tightly to cover the graft and stabilized on the labial cortical plate with additional bone titan pins. More bone was packed laterally to overfill the site; then titan pins were fixed in place.

Group 2 (TM). Aluminum foil was adapted and trimmed to be a proper fit at the defect site, then served

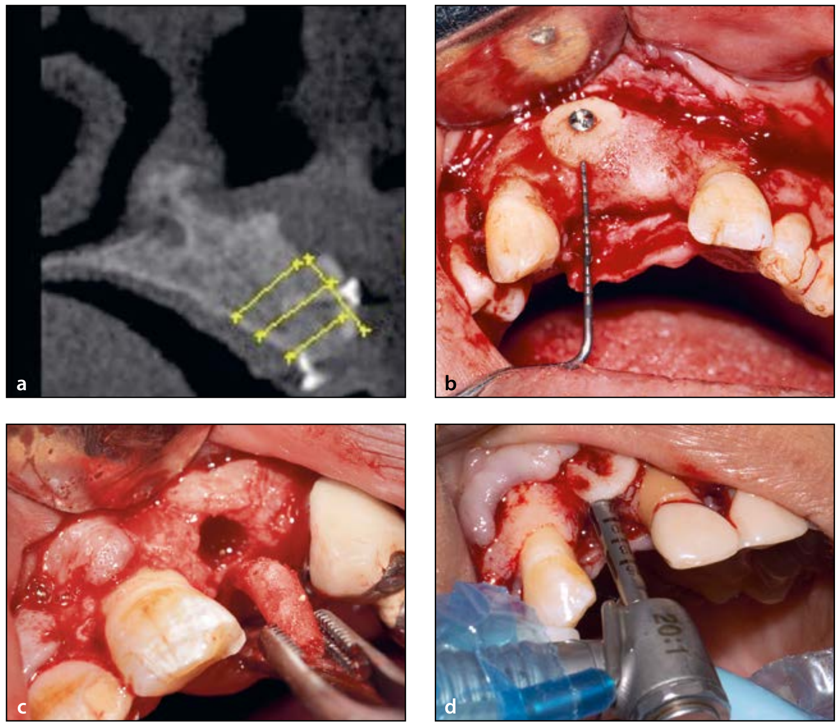


Fig 3 *(a)* Sagittal section from CBCT shows the evaluation of alveolar ridge width after 4 months before the stage-two surgery. *(b)* Occlusal view exposure of the augmented site of PM after 4 months and the final bucco-palatal measurement of 6 mm using UNC-15 periodontal probe. *(c)* Trephine bur with an inner diameter of 1.7 mm was used to obtain a core biopsy specimen of the harvested bone in both groups.

as a guide for cutting the titanium mesh, which was performed extraorally. The minimum distance from the titanium mesh margin to the periodontium of neighboring teeth was 1.5 mm to prevent possible infection through the gingival sulcus and to allow reattachment of gingival fibers. The mesh was stabilized using 2.0 mm titanium self-tapping miniscrews (2.0 mm self-tapping miniscrew, BioMaterials Korea) on the palatal side, whereafter the defect was filled with the bone mixture. Fixation of Ti mesh on the labial side of the defect was performed using titanium screws to confirm stabilization of the graft and membrane and to prevent any micromovement during the healing phase (Fig 2f).

After the membrane was completely secured, a horizontal periosteal release incision was carried out to obtain tension-free closure. A double layer suturing technique was performed using a horizontal mattress suture placed 5 mm from the incision line, along with simple interrupted sutures using 5-0 polypropylene.

Postoperative Care and Follow-up

All patients received postoperative antibiotics (amoxicillin 500 mg and metronidazole [Flagyl, Sanofi Aventis] 500 mg twice/day orally for 5 days)[28] and a nonsteroidal anti-inflammatory (ibuprofen 600 mg every 8 hours orally for 5 days [Brufen 400 mg 30 tablets, Abbott]). Patients were instructed to follow oral hygiene procedures and use CHX 0.12% mouthwash for 2 weeks. The sutures were removed 2 weeks after the operation.

All patients were clinically examined 1 week, 2 weeks, 1 month, and 4 months after the operation. At follow-up visits, both recipient and donor sites were assessed for soft tissue healing.[20] After 4 months, before the second operation (Fig 3a), the second radiographic assessment of alveolar ridge width by CBCT was performed to assess the 3D volume of bone ingrowth.

Prior to acquisition, each scan was adjusted to replicate the same preoperative view to ensure accurate measurements. All data were collected and tabulated for statistical analysis.

Stage-Two Surgery

After 4 months, a flap was raised for both groups to clinically assess the amount of bone in the augmented area and implant insertion. For the PM group, a crestal incision was made with a vertical releasing incision. In some patients, the titanium titan pins were removed, but not in others.

For the TM group, a flap was reflected to expose the augmented alveolar ridge along with the Ti mesh. The titanium screws and mesh were removed.

For both groups, the buccopalatal width of augmented bone was recorded using a UNC-15 mm periodontal probe (Fig 3b). Measurement data were recorded in an Excel (Microsoft) sheet for statistical results. A trephine bur with an inner diameter of 1.7 mm (Helmut Zepf Medizintechnik) was used initially to obtain a core biopsy specimen of the harvested bone in both groups for histologic analysis (Figs 3c and 3d).

Histologic and Histomorphometric Measurements

The specimens were immediately fixed in 10% buffered formalin for 48 hours, then decalcified and processed according to a standardized protocol for ethylenediaminetetraacetic acid (EDTA)–formic acid combination. Then, specimens were embedded longitudinally into paraffin blocks for labeling and differentiating the newly formed bone end from the native bone end. Blocks were cut into longitudinal 5-mm–thick sections using a manual rotary microtome (Leica, RM2135 microtome, Heidelberger Strasse) and stained with Mayer hematoxylin and eosin stain (H&E) for histologic analysis.

Histologic Examination

Hematoxylin and eosin (H&E) staining. Staining of the fixed slides was done in the Oral Biology Laboratory, Oral Pathology Department, Faculty of Dentistry, Ain Shams University. The fixed slides were rehydrated by dipping them in descending concentrations of alcohol (100%, 90%, 75%, then 50% ethanol) and after that were briefly rinsed in distilled water. The following step was immersing the slides in filtered Mayer hematoxylin solution for 3 minutes, followed by washing with distilled water twice. Afterward, the slides were immersed in eosin stain for 5 seconds, followed by rinsing with distilled water. The stained slides were dehydrated by putting them in ascending concentrations of ethanol, then soaked in xylene for 10 minutes. The final step was adding one small drop of the mounting medium to the slide, then placing a clean coverslip onto it. The slides were left to dry.

Histomorphometric analysis and imaging. This work was performed in the Precision Measurement Unit, Oral Pathology Department, Faculty of Dentistry, Ain Shams University. For each H&E-stained section, three microscopic fields showing the most abundant formation of newly formed bone were selected, and photomicrographs were captured at an original magnification of ×20. All images were taken using a digital camera mounted on a light microscope. Images were then transferred to the computer system for analysis. All the steps of immunohistochemical assessment were carried out using ImageJ, 1.41a image analysis software. The steps were as follows:

- Step 1: Images were first corrected for brightness and contrast.
- Step 2: Corrected images were then converted into 8-bit type grayscale.
- Step 3: Color thresholding was then adjusted to exclusively select the eosinophilic newly formed bone.
- Step 4: The area fraction (AF) of newly formed bone was measured automatically. The area fraction represents the percentage of the newly formed bone trabeculae to the total area of the microscopic field.

The mean area fraction (MAF) for each case was calculated. For the estimation of osteocyte count in each microscopic field, viable osteocytes within their lacunae in the newly formed bone were manually marked with a different color using ImageJ software. Thresholding was again tuned to only extract the marks of the different color, to be automatically counted. For each case, the mean osteocyte count was calculated. The collected numerical data were tabulated in a Microsoft Excel sheet.

RESULTS

Clinical follow-up revealed that in all the present cases, no patients suffered from any postoperative complications like dehiscence or infection. All patients reached the 4-month postoperative evaluation point.

Radiographic results. Regarding group 1 (PM), there was a statistically significant difference in 3D volume, with 1,783.36 ± 542.54 mm^3 at baseline increasing to 2,340.98 ± 533.38 mm^3 4 months postoperatively (P = .008). Regarding group 2 (TM), there was also a statistically significant difference in 3D volume between baseline and after 4 months: BL dimension at baseline was 1,554.50 ± 292.78 mm^3 and increased to 2,938.73± 1,088.18 mm postoperatively (P < .05). Conversely, there was no statistically significant difference in 3D volume between the groups at baseline and after 4 months (P = .203 and P = .755, respectively), There was no significant difference in volume (P = .059). The percentage change in the TM group was significantly higher than the PM group (P = .020; Table 2).

Clinical results. Regarding group 1 (PM), there was a statistically significant difference in BL dimensions (mm) between baseline and after 4 months, with 3.25 ± 0.71 mm at baseline increasing to 6.13 ± 0.64 mm postoperatively (P < .001). Concerning group 2 (TM), there was also a statistically significant difference in BL dimension between baseline and after 4 months, with 3.33 ± 0.71 mm at baseline increasing to 7.00 ± 1.07 mm postoperatively (P < .001). Conversely, there was no statistically significant difference in BL dimension between the groups at baseline and after 4 months (P = .832 and P = .067, respectively; Table 3).

Histologic Assessment and Histomorphometric Analysis Results

The results of the present study revealed that no difference was seen in the bony trabeculae or cells when comparing the PM group and the TM group (Figs 4a and 4b). Both groups revealed a typical alveolar ridge structure. The PM group had a lower area fraction of newly formed bone (AF) mean value (56.16 ± 4.57) than the TM group (58.45 ± 3.90), yet the difference was not

Table 2 Mean and Standard Deviation (SD) Values for Radiographic Volumetric Measurement, Difference in Volume, and Percentage Change of 3D Volume for Both Groups

	3D volume in mm^3 (mean ± SD)		
Follow-up	PM	TM	*P* value
Baseline	1,783.36 ± 542.54	1,554.50 ± 292.78	.203 (ns)
After 4 months	2,340.98 ± 533.38	2,938.73 ± 1,088.18	.755 (ns)
P value	.008*	.002*	
Difference	557.62 ± 120.88	1,384.23 ± 1,138.72	.059 (ns)
Percentage change (%)	31.43 ± 10.41	62.53 ± 32.58	.020*

SD = standard deviation. *Significant ($P \leq .05$); ns = not significant ($P > .05$)

Table 3 Mean and SD values for Labiopalatal Alveolar Ridge (LP) Dimension (mm), Measured Clinically for Both Groups

	LP dimension (mean ± SD)		
Follow-up	PM	TM	*P* value
Baseline	3.25 ± 0 .71	3.33 ± 0.87	.832 (ns)
After 4 months	6.13 ± 0.64	7.00 ± 1.07	.067 (ns)
P value	< .001*	< .001*	

*Significant ($P \leq .05$) ; ns = nonsignificant ($P > .05$).

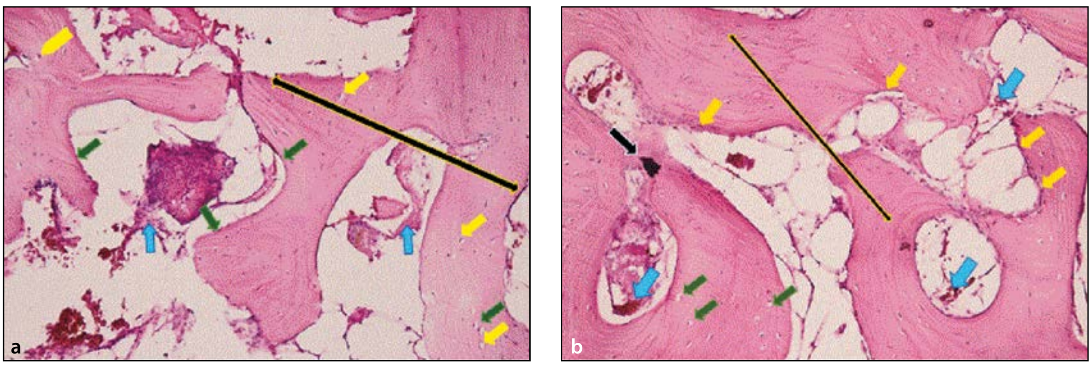


Fig 4 *(a)* A photomicrograph of PM stained with H&E showing formation of newly formed bone with a fair thickness (*double-head arrow*) and vascularity (*blue arrow*). The osteoblastic cells lining the bone surface (*yellow arrow*) and abundance of osteocytes (*green arrow*) are less pronounced. Note the presence of residues from the grafting material (*black arrow*; original magnification ×20). *(b)* A photomicrograph of TM stained with H&E showing dense deposition of newly formed bone. The bone trabeculae are highly vascularized and highly cellular (*blue arrows*). The formed bone exhibits signs of viability in the abundance of osteocytes (*yellow arrows*) and osteoblastic cells lining the bone surface (*green arrow*). Newly formed bone with a fair thickness (*double-head arrow*; original magnification ×20).

Table 4 Mean and SD Values for Histomorphometric Analysis for Both Groups

	Histomorphometric analysis (mean ± SD)		
Parameter	PM	TM	*P* value
AF of newly formed bone (%)	56.16 ± 4.57	58.45 ± 3.90	.426 (ns)
Osteocyte count	148.27 ± 5.20	143.67 ± 3.85	.710 (ns)

*Significant ($P \leq .05$); ns = nonsignificant ($P > .05$)

Table 5 Mean and SD Values for Labiopalatal Alveolar Ridge (LP) Dimension Changes (mm) Measured Clinically for Both Groups

LP dimension changes (mean ± SD)		
PM	TM	*P* value
2.88 ± 0.64	3.50 ± 0.93	.139 (ns)

*Significant ($P \leq .05$) ns; nonsignificant ($P > .05$).

significant ($P = .426$). The PM group had a higher osteocyte count mean value (148.27 ± 5.20) than the TM group (143.67 ± 3.85), but again, the difference was not significant ($P = .710$; Table 4).

DISCUSSION

This randomized clinical study was conducted in 20 patients with complaints of maxillary ridge defects. The study estimated that either group 1 using bovine pericardium (BPs) or group 2 using titanium mesh was effective in horizontal ridge augmentation. Both histologic and 3D volumetric x-ray studies were performed; bone volume significantly increased after augmentation, and there were no significant differences in clinical and 3D x-ray amounts of bone gained between the two groups. In both groups, the tent-block technique and a 1:1 mixture of autologous and foreign bone were used.

Tenting of the periosteum and soft tissue matrix was done by a cortical bone block that maintains space, minimizes resorption of the particulate graft volume, and minimizes the amount of autogenous bone needed in augmentation. It also guaranteed stabilization of the bone graft.

In the present study, cancellous autogenous particulate bone was used. This had a major impact on bone formation via proteins released from the extracellular matrix, transforming growth factors βI and β2, osteoblast-stimulating factor-1, galectin-1, bone morphogenetic proteins, and other proteins that played an essential role in bone formation.[29,30]

The vitality of this bone particulate was achieved using an Auto-Max drill, which is an efficient and easy way to harvest up to 1 cc autogenous graft in a short time. By contrast, bone crushing causes a degree of wastage, and the harvested autogenous bone loses some of its viability.[31]

BP was chosen in the present study because it resorbs slowly over 4 to 6 months. It provides a biocompatible barrier that will allow the grafted region to consolidate, especially with the BP permeability that enriches the graft with blood supply from the periosteum. It has shown better soft tissue compatibility than nonresorbable membranes. Pericardium membrane from bovine sources has higher collagen content than porcine pericardial tissue.[32,33]

The selection of titanium mesh in the present study was based on its ability to be the most predictable and successful barrier for GBR. It is characterized by a macroporous structure that enhances bone regeneration by providing the graft with a rich blood supply for vascularization. It has a lower cost compared with other barriers.[34]

In the present study, the use of autogenous bone in combination with ABBM in a 1:1 ratio is based on different radiographic and clinical studies that concluded that the 1:1 ratio is the ideal grafting material for vertical and horizontal GBR.[35–37]

Four months was selected to be the follow-up period in this study because studies reported that cases with 3 to 4 months of graft healing presented less resorption (0.33 mm) than cases with 5 to 8 months of graft healing (1.22 mm).[8,38,39]

CBCT was used to measure the horizontal ridge 3D preoperatively and after 4 months. CBCT scans allow for similar precise measurement of bone volume as that available through CT and micro-CT scans. CBCT scans offer some advantages, such as lower cost, reduced radiation dose exposure, smaller device size, and high isotropic spatial resolution.[40–42]

In the majority of clinical trials, linear assessments of the thickness of the grafted facial bone surrounding dental implants are made using CBCT cross-sectional scans. However, it is advised that the measurements not be restricted to the evaluation based on 2D in the full region of interest.[43]

CBCT is currently the most used 3D radiographic imaging method in dentistry compared to 2D imaging technologies and conventional CT scans. Alveolar ridge preservation was previously assessed using CBCT and linear intraoperative measures; however, the subtraction analysis of CBCT data offers a more precise method. Radiographic image segmentation methods may be used to convert DICOM images into 3D virtual models. Creating 3D reconstructions of the alveolar ridge and teeth makes it easier to analyze defect morphology and posttreatment changes.[13,44]

In the present study, radiologic assessment was considered one of the most consistent methods for assessing the amount of bone regeneration and identifying the amount of new bone and the resorption rate of the graft. The present technique provides a repeatable 3D assessment of the complete augmented bone, not just a portion or section of the augmented area. All image-generating parameters are specified in full, allowing replication of the process and comparison of the results to future research in a consistent manner. Another virtue is that all patients were treated in a uniform manner in terms of the surgery and scanning procedures.

A study by Benic and Hämmerle mentioned that radiographic assessment was critical in determining the clinical efficacy of the GBR technique.[17] However, most studies have examined the volume change after GBR using reconstructions from 3D renderings of augmented bone.[45,46]

The mean 3D volume bone gain was 557.62 ± 120.88 mm^3 in the PM group and 1,384.23 ± 1,138.72 mm^3 in the TM group (Table 1). This increase in radiographic bone gain in TM compared with that in PM was attributed to the ability of the Ti mesh membrane to maintain the space for osseous regeneration beneath the membrane for a sufficient period in a stabilized environment.[47]

A few studies demonstrated the 3D volume change between before and after augmentation of a horizontal ridge. A clinical and radiographic study by Hofferber et al[48] reported that the mean percentage of volumetric bone gained in partially edentulous alveolar ridges augmented with customized titanium ridge augmentation matrices and freeze-dried bone allograft and a resorbable collagen membrane was 85.5% ± 30.9%, which was higher than the results in the present study (62.53% ± 32.58%); this may be due to the better fit and more stabilized customized titanium matrices combined with collagen membrane. The mean horizontal augmentation (measured clinically) was 3.02 mm, which is similar to the result of the TM group in the present study (3.50 ± 0.93 mm).

In a study by Abuelnaga et al,[49] 3D radiographic analysis compared reconstruction of mandibular alveolar ridges using customized xenogeneic bone graft Smartbone versus particulate xenogeneic bone with Ti mesh. At 4 months postoperative, there was a significant increase in bone volume by 40% in the area of newly formed bone in customized bone compared with 23% in particulate. The results were less than that presented in PM and TM; this may be due to use of tenting bone block in the present study. In the same study, Abuelnaga et al reported that the bone mass obtained by bone graft was 605 mm^3, which was lower compared with the results in the Ti mesh TM group in this study. This may be due to the high osteogenic potential of autologous bone and the combination of the tent technique and Ti mesh.

In the present study, radiographic analysis of both groups (PM and TM) showed significant bone gain after 4 months of augmentation compared with baseline data, but there was no significant difference in the amount of bone gained between the groups. This is due to the augmentation technique, which was used in both groups. It depended on GBR principles involving the placement of mechanical barriers to protect from blood clots and to isolate the bone defect from the surrounding connective tissue, thus providing bone-forming cells with access to a secluded space intended for bone regeneration.[34]

In the present study, the mean clinical buccopalatal width in the PM group was 2.88 mm, which was lower than that of the TM group (3.50 mm); however, the difference was not statistically significant (Table 5). This increase regarding TM could be due to the space-making capability and adaptability of Ti mesh, which allows host tissue integration with the membrane for predictable bone formation.[34]

Sterio et al[50] evaluated horizontal defect augmentation using bovine pericardium membrane in combination with freeze-dried bone allografts at baseline and at reentry surgery, which was performed 6 months later. They reported that the mean bone gain in the clinical evaluation of the ridge width after augmentation was 2.61 mm, which was comparable with the results of the PM group in the present study.

The clinical results of the TM group in the present study were in agreement with a study by Proussaefs and Lozada[51] who used Ti mesh in alveolar ridge augmentation, and the mean horizontal bone gain after 6 months was 3.88 ± 1.43 mm.

Regarding histomorphometric analyses, the PM group had a higher osteocyte count mean value than the TM group, but the difference was not significant. This may be attributed to specific criteria of native collagen membrane as pericardium membrane to promote an environment for chemotactic action on regenerative cells, such as fibroblasts and osteoblasts, and rapid recruitment of different cell types in the defect.[52]

The PM group had a lower AF mean value than the TM group. This increase in the TM group is related to the ability of the Ti mesh membrane to maintain the space for osseous regeneration beneath the membrane for a sufficient period in a stabilized environment.[47]

Histologic analysis in the present study showed bone structure comparable to that of a study by Berberi et al.[53] Bony buccal wall of the sinus was used as tenting, the defect was filled with a mineralized cortical bone allograft, and then a bovine pericardium membrane was placed on the graft. A biopsy for histologic evaluation was taken after 6 months.

Proussaefs and Lozada[51] used an equal mixture of autogenous bone graft and inorganic bovine mineral, covered by Ti mesh for horizontal ridge augmentation. After 6 months, the histomorphometric analysis showed 36.47% new bone formation, which was less than that of the present study (58.45% ± 3.90%). This may be due to the cortical tenting block that was used in the present study.

CONCLUSIONS

Both groups exhibited clinical and radiographic dimension change and increase in 3D volume, but with no significant difference. Regarding the histologic results, both the pericardium membrane group and Ti mesh group showed newly developed osteocyte count and exhibited percentage of area fraction of newly formed bone, but with no significant difference between both groups. Ridge augmentation using the BP and Ti mesh as a barrier with a mixture of 1:1 autogenous and ABBM is a favorable technique for horizontal augmentation for deficient maxillary ridges.

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