Horizontal Ridge Reconstruction of Atrophic Anterior Maxillary Ridges Using Customized Xenograft Bone Shell with a 1:1 Mixture of Autogenous and Xenograft Bone Particulate: A Case Series Study

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Purpose: To evaluate the efficacy of using a customized xenograft shell with a 1:1 mixture of particulate xenograft and autogenous bone for the reconstruction of horizontally deficient anterior maxillary alveolar ridges. ***Materials and Methods:*** CBCT images of the atrophic maxilla of eight patients were acquired and generated into 3D models. The data were transferred to a 3D printer for fabrication. During the surgery, xenograft blocks were manually sliced and customized on the 3D-printed models into bone shells. Then they were fixed to the atrophic site, and the gap was augmented with a 1:1 mixture of particulate xenograft and autogenous bone. ***Results:*** Clinical assessment showed no adverse effects; however, one patient exhibited wound dehiscence. The mean difference between the preoperative and 6-month postoperative CBCTs showed a net average bone gain of 4.06 mm at 2 mm from the crest and 4.34 mm at 5 mm from the crest, which was statistically significant. On the other hand, a statistically significant graft resorption of 1.41 mm at 2 mm from the crest and 2.19 mm at 5 mm from the crest was found when the mean difference between the immediate and 6-month postoperative CBCTs was calculated. ***Conclusions:*** Within the limitations of the study, the use of xenograft shells as a barrier for maxillary alveolar ridge reconstruction is a predictable technique; however, further investigations regarding the required time for graft consolidation are required. *Int J Oral Maxillofac Implants 2024;39:546–556. doi: 10.11607/jomi.10613*

Keywords: atrophic maxilla, bone augmentation, bone shells, bone width, bone gain, histomorphometry, xenograft

The presence of sufficient bone volume is one of the main factors affecting the long-term success of implants placed in maxillary alveolar ridges.[1] Reconstructive surgeries that precede implant placement were introduced in the literature to reconstruct bony defects caused by trauma, extractions, or periodontal disease.[2,3] Several surgical techniques have been used to increase the residual bone width prior to or during implant placement,[4,5] including guided bone regeneration (GBR), ridge splitting, and block grafting.[5,6]

Autogenous bone grafting has always been considered the gold standard with its osteogenic characteristics and optimal integration into the host tissues.[7–9] It can be harvested from intraoral sites such as the mandibular rami and symphysis or extraoral sites such as the iliac crest,[10] tibia,[10] and calvaria.[11–13] Donor site morbidity, bone resorption, limited bone quantities, and injury to nerves are among the risks associated with the use of autogenous bone, which compelled researchers to investigate bone substitutes.[14]

Allografts, xenografts, and alloplasts have been used as alternatives to autogenous bone in ridge augmentation procedures.[15] Experimental studies have shown that the use of particulate xenograft on the outer surface of autogenous bone during alveolar ridge augmentation reduced bone resorption when compared to the use of autogenous bone alone.[16,17] Moreover, in a clinical study by Maiorana et al, the resorption rate was almost reduced to half when autogenous bone was covered with xenograft particles (9.3%) compared to autogenous bone alone (18.3%).[18]

The use of retromolar mandibular blocks is a well-reported and successful technique whereby thin mandibular cortical plates harvested from the retromolar region are fixed at a distance from the defect to augment a deficient ridge. In an attempt to avoid donor site morbidity, a study introduced a modification to this technique whereby allograft shells are used in the same way as the cortical bone of the mandible to correct deficient ridge width and in turn minimize operating time

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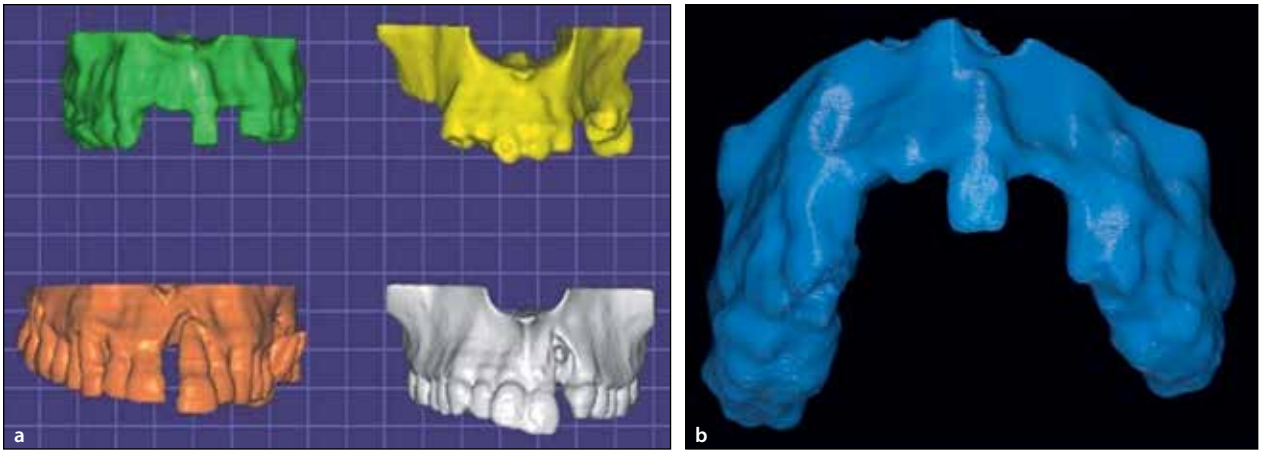

Fig 1 Virtual 3D models *(a)* and after printing *(b)*.

and prevent donor site morbidity.[7,19] Xenogeneic bone blocks were also introduced as alternatives to autogenous blocks[20] because they provide osteoconductive properties, and recently the standards were raised regarding its harvest, processing, and storage.

The aim of this study was to assess the effectiveness of using a customized xenograft bone shell with a particulate mixture of autogenous and xenograft bone in the horizontal grafting of the atrophic anterior maxilla.

MATERIALS AND METHODS

This prospective case series study was registered on ClinicalTrials.gov with the Identifier NCT04075942. This study gained its approval number (19-7-2) from the Research Ethics committee and the Faculty of Dentistry at Cairo University. The sample size was determined according to the study performed by Stimmelmayr et al.[21]

Patients of both sexes indicated for horizontal augmentation in the anterior maxilla due to insufficient bone width (less than 5 mm) but maintaining at least 12 mm of residual bone height were recruited from the outpatient clinic of the Department of Oral and Maxillofacial Surgery, faculty of dentistry, at Cairo University. Patients with systemic conditions that contraindicate surgical procedures and those with intraoral soft and hard tissue pathology were excluded. Overall, eight patients were enrolled, and they all followed the inclusion criteria of having a residual alveolar width less than 5 mm but a bone height of at least 12 mm to avoid the need for vertical augmentation. The duration of edentulism ranged from 10 to 15 years, and the loss of teeth occurred due to traumatic incidents, periodontal infection, and traumatic extraction.

Each patient was interviewed to obtain a comprehensive history including full medical and dental history. Patients were inspected for adequate interarch space, a normal covering of mucosa, and periodontal condition of adjacent teeth. The details of the surgical procedure and possible complications were discussed with the patients, and written consents were signed. A preoperative digital panoramic radiograph with 1:1 magnification was taken for each patient as a primary survey to identify the deficient areas and exclude any pathologic lesions or remaining roots. Then a preoperative CBCT was requested from all patients while biting in centric occlusion (Planmeca ProMax 3D Classic) to assess the extent of the defect and to measure the residual bone height and width.

The DICOM files were imported to Mimics 21.0 software (Materialise), where the bone was segmented. The deficient maxilla was exported in STL (standard tessellation language) format to be 3D printed by a fused deposition modeling (FDM) machine (Ling Tong III, Beijing SHINO); then it was chemically sterilized in 2% glutaraldehyde solution (Cidex, Johnson & Johnson) for 12 hours (Fig 1).

Stage-One Surgery

All cases were operated under local anesthesia using articaine 4% with 1:100,000 epinephrine (Inibsa Dental). After rinsing with 1.25% chlorhexidine HCL mouthwash (Orovex, Macro Group), the recipient site was first exposed through a trapezoidal full-thickness mucoperiosteal flap extending to a minimum of two teeth on each side of the defect. The flap was reflected to expose the underlying bone with minimal reflection of the palatal mucoperiosteum (Fig 2). Then flap advancement was performed by periosteal incision and submucosal dissection to allow for a tension-free closure, which is one of the keys to success in bone augmentation. Xenograft blocks (Tutobone, Tutogen Medical) were sectioned into shells 1 to 1.5 mm in thickness with a diamond disc under copious saline irrigation. These shells were then customized over the 3D-printed models of the deficient

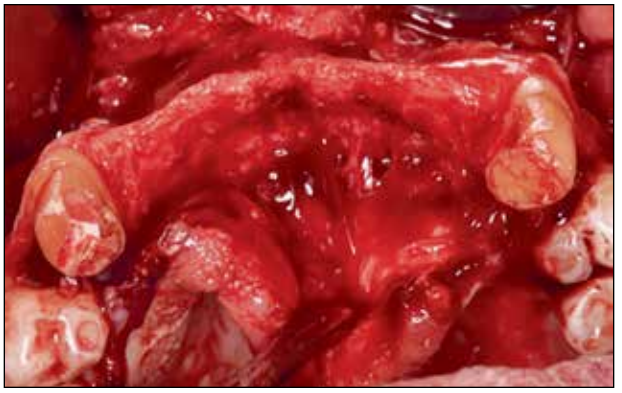

Fig 2 Labial and palatal reflection.

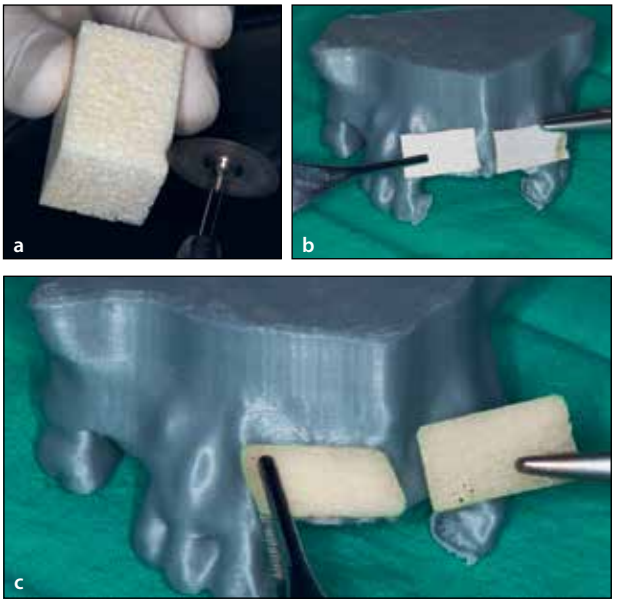

Fig 3 *(a to c)* Customizing the xenograft block on the model using a sterile template.

maxillae using a sterile template (Fig 3), and the edges were trimmed.

The mandibular symphysis was the donor site for the autogenous particulate. A vestibular incision 5 to 10 mm below the mucogingival junction extending just distal to the mandibular canines was made, and the flap was elevated to expose the chin. With the help of a 4-mm-diameter rotary autogenous bone collector (Auto Chip Maker [ACM], Neobiotech), three to five entries were sufficient to obtain autogenous cortical particulate bone for equal mixing at a 1:1 ratio with anorganic bovine bone mineral (ABBM; OsteoBiol) (Fig 4). The xenogeneic bone shell was fixed (Fig 5) to the recipient site with a minimum of two microscrews (Stryker CMF, Newman), and the interpositional gap was filled with the particulate mixture. Overpacking with the particulate mixture was performed in the gap and around the periphery of the shell (Fig 6).

Fig 4 *(a)* Harvest of particulate autogenous bone from the mandibular symphysis. *(b)* Mixture of 1:1 xenograft-autograft particulates.

Closure of the labial flap was performed with apical horizontal mattress sutures and the crestal simple interrupted suturing technique (two layers) with 4/0 synthetic monofilament sutures (Polypropylene, Assut). The donor site was closed in two layers: The mentalis muscle was first resuspended by multiple horizontal mattress sutures using 4/0 Vicryl (Assucryl, Assut), and then the mucosal layer was closed with a running 4/0 synthetic monofilament suture (Fig 7).

Postoperative Care and Follow-up

All patients received a postoperative regimen including 1 g of amoxicillin plus clavulanic acid (Augmentin, GlaxoSmithKline) twice daily for 5 days and 600 mg of ibuprofen (Brufen, Abbott) every 8 hours for 5 days. Patients were also instructed to follow oral hygiene measures and to use 0.2% chlorhexidine mouthwash for 2 weeks (Orovex). Sutures were removed 2 weeks postoperatively, and all patients were clinically evaluated at intervals of 1 week, 2 weeks, 1 month, and 6 months. Neurosensory assessment of the mental nerves was performed at 1 week postoperative following the same steps described by Atef et al.[22] CBCT scans were ordered for all patients cases immediately postoperative and at 6 months.

Stage-Two Surgery

The minimum acceptable graft consolidation period is 6 months. Therefore, at 6 months, the recipient sites

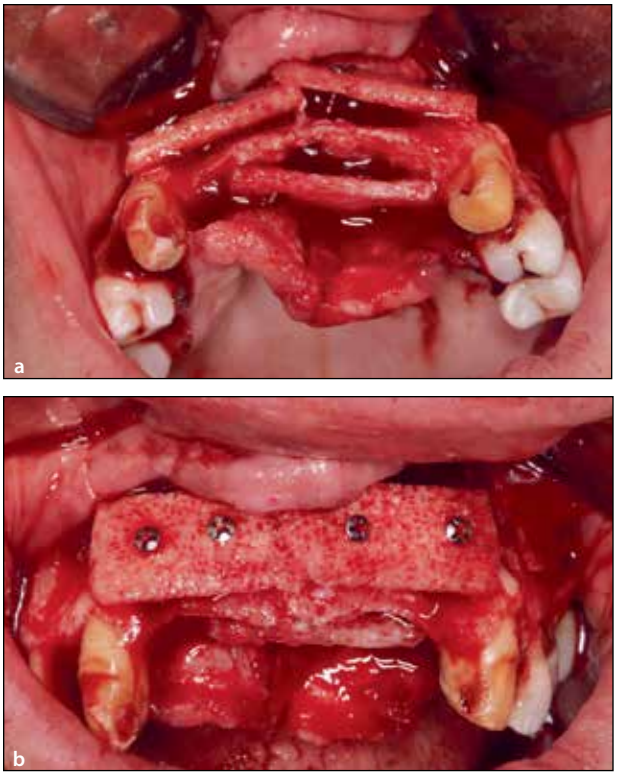

Fig 5 *(a and b)* Fixation of xenograft shells.

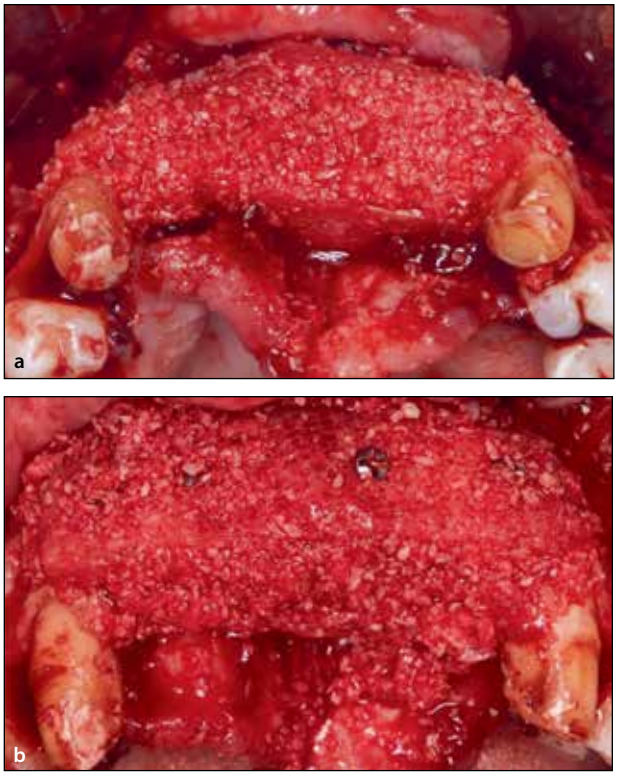

Fig 6 *(a and b)* Packing of the particulate mixture.

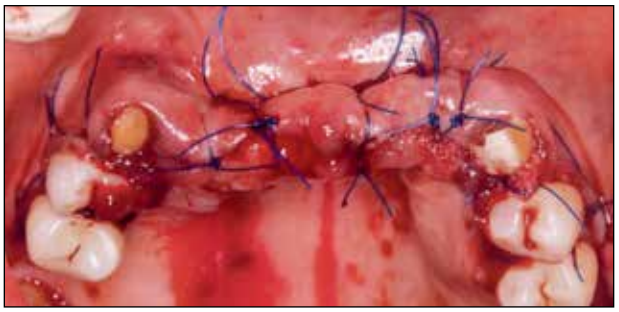

Fig 7 Suturing.

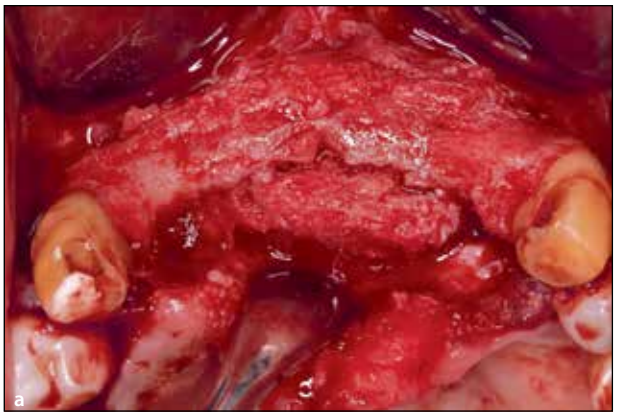

Fig 8 Stage-two surgery exposure *(a)* and core biopsy *(b)*.

were adequately exposed under local anesthesia and the microscrews were removed. A total of 18 implants were placed (Implant Direct) with 3.7-mm diameter and 13-mm length. Core biopsies were then harvested with a 3-mm-diameter trephine bur and sent for histomorphometric analysis (Fig 8).

Smart pegs were fastened to the implant platforms, and the Osstell device was used to record the primary stability; an average implant stability quotient (ISQ) of 60 ± 3.6 was recorded. The flap was closed using crestal 4/0 synthetic monofilament simple interrupted sutures (Polypropylene, Assut).

After 10 months, all patients were recalled for implant exposure and prosthetic loading. The ISQ was recorded

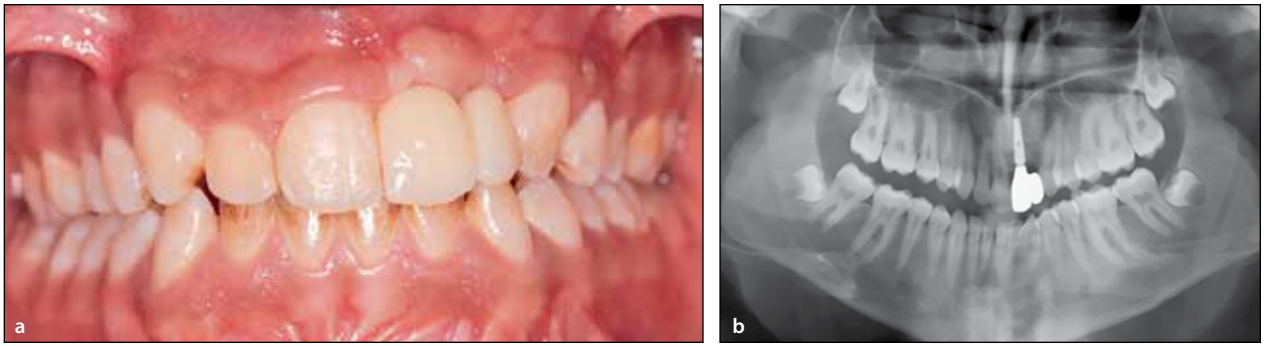

Fig 9 *(a and b)* Clinical and radiographic follow-up.

again as a secondary stability measurement, with a mean of 71.5 ± 2.4. Healthy covering gingival and mucosal tissues were observed, and all cases were successfully loaded. Following 3 months of functional loading, the patients were recalled for clinical evaluation, and no abnormal finding were documented (Fig 9).

Postoperative Assessment

Histomorphometric processing

The core biopsies were fixed in formalin for 1 week, then decalcified using a combination of ethylenediaminetetraacetic acid (EDTA) and formic acid. The solutions were changed daily for 2 weeks, and the specimens were regularly checked for softening. Following softening, the specimens were longitudinally embedded in paraffin blocks. From each block, three sections were cut at 4 µm thick, mounted on glass slides, and stained by routine hematoxylin and eosin (h&e) stain. Then the fixed slides were rehydrated in descending concentrations of alcohol (100%, 90%, 75%, then 50%) and subsequently washed in distilled water for 5 minutes. The slides were immersed in filtered hematoxylin stain for 3 minutes and washed with distilled water twice. Afterward, they were immersed in filtered eosin stain for 45 seconds and then washed with distilled water. Dehydration was then performed in ascending concentrations of alcohol (70%, 90%, then 100%) for 1 minute in each concentration, followed by rinsing with distilled water for 5 minutes. Dried slides were immersed in xylene and mounted with Canada balsam, and then coverslips were placed and left to dry. For histomorphometric examination, an image analyzer computer system (Leica software) was used for automated measuring of the area percentage of both newly formed bone and residual material in each group. These h&e-stained sections were examined at 100× magnification power, and five representative fields were chosen for evaluation.

Radiographic Assessment and Outcomes

Immediate postoperative and 6-month postoperative CBCTs were requested for all patients while they were closing in maximum intercuspation for accurate measurement of bone width and to assess the amount of horizontal bone gain of the grafted ridges while they were biting in centric occlusion. While drawing the panoramic curve on the axial views of the scan, guiding points were located at the center of natural teeth and/or the center of the edentulous ridges. The coordinates on the panoramic view were adjusted to be on the crest of the alveolar native bone; then anatomical landmarks (reference points) such as adjacent foramina, opposing teeth, or the nasal septum were used for repeated cuts preoperatively, immediately postoperatively, and 6 months postoperatively.

Using the selected anatomical landmarks as references, the alveolar width was measured in each of the selected cuts at 2 and 5 mm from the crest. The averages were then calculated, taking care to repeat this in three different slices throughout the area of interest. The average of the three measurements was calculated to represent each augmented site. Data was tabulated and sent for statistical analysis.

Statistical Analysis

The paired sample *t* test, also termed the dependent sample *t* test, was used in this study with eight participants. This test compares the means of two measurements taken from the same patient at two different times (eg, pretest and posttest score) using the R-statistical analysis software version 4.3.3 for windows. (R Core Team; R Foundation for Statistical Computing, https://www.R-project.org/.) The present study compared the statistical difference between these two measurements in all eight included patients.

RESULTS

A total of eight participants were included (five males and three females), each with one site. The routine postoperative edema was experienced during the first week. Sutures were removed 2 weeks postoperatively,

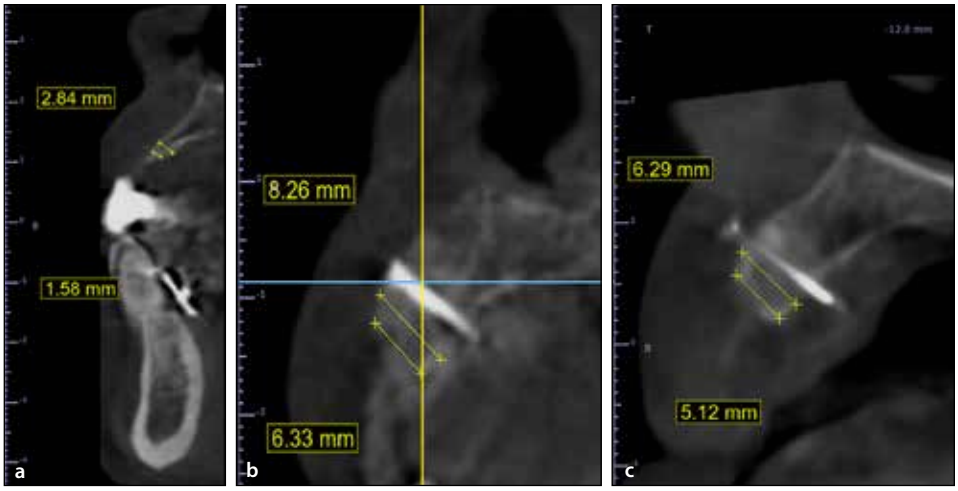

Fig 10 Bone width measurements at 2 and 5 mm from the alveolar crest: *(a)* preoperative; *(b)* immediately postoperative; *(c)* 6 months postoperative.

and no infections were reported. All patients but one healed normally. In the case of abnormal healing, a dehiscence was observed at 4 months postoperative, and the site was managed by reducing the exposed shell. The site then healed normally and received dental implants 2 months later (the same time as the other cases) at 6 months postoperative.

In another case, the covering mucosa was thinned and, in turn, left a remaining unfused part of the shell that was discovered during stage-two surgery. Following its removal, implants were placed normally, but three implant threads were still exposed. To address this problem, the threads were covered by particulate xenograft and a native collagen membrane.

A total of 18 implants were placed, and the ISQ measurements showed a mean primary stability of 60 ± 3.6 and secondary stability of 71.5 ± 2.4. The neurosensory assessment at 1 week postoperative showed complete recovery for all patients and was graded as S4 according to the modified Medical Research Council scale.[19] All patients received dental implants successfully despite the need for secondary grafting in several cases at the time of implant placement. All implants were integrated and loaded successfully 4 months after placement. Furthermore, the patients were clinically evaluated after 3 months of functional loading, and no abnormal findings were documented.

Radiographic Results

Radiographic assessment of bone width (Figs 10 and 11 and Table 1) showed that at 2 mm from the crest, there was a statistically significant increase in the mean bone width of 4.06 mm from the preoperative stage (mean 3.42 ± 0.81 mm) to the 6-month postoperative stage (mean 7.48 ± 1.81 mm) (conditions: t [7] = –5.95; P = .001) (Table 2). However, when the immediate postoperative data were compared to the 6-months postoperative data, a statistically significant decrease in the average bone width was observed from the immediate postoperative stage (mean 8.85 ± 2.3 mm) to the 6-month postoperative stage (mean 7.48 ± 1.8 mm) (conditions: t [7] = 5.66; P = .001), indicating an average of 1.41 mm of volume loss after 6 months (Table 3).

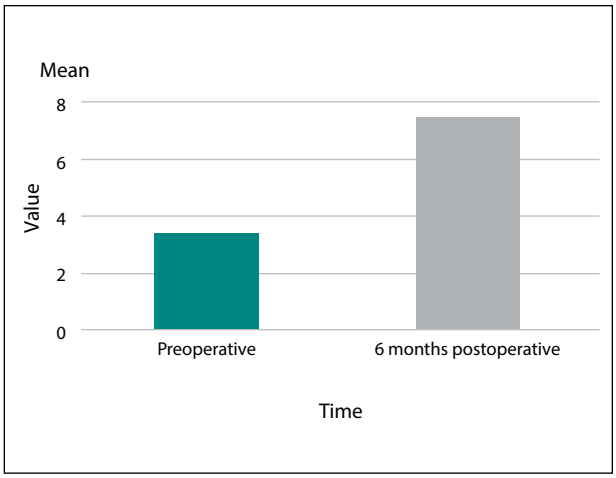

Fig 11 The difference between preoperative and 6-month postoperative width measurements for pair 1 at 2 mm from the crest.

At 5 mm from the crest, there was a statistically significant increase in bone width of 4.34 mm from the preoperative stage (mean 4.41 ± 0.89 mm) to the 6-month postoperative stage (mean 8.75 ±1.93 mm) (conditions; t [7] = –5.69; P = .001) (Table 4). However, when the immediate postoperative data were compared to the 6-month postoperative data, a statistically significant decrease in the average bone width was observed from the immediate postoperative stage (mean 10.94 ± 3.14 mm) to the 6-month postoperative stage (mean 8.75 ± 1.93 mm) (conditions; t [7] = 3.966; P = .005); this indicates an average of 2.19 mm of volume loss after 6 months (Table 5).

Table 1 Radiographic Measurements of Bone Width (mm) Preoperatively, Immediately Postoperatively, and 6 Months Postoperatively at 2 and 5 mm from the Alveolar Crest

		Preoperative		Immediately postoperative		6 mo postoperative	
Case no.: Sex	Age, y	2 mm	5 mm	2 mm	5 mm	2 mm	5 mm
Case 1: Male	42	4.1216	4.6466	10.766	14.88	8.89	12.03
Case 2: Male	56	2.5466	2.8349	10.63	12.96	8.44	9.24
Case 3: Female	40	2.87	4.92	5.669	7.989	5.179	7.0225
Case 4: Male	52	2.095	3.368	10.5866	13.5958	8.3775	9.4108
Case 5: Male	54	4.098	4.5138	6.553	7.1205	5.8838	7.626
Case 6: Male	54	3.5377	4.3516	6.045	6.865	4.985	5.7144
Case 7: Female	45	4.201	5.362	10.334	11.966	8.766	9.044
Case 8: Female	45	3.933	5.305	10.213	12.143	9.334	9.889

Table 2 Comparison of Bone Width (mm) Preoperatively and 6 Months Postoperatively 2 mm from the Crest

		Mean	N	SD	SEM
Pair 1	Preoperative	3.42	8	0.817	0.289
	6 months postoperative	7.48	8	1.811	0.640

SEM = standard error of mean.

Table 3 Comparison of Bone Width (mm) Immediately Postoperatively and 6 Months Postoperatively 2 mm from the Crest

		Mean	N	SD	SEM
Pair 1	Immediately postoperative	8.85	8	2.308	0.816
	6 months postoperative	7.48	8	1.811	0.640

SEM = standard error of mean.

Table 4 Comparison of Bone Width (mm) Preoperatively and 6 Months Postoperatively 5 mm from the Crest

		Mean	N	SD	SEM
Pair 2	Preoperative	4.41	8	0.896	0.317
	6 months postoperative	8.75	8	1.939	0.686

SEM = standard error of mean.

Table 5 Comparison of Bone Width (mm) Immediately Postoperatively and 6 months Postoperatively 5 mm from the Crest

		Mean	N	SD	SEM
Pair 2	Immediately postoperative	10.94	8	3.143	1.111
	6 months postoperative	8.75	8	1.939	0.686

SEM = standard error of mean.

Table 6 Histomorphometric Results in Four Cases

	Bone area (%)	Residual graft area (%)
Case 1	56.90%	4%
Case 2	40.022%	7.588%
Case 3	17.767%	12.88%
Case 4	36.8%	8.665%

Histomorphometric Results

The stained sections were examined using low- and high-power light microscopy (Leica). An image-capturing computer system using the software Leica Application Suite was used for imaging of the histologic sections. Images were captured under a magnification of ×100. The histologic findings of core biopsy samples were obtained from only four patients, because the other cases had either friable bone or a relatively resorbed graft shell that did not allow the core biopsy procedure (Table 6). The scanned sections showed trabeculae of mature lamellar bone with obvious reversal lines and established fibrofatty marrow with some inflammatory cells (Fig 12). The average newly formed bone area was 37.87%, while the average residual graft area was 8.28%.

DISCUSSION

Rehabilitation of the anterior maxilla with dental implants demands not only a functional outcome but also a unique esthetic result. Various techniques have been used to increase the bone volume in severely atrophied alveolar ridges to meet the prerequisites for successful

dental implant placement. The present technique of using customized xenograft blocks can provide different benefits for the patient and the clinician. In fact, a 3D reproduction of the patients' models simplified the surgery and reduced the intraoperative time. In addition, the fixation stability of the xenograft shell contributed to faster and better bone healing and graft consolidation with the advantages of its compatibility.[23]

A major drawback of using autogenous bone blocks is the morbidity of another stage-two surgical site (donor site) with an increased risk of infection and, in some donor sites, sensory disturbances that may reach up to 43%; however, such disturbances can recover spontaneously with time. Another drawback is the incomplete bony regeneration of donor sites that has been reported, especially in elderly patients, requiring around 6 months for complete healing even in successful cases.[24] The final disadvantage is the significant volume loss that occurs during bone healing, ranging from 35% to 51%.[25] Nguyen et al[26] used iliac onlay bone grafting combined with dental implant placement; the cumulative 5-year bone height change was 4.05 ± 1.83 mm, which corresponded to a mean resorption of 42.5% throughout the treated patients.

Xenografts are osteoconductive bone substitutes that are processed at high temperatures, deproteinized, and lyophilized to make them nonimmunogenic and slow down their resorption rate. They lose their organic components, especially the bone morphogenic proteins (BMPs), acting only as a skeleton (scaffold) for neovascularization and migration of osteoprogenitor mesenchymal cells and osteoblasts. The cortical or cancellous structure of the bone shell or block also plays an important role. The porous nature of the cancellous block promotes neovascularization, cell migration, adhesion, and proliferation, which also speeds up the rate of new bone formation and its integration into the host compared to cortical grafts. On the other hand, cortical grafts exhibit higher initial strength, which makes them more reliable during fixation. It also allows them to resist the forces of the surrounding soft tissues, especially when the bone block is placed outside the anatomical boundaries of the skeleton to augment a defect as an onlay. In addition, these types of defects provide less host vasculature to the graft compared to inlay grafting.[27,28] The augmented defects in the present study exhibited the above-mentioned challenges and could have contributed to the friability discovered in some of the cases during stage-two surgery, as all the defects required onlay-type augmentation.

In a 6-year prospective study by Qiu and Yu,[29] 14 patients were treated using onlay bovine bone mineral blocks, and a horizontal bone gain of 8.73 ± 0.82 mm and resorption rate of 7.03% were reported. Severe bone resorption was noted at 6 months and 2 years following loading; as a result, they recommended using a mixture with autogenous bone particulate and the application of a membrane to cover the grafted site.

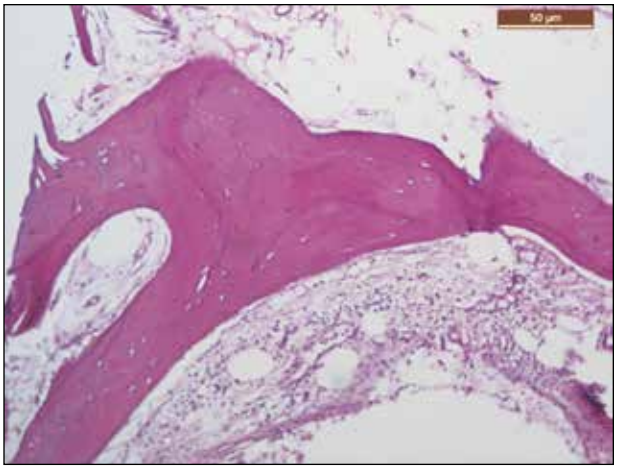

Fig 12 Core biopsy stained by h&e showing large areas of lamellar bone formation (×100).

Xenografts were also used in another randomized controlled trial by Mounir et al[30] for vertical augmentation of atrophic anterior maxillae, both as onlay particulate grafts supported by titanium mesh and as inlay blocks in the space created after downfracturing the crestal segment followed by fixation with miniplates. No statistically significant results were found between both groups.[30] A systematic review by Sánchez-Labrador et al[31] evaluated xenograft blocks compared with autogenous blocks. A total of 333 patients were incorporated with a total of 337 xenograft blocks and 82 autogenous blocks used; as a result, the rates of failure were 6.82% and 6.1%, respectively. The vertical and horizontal gains were similar among both groups despite the greater resorption in the autogenous block group.[31]

In the present study, the cases that included extraction sites were classified as class 3 extraction sockets, according to Nicolas Elian; they lacked the labial plate and needed alveolar bone reconstruction.[32] Customization of the xenograft bone shell took place extraorally to fit the contours and curves of the anterior maxillary ridges based on the 3D-printed models. Better adaptation was feasible because of the malleability of the thinned xenogeneic bone shells, which would have been difficult with autogenous blocks due to the inherent shape of the cortical shell itself. Therefore, the technique described by Khoury et al[33] of thinning the bone shell, which was applied in the present study but with xenogeneic bone, enabled a better 3D reconstruction that preserved the unique shape and contour of the anterior maxilla.

The same digital workflow was reported by Venet et al,[34] who used 3D-printed models of the atrophic maxilla to customize allogeneic corticocancellous block

grafts that were placed through a minimally invasive surgical technique using subperiosteal tunneling. They reported satisfactory results for augmentation of horizontally atrophic anterior maxillary ridges in addition to the reduced surgical time and eliminated morbidity of the donor site. However, several limitations were reported, including the inaccessibility of the tunneling technique, which limited the study to nothing more than a single-tooth augmentation, with recommendations for longer follow-ups and histologic evaluation.[34]

The blocks were sectioned into shells at the time of operation (not before) to avoid distortion or dissolution of the shell if placed in saline for too long. It would have been better to use the cortical type of xenogeneic blocks for a more acceptable result of bone gain and reliability of fixation; however, to reduce the graft integration time, cancellous blocks, which are characterized by wide pores that enhance permeability and vascularity, were used.[27,28] Nonetheless, this rendered the fixation process too challenging to withstand fixation by microscrews.

Monje et al used mandibular ramus bone blocks to augment severely atrophic maxillary anterior ridges, and a mean gain of 3.23 mm in bone width was obtained.[8] Another clinical study using the iliac crest showed that the horizontal bone gain was 2.7 mm at the marginal level and 5.0 mm at 5 mm apically, which is comparable to the results of the present study.[35] Other studies also used xenogeneic blocks with a bone width gain between 3.28 and 4.12 mm.[36–39] In a clinical trial that compared the use of the gold standard autogenous blocks with xenogeneic blocks for horizontal bone regeneration, it was possible to observe a similar bone gain in both groups but with less morbidity in those cases treated with xenogeneic blocks.[40]

The use of 1:1 autogenous/xenograft mixture in this study was in accordance with Urban et al,[41] who grafted knife-edge ridges with this mixture covered by collagen membranes with only one case that showed complications.[41] Hence, the high biologic effects of autogenous bone and the slow resorption rate of xenografts synergized each other. The needed volume to fill the interpositional gap between the xenogeneic shell and the native ridge was estimated preoperatively during customization of the shells and intraoperatively following fixation. Overall, 50% of the needed volume was collected from the symphysis region using the ACM bur. Only three to five entries by the ACM bur were sufficient in all cases to provide the needed volume of autogenous particulate, and the other 50% of the graft was in the form of xenograft powder. Moreover, in the present study the vestibular approach was kept between the canines, with no need to approach the mental foramina or apply any tension to the neurovascular bundles; in turn, no neurosensory deficits were reported.

On the contrary, if autogenous cortical or corticocancellous blocks from the symphysis were to be used instead of xenogeneic blocks, it would have required an extension of the vestibular incision beyond the premolars to identify the mental nerves and protect them, all while providing adequate exposure for harvesting bone blocks with the needed dimensions. In addition, particulate autogenous bone collection by ACM bur would be needed to be mixed with xenograft for obliteration of the gaps. Hence, the exposure of the chin would have been more extensive for autogenous block harvesting and with a greater risk of neurosensory impact compared to just for ACM bur use. Moreover, regarding donor site morbidity, the defect created by a 4-mm-diameter ACM bur was expected to heal and regenerate better than that created following a chin block harvest.

In GBR, xenografts are believed to preserve the gained volume with their osteoconductive properties and slow resorption rates taking up to a minimum of 6 months.[42] Although xenogeneic graft materials represent a generous noninvasive graft available in different forms that suit various augmentation purposes, several limitations still exist such as *(1)* the degradation time, and *(2)* the ultimate fate of the graft materials, which depends on the graft processing protocol and can cause variations in the material hydrophilicity; and the viscoelasticity with the resultant alteration in the physicochemical properties.[43] This fact motivated the choice of extending the consolidation period and the placement of implants at 6 months in the present study rather than the 4 months elected by Khoury et al in their original autogenous cortical shell technique.[7]

In the present study, the histologic findings of core biopsies were obtained from only four cases due to clinical availability. The other cases had either friable bone or a relatively resorbed graft shell that did not permit taking a core biopsy. All captured samples showed the presence of newly formed trabeculae of lamellar bone, with residual graft particles, some inflammatory cells, and small fibrous tissue formation. The average percentage of newly formed bone area was 37.87%, which indicated the adequate osteoconductive capacity of the grafting materials.

Coinciding with the present study, other experimental studies with 6-month histomorphometric analysis of biopsies obtained from regenerated areas with xenograft blocks showed neoformation of vital bone in the block itself together with zones of nonresorbed residual xenogeneic material.[44,45]

CONCLUSIONS

Within the limitations of the study, the use of xenograft shells as a barrier for maxillary alveolar ridge

reconstruction is promising; however, further studies investigating the required time for graft consolidation and the effect of using collagen membranes are required.

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