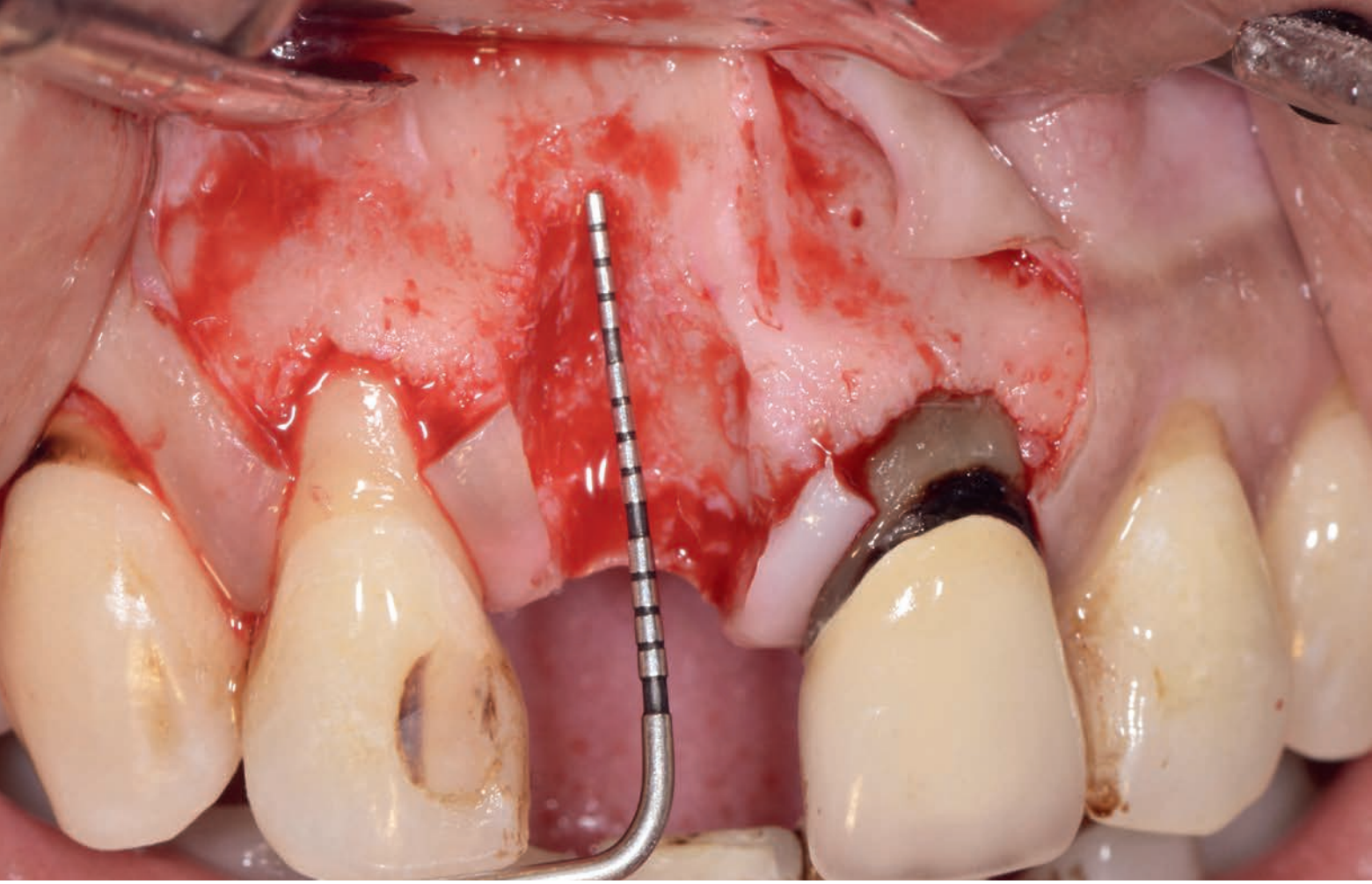

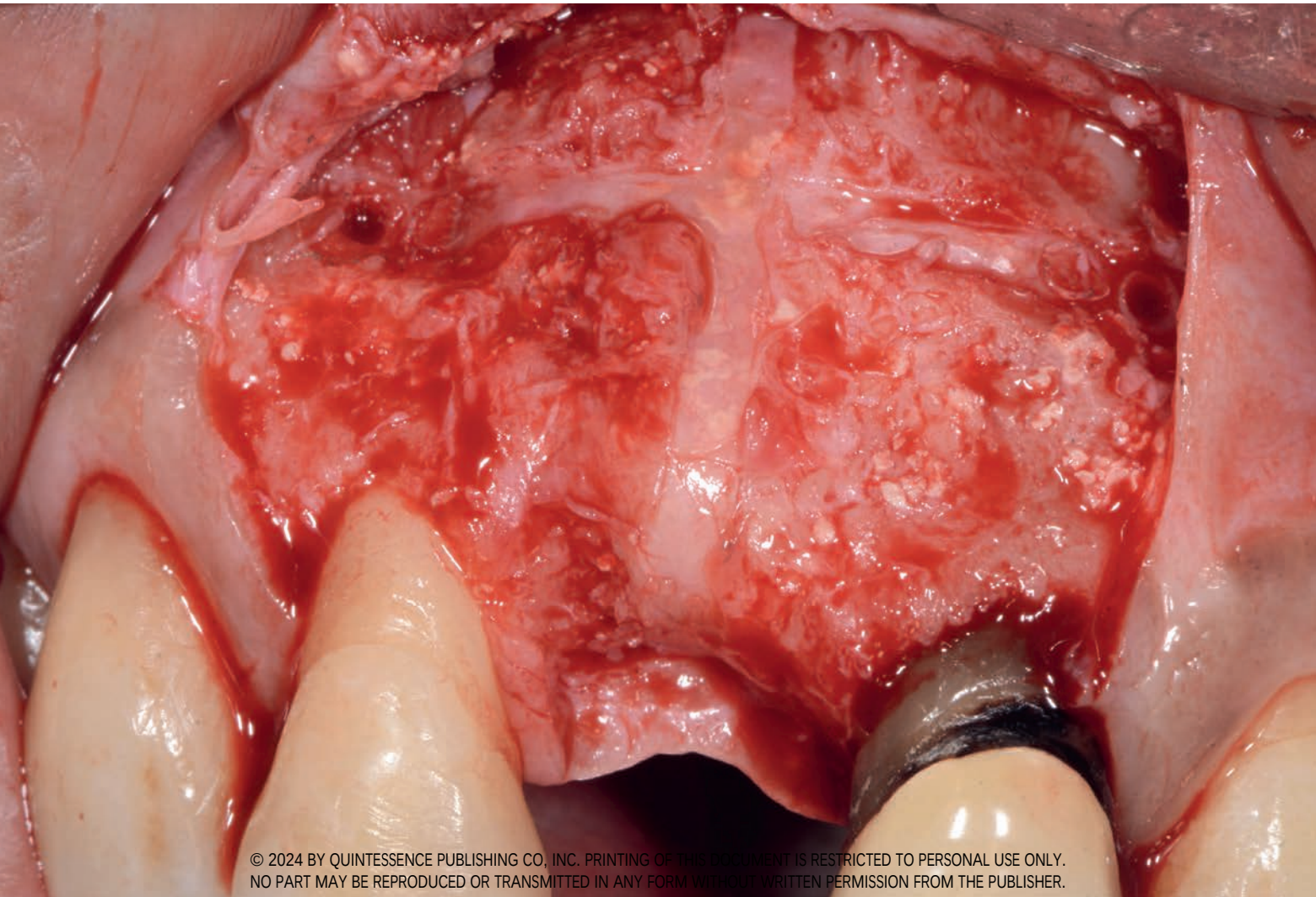

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Shih-Cheng Wen, DDS, MS
Muhammad Saleh, BDS, MDS
Abdusalam Alrmali, BDS, MFDS RCS, MDS
David T. Wu, DMD
Hom-Lay Wang, DDS, MSD, PhD

Utilizing Individualized Titanium Frames for Protected Alveolar Bone Augmentation: A Feasibility Case Series

Despite the various treatments proposed with barrier membranes, one of the main challenges for guided bone regeneration (GBR) is maintaining space for large defects and ensuring an adequate blood supply. The presented feasibility case series aims to introduce an original titanium frame (TF) design, customized for each defect, as a modification of well-known principles and materials for GBR to achieve an enhanced and more predictable horizontal and vertical bone augmentation. Three patients with significant horizontal defects were treated with pre-trimmed TFs to create needed space, and then a 50/50 mixture of autograft and bovine xenograft was placed and covered with a collagen membrane. After 8 months of healing, the sites were reopened, and the titanium screws were removed with the frame. An average of 8.0 ± 1.0 mm of horizontal and 3.0 ± 0.0 mm of vertical bone gain were achieved at the time of reentry and implant placement surgery. Bone core biopsy sample was obtained during the implant placement. Histomorphometric analysis revealed that 42.8% of the sample was new vital bone, 18.8% was residual bone graft particles, and 38.4% was bone marrow–like structures. After 3 to 4 months from implant placement, the implants were restored with provisional crowns and then finalized with zirconia screw-retained crowns. This case series suggests that GBR utilizing TFs with or without collagen membranes can be considered a suitable approach for horizontal and vertical bone augmentation. However, based on only three reported cases, the results should be carefully interpreted. *Int J Periodontics Restorative Dent 2024;44:277–285. doi: 10.11607/prd.6568*

The goal of implant dentistry is to replace missing teeth and restore lost oral functions in an esthetically and restoratively driven way. Loss of alveolar supporting bone, either horizontally or vertically, would compromise this equation.[1] Therefore, alveolar ridge preservation and/or augmentation are proposed to accomplish these goals. As a result, over the decades, several augmentation materials and techniques have been described in the literature.[2–5]

Simply placing an implant where the bone is most available, regardless of the future restoration position, requires nonaxial implant loading, which has an increased potential for prosthetic complications.[6] One of the main challenges is creating the necessary space for bone formation while providing the needed blood supply, and it has been noted that wound closure and flap advancement results in considerable displacement of particulate bone graft.[7,8] Space-maintaining devices like

titanium mesh, customized or pretrimmed titanium frames, tenting screws, and bone shells are best suited for creating space; because these devices do not meet the criteria for guided bone regeneration (GBR), which must involve selective cell exclusion, protected bone augmentation[9] (PBA) is the best term to use for techniques that use these devices. Nevertheless, many drawbacks were reported with such techniques.[1] Through the addition of a barrier membrane, they may still be considered GBR.

Although all of the mentioned devices share the basic principles and materials for PBA, predictability has not yet been achieved, especially among vertical ridge augmentation cases. Nevertheless, the complexity of some devices, time-consuming intraoperative adaptation, and rate of associated complications keep some clinicians looking for more simple, individualized designs that are more friendly for the soft tissue.[1,10] Furthermore, some complications have been described in the clinical application of GBR, including *(1)* soft tissue dehiscence with subsequent membrane exposure; *(2)* membrane displacement during wound closure; *(3)* lack of stiffness causing membrane collapse during healing, therefore reducing the space needed for bone regeneration; and *(4)* complete blockage of the periosteal blood supply by ingrowth of the angiogenic cells, resulting in slow healing.[10] These complications may be due to *(1)* shrinkage of the blood clot underneath the membrane during initial healing; *(2)* entrapment of air beneath the membrane; *(3)* membrane micromovement; and *(4)* insufficient healing period. In contrast, nonresorbable titanium mesh is a metal laminate that can adopt a 3D shape without blocking the blood supply from the bone and mucosal sides thanks to the presence of pores in the mesh.

Thus, a titanium frame (TF) was developed and reported in this feasibility case series as a simple and efficient space-maintaining device for bone regeneration with minimal potential flap dehiscence during the healing period. The proposed titanium frame fulfills the criteria of the PASS principles for successful bone augmentation, described by Wang and Boyapati in 2006.[11] These four biologic criteria are as follows: *(1)* primary closure after placing the bone and fixing the TF; *(2)* angiogenesis (which is very apparent TF feature, as it provides more spaces for more blood supply); *(3)* space maintenance (also presented by TF); and *(4)* stability of the device, which is critical for an uneventful healing process (this was accomplished by fixing the TF with microscrews).

Materials and Methods

Description of TF-Protected GBR Procedures

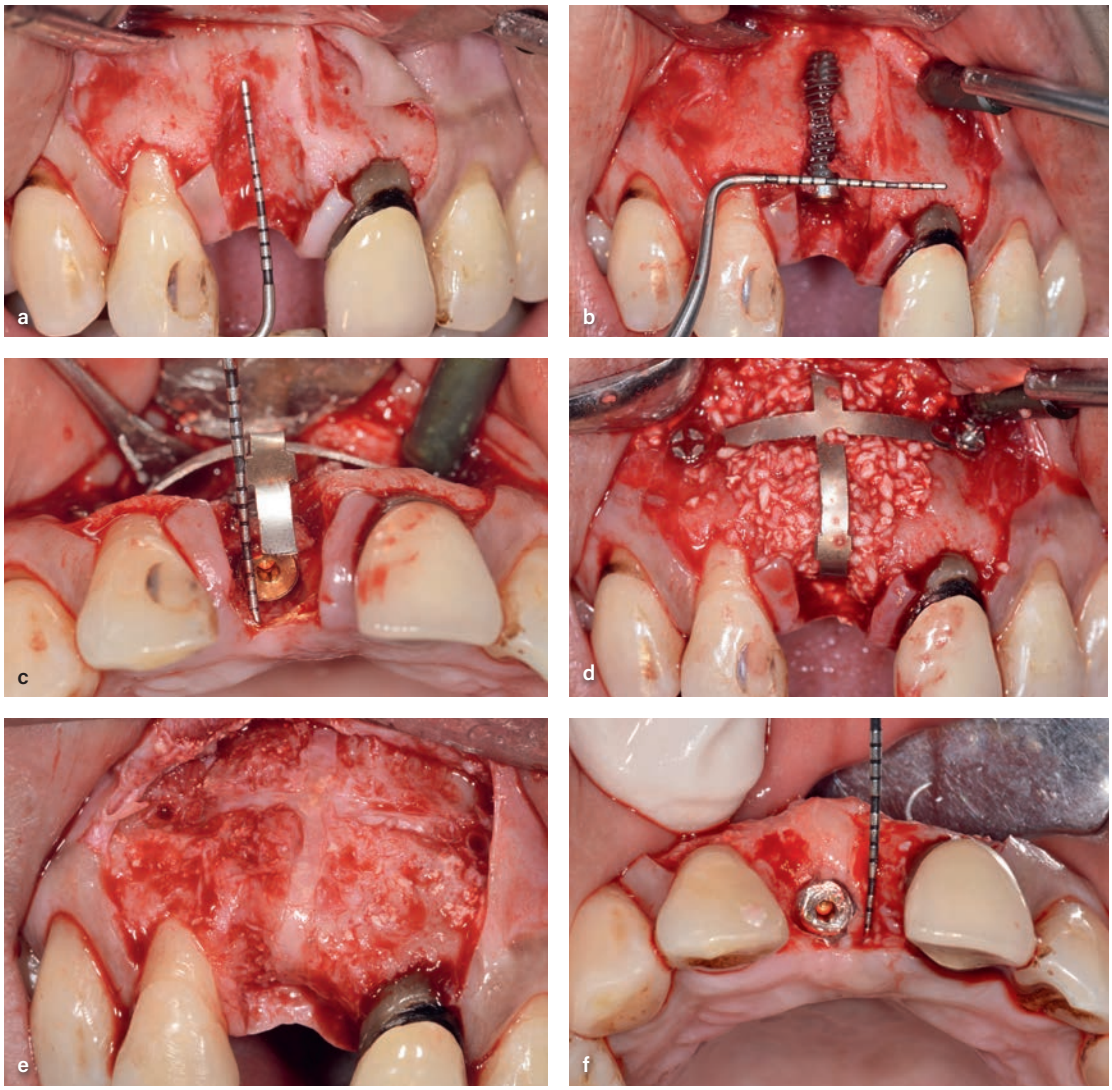
This feasibility case series study was conducted in a private practice (Taipei, Taiwan) between October 2018 and February 2019. Three patients in need of single or multiple implant restorations were included. Clinical and radiographic examinations for the cases revealed ridge deficiency (HVC classification: Type C defects) with medium/large horizontal and vertical bone loss (≥ 4 mm), and the patients were consecutively enrolled.[12] CBCT scans (ProXam 3DQ, KaVo) were obtained preoperatively and at 8 months posttreatment to evaluate ridge dimensions. All patients were treated with the same surgical and prosthetic protocol.

Case Reports

Case 1: GBR for a Single Anterior Implant

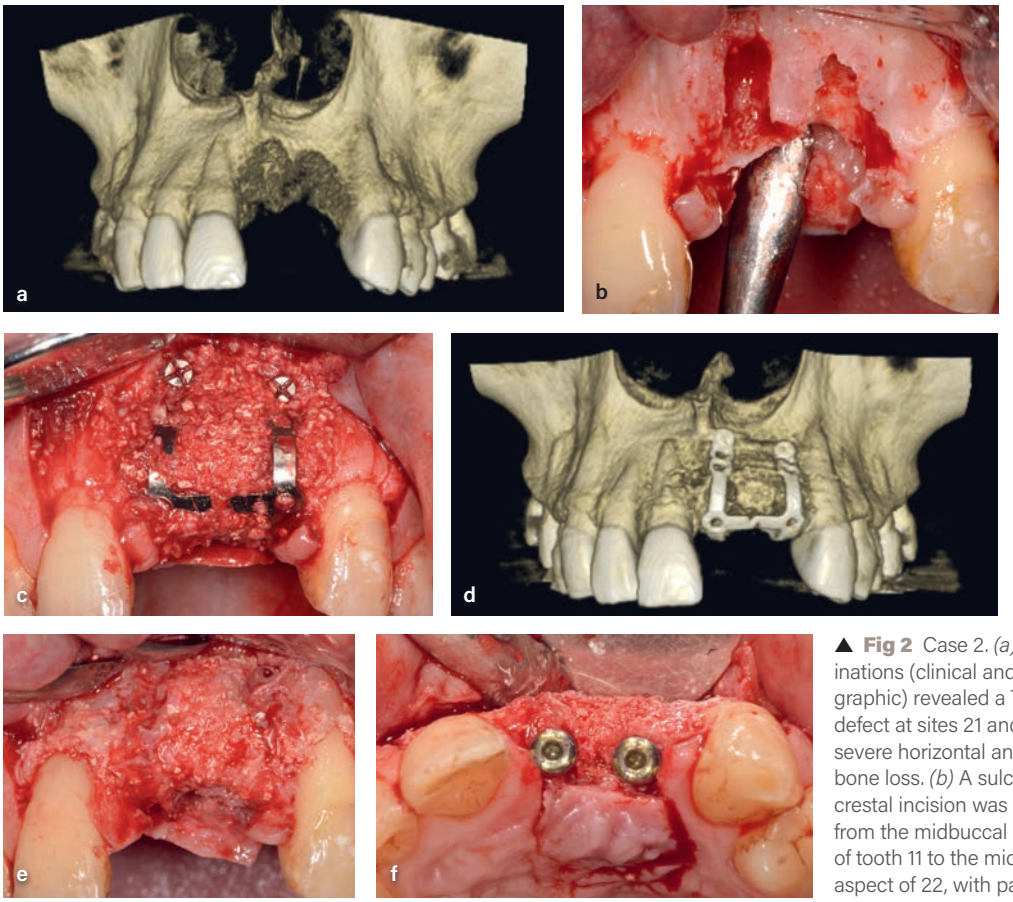
A 46-year-old woman presented to the clinic with a chief request to replace her missing maxillary right central incisor. Clinical and radiographic examinations revealed a Type C defect with severe horizontal and vertical bone loss (Fig 1a).

A sulcular incision was performed at the midbuccal aspect of teeth 12 and 21 (FDI tooth-numbering system), using papilla-preserving incisions to conserve the interproximal papilla of the teeth, and a full-thickness flap was reflected (Fig 1b). An immediate implant (3.8-mm diameter and 14-mm length; anterior iEZ implant, iEZ Dental Implant System) was placed into site 11, and a primary stability of > 35 Ncm was achieved. Upon implant insertion, a three-wall defect was observed with complete buccal dehiscence. A TF tent (grade 2 pure titanium; see Appendix Fig 1 in the online version of this article) was pretrimmed based upon a CBCT scan (which was taken for every case defect),



▲ **Fig 1** Case 1. Clinical and radiographic examinations revealed a Type C defect with severe horizontal and vertical bone loss. *(a)* A sulcular incision was performed at the midbuccal aspect of teeth 12 and 21, using papilla-preserving incisions to conserve the interproximal papillae, and a full-thickness flap was reflected. *(b)* An implant (3.8-mm diameter and 14-mm length) was immediately placed into site 11, and a primary stability of > 35 Ncm was achieved. *(c)* Upon implant insertion, three-wall defects were observed with complete buccal dehiscence. The TF was contoured to achieve space maintenance and fixed with two screws at the mesial and distal aspects. *(d)* The bony defect was filled with a combination of 50% particulate autogenous bone graft and 50% particulate porcine hydroxyapatite. A resorbable collagen membrane was then placed over the defect, and primary closure was achieved (not shown). *(e)* Surgical reentry after 8 months showed an adequate amount of bone. Note that the implant was still buried under the regenerated bone. *(f)* Excess bone was removed to uncover the healing cap, which was replaced with a healing abutment.

sterilized using an autoclave (121ºC for 30 minutes), and contoured slightly to achieve the best adaptation and space maintenance. The TF was then fixed with two fixation screws (Stoma) on the predesigned screw holes at the mesial and distal aspects (Fig 1c). The bony defect was filled (Fig 1d) with a combination of approximately 50% particulate autogenous bone graft (harvested from the adjacent sites using a bone scraper [Safescraper Twist, Meta]) and 50% particulate porcine hydroxyapatite (Gen-Os, OsteoBiol). An absorbable collagen matrix (Jason pericardium membrane, Botiss) was placed over the defect after adequate flap release, and primary closure was achieved using 6/0 poly glycolic acid sutures. Oral and written postoperative instructions were



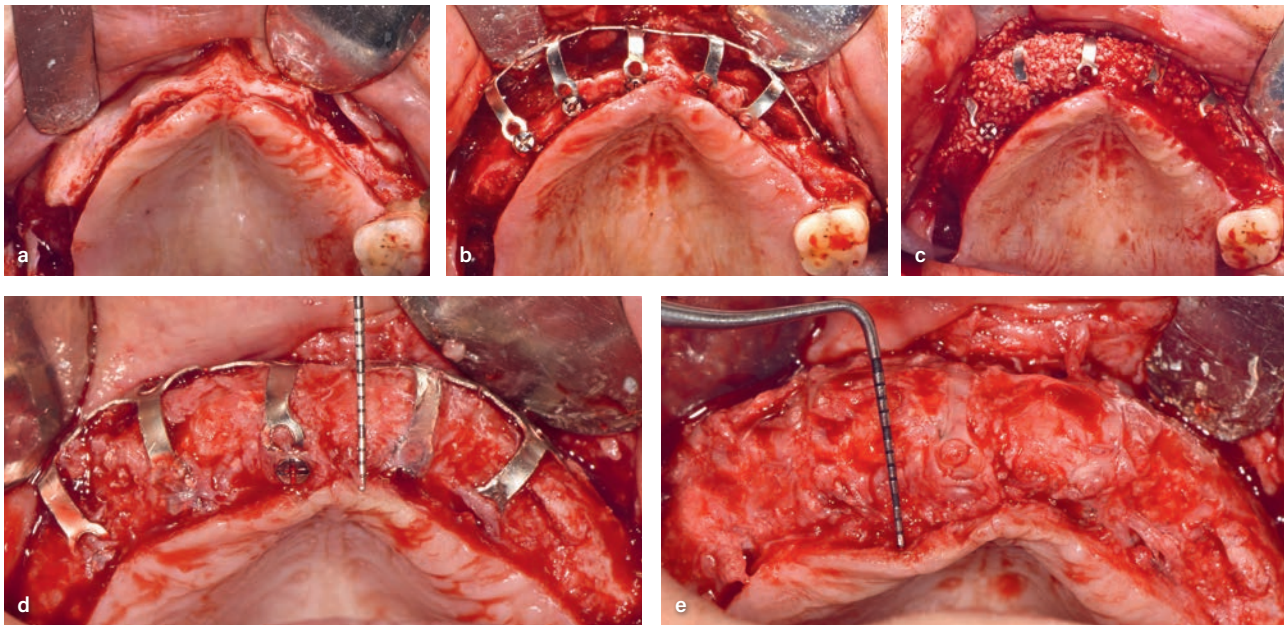
▲ **Fig 2** Case 2. *(a)* Examinations (clinical and radiographic) revealed a Type C defect at sites 21 and 22 with severe horizontal and vertical bone loss. *(b)* A sulcular and crestal incision was performed from the midbuccal aspect of tooth 11 to the midbuccal aspect of 22, with papilla-preserving incisions to conserve the interproximal papillae at sites 11 and 22, and a full-thickness flap was reflected. *(c)* A TF was then secured to the buccal and palatal aspects of the defect using four fixation screws, the bone graft and membrane were placed, and primary closure was achieved. *(d)* CBCT imaging at 8 months showed gains in vertical and horizontal volume. *(e)* Reentry surgery revealed an adequate amount of bone after TF removal. *(f)* Two implants (3.8-mm diameter and 14-mm length) were placed at sites 21 and 22, achieving a primary stability of > 35 Ncm.

provided to the patients, as well as prescriptions for analgesics (600 mg ibuprofen every 8 hours as needed), antibiotics (500 mg amoxicillin tid for 7 days), and a mouthrinse (chlorhexidine gluconate 0.12% for the first 2 weeks). Sutures were removed at the 2-week follow-up.

After 8 months, surgical reentry revealed an adequate amount of bone (Figs 1e and 1f). Excess bone was removed to uncover the healing cap, which was replaced with a healing abutment. Histologic analysis was performed on the removed excess bone and revealed 52.7% vital bone, 27.6% residual bone graft particles, and 19.7% connective tissue. CBCT volumetric analysis comparing the preoperative and 8-month postoperative volumes at site 11 revealed a total hard tissue gain of 1,359.3 mm^3. CBCT cross-sectional analysis identified mean and maximum horizontal bone gains of 5.4 mm and 8 mm, respectively. In addition, mean and maximum vertical bone gains of 2.3 mm and 3 mm were achieved, respectively. This case demonstrates the use of TF as a nonresorbable device for GBR in conjunction with single immediate implant placement in the esthetic region.

Case 2: GBR for Two Anterior Implants

A 43-year-old man presented to the clinic to replace two missing anterior teeth. Clinical and radiographic examinations revealed a Type C defect at sites 21 and 22 with severe horizontal and vertical bone loss (Fig 2a).



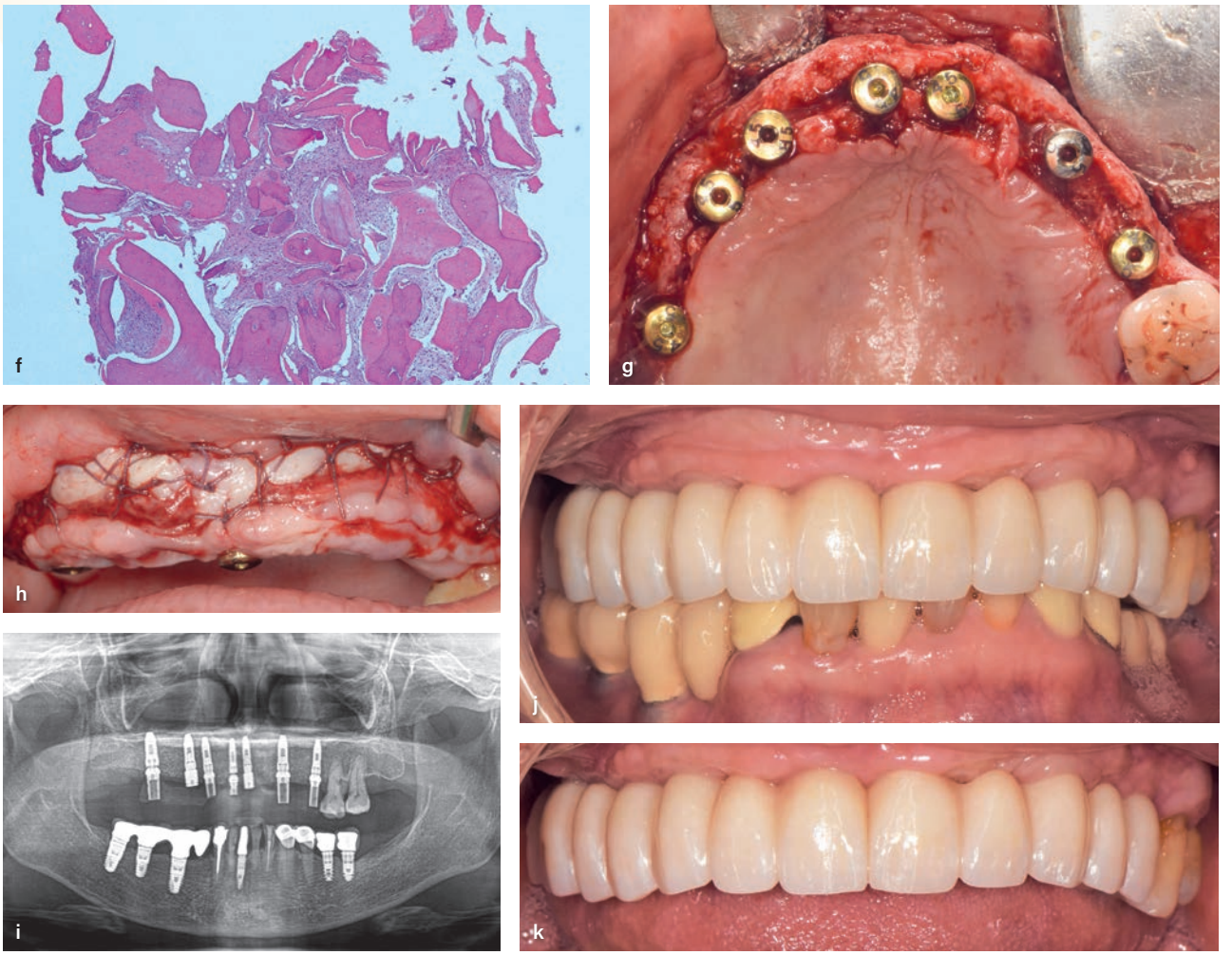
▲ **Figs 3a to 3e** Case 3. Clinical and radiographic examinations revealed a Type C defect with severe horizontal bone loss across the entire maxilla. *(a)* A crestal incision was performed, and a full-thickness flap was reflected, revealing the severe maxillary deficiency. *(b)* A full-arch TF frame scaffold was used to achieve space maintenance. *(c)* A composite bone graft was used to fill the defect. A resorbable collagen matrix was placed over the defect, and primary was closure achieved (not shown). *(d and e)* After 8 months, surgical reentry revealed an adequate amount of bone formation. ⟶

A sulcular and crestal incision was performed from the midbuccal of tooth 11 to the midbuccal of tooth 22, using papilla-preserving incisions to conserve the interproximal papilla at sites 11 and 22, and a full-thickness flap was reflected (Fig 2b). Following corticotomy procedures, a custom pre-trimmed TF was sterilized and secured to buccal and palatal aspects of the defect with four fixation screws on the predesigned screw holes, and the same type of bone graft and membrane as described in Case 1 were placed to achieve space maintenance, and primary closure was achieved (Fig 2c). The same postoperative regimen as Case 1 was provided to the patient. Sutures were removed at the 2-week follow-up.

After 8 months, surgical reentry revealed an adequate amount of bone after TF removal (Figs 2d and 2e). Two implants (3.8-mm diameter and 14-mm length; Anterior iEZ implant) were placed into sites 21 and 22, and a primary stability of > 35 Ncm was achieved for both (Fig 2f). Excess bone was removed, and a histologic analysis revealed 38.6% vital bone, 12.2% residual bone graft particles, and 49.2% connective tissue. CBCT volumetric analysis comparing the preoperative and 8-month postoperative volumes at sites 21 and 22 revealed a total hard tissue gain of 818.6 mm^3. CBCT cross-sectional analysis identified mean and maximum horizontal bone gains of 4.3 mm and 9 mm, respectively. In addition, the mean and maximum vertical bone gains were 3.1 mm and 5 mm, respectively. This case demonstrates the use of TF as a nonresorbable scaffold in GBR for site preparation of two adjacent implant placements in the esthetic region.

Case 3: GBR for Full-Arch Implant Reconstruction

A 52-year-old woman presented to the clinic to replace her missing maxillary anterior teeth. Clinical and radiographic examinations revealed a Type C defect with severe horizontal and minor vertical bone loss across the entire maxillary arch. A crestal incision was performed, and a full-thickness flap was reflected, revealing the severe maxillary deficiency (Fig 3a). A full-arch TF scaffold was adapted around the entire arch to achieve space maintenance, with fixation



▲ **Figs 3f to 3k** *(f)* Histologic analysis showed new bone formation. *(g)* A ridge split was performed to allow implant placement in a prosthetically and biologically correct position. *(h)* A strip free gingival graft was used to improve the peri-implant tissue quality and restore the vestibular depth. *(i)* Panoramic radiographic view of the implants in position. *(j and k)* Six-month and 1-year follow-ups, respectively, with the final restoration in place.

screws placed at the crest of the overly thin ridge, slightly towards the palatal side (Fig 3b). The same composite bone graft used in Cases 1 and 2 was used to fill the defect (Fig 3c). An absorbable collagen matrix was placed over the defect, and primary closure achieved. The same postoperative regimen as described in Cases 1 and 2 was provided to the patients. Sutures were removed at the 2-week follow-up.

After 8 months, surgical reentry revealed an adequate amount of bone (Figs 3d and 3e). Histologic analysis of a bone core sample revealed 37.2% vital bone, 16.7% remaining particles, and 46.1% connective tissue (Fig 3f). CBCT volumetric analysis comparing preoperative and 8-month postoperative volumes identified mean and maximum horizontal bone gains of 4.5 mm and 8 mm, respectively. The mean vertical bone gain of all cross-sectional cuts was 1.2 mm, with a maximum vertical bone gain of 3 mm. A ridge split was performed to allow implant placement in a prosthetically and biologically correct position (Fig 3g). Three months later, a strip free gingival graft was placed to improve the peri-implant tissue quality and restore the vestibular depth (Fig 3h). Full-mouth restoration was constructed 3 months after the free gingival graft. Figures 3i and 3j show the results 1 year after treatment.

Table 1 Mean Linear and Volumetric Changes Achieved Using the TF Augmentation Technique

Case no. (age)	Total CBCT hard tissue gain	Horizontal bone gain	Vertical bone gain	New/vital bone	Residual bone defect	Soft tissue
1 (46 y)	1,359.3 mm^3	5.4 mm	2.3 mm	52.7%	27.6%	19.7%
2 (43 y)	818.6 mm^3	4.3 mm	3.1 mm	38.6%	12.2%	49.2%
3 (52 y)	2,909.6 mm^3	4.5 mm	1.2 mm	37.2%	16.7%	46.1%
Average	1,695.9 ± 886.1 mm^3	4.73 ± 0.5 mm	2.2 ± 0.8 mm	42.8% ± 7.0%	18.8% ± 6.5%	38.3% ± 13.2%

Discussion

In this feasibility case series, the average horizontal bone gain was 4.73 mm, and the average vertical bone gain was 2.2 mm. Through the 8 months of healing, no complications related to TF were found. After 8 months, surgical reentry revealed an adequate amount of bone, and the TFs were surrounded by a dense connective tissue without any clinical signs of inflammation. The TFs adhered well to the newly formed tissues. The grafts were well-maintained and incorporated into the native bone. CBCT volumetric analysis compared preoperative and 8-month postoperative volumes to measure the total hard tissue gain of all cases (Table 1). The total average bone volume gain was 1695.9 ± 886.1 mm^3. Histologic results showed averages of 42.8% ± 7.0% of new and vital bone, 18.8% ± 6.5% of residual bone graft particles, and 38.3% ± 13.2% of soft tissues. The bone grafting procedure was 100% successful in all three cases, and regrafting was not required.

Alveolar ridge augmentation can be performed via different techniques to accomplish predictable results. However, adequate space maintenance remains a key challenge. In the present case series, TF scaffold technology was used for horizontal and vertical bone regeneration with predictable results after 8 months of follow-up. To ensure predictable long-term esthetic and functional outcomes, sufficient bone volume and quality alveolar bone are essential for future implant sites. Several ridge reconstructive procedures have been established to increase ridge height and/or width,[1,3] but it is difficult to maintain an ideal bone contour when bone substitutes resorb faster than the rate of bone formation.[1] The present case series showed considerable improvements in all clinical measurements and a significant reconstruction of horizontal and vertical bone defects, as measured by volumetric CBCT analysis and histology.[2–4]

In the present study, autogenous bone graft was harvested and mixed with xenograft as a scaffold for more controlled healing.[13] Postoperative histologic results demonstrated means of 42.8% of new vital bone and 18.8% of residual bone defect, which is slightly higher than similar reports using resorbable membranes.[14] This is also reported by Simion et al in their clinical and histologic study, where they highlighted that bovine xenograft undergoes very slow resorption and allows time for substitution with new bone, supporting the use of xenograft with autogenous bone in a 1:1 ratio for GBR cases.[10] One other, seemingly essential requirement is covering the composite graft with a membrane; this was reportedly accompanied with less bone resorption due to its protective effect during healing.[15]

The present study reported a novel TF for vertical and horizontal ridge augmentation, which act as a tent for protective ridge augmentation without blocking the blood supply or having a high risk of exposure. In addition, the membrane can easily be trimmed and folded to fit nicely at the planned augmented defect, with predesigned holes for membrane fixation. No exposure occurred in the presented case series, either early or delayed. A collagen membrane was used as the barrier over the TF. This was validated in a study that reported a lower rate of exposure when titanium grids were adopted as compared to e-PTFE membranes.[16]

Both simultaneous and two-stage approaches were used in the present cases, with implants placed either with or after bone augmentation and TF removal. The newly formed bone obtained in

both approaches responded to implant placement in a manner similar to native, nonregenerated bone (ie, capable of bearing and sustaining the functional load).[17,18] With this surgical technique, a sufficient bone mass was achieved to facilitate implant placement in the desired corono-apical position and angulation. The overall clinical and radiographic results of the present study show a survival and success rate of 100% (according to Albrektsson et al's proposed criteria), confirming the favorable results of previous clinical studies on implants placed in regenerated bone using titanium deevices.[19–21]

As a case series, the present study has inherent limitations, as there was no control group and cases that were most suited for the procedure were selected. Future randomized controlled trials are encouraged to compare the success, complication rate, bone quality, and cost-effectiveness of this novel technique compared to other established PBA techniques.

Conclusions

Considering the limitations of this case series study, it can be concluded that GBR using a pretrimmed and sterilized TF with or without collagen membrane can be considered a better predictable approach for both horizontal and vertical bone volume gain. However, the results should be carefully interpreted.

Acknowledgments

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S.C.W.: Conception and design of the study; performed the surgical procedures; initial and final drafting of the work. M.S., A.R., D.W.: Initial and final drafting of the work. H.L.W.: Design of the study; critical review of the draft and contribution to the writing of the manuscript. All authors gave their final approval of the version to be published and are accountable for the accuracy and integrity of the work.

The data that support the findings of this study are available from the corresponding author upon request. The authors do not have any financial interests, either directly or indirectly, in the products or information listed in the paper.

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Shih-Cheng Wen, DDS, MS
Taipei Medical University, Taipei, Taiwan; Private practice, Taipei, Taiwan.

Muhammad Saleh, BDS, MDS
Department of Periodontics & Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

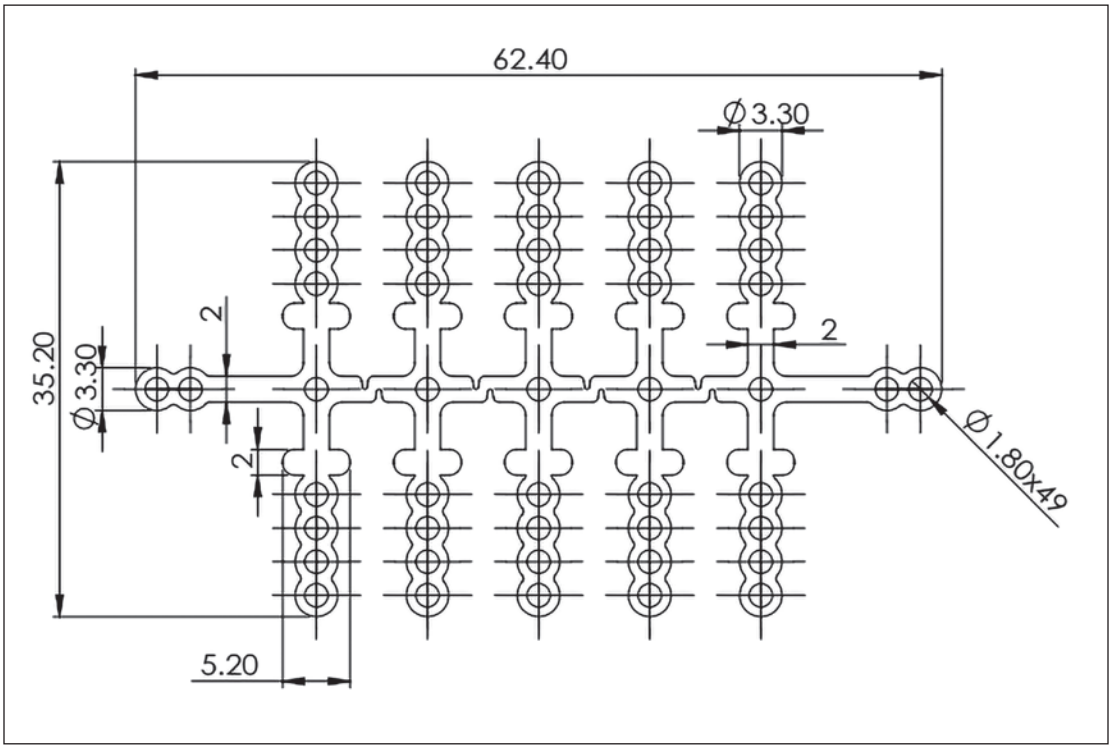
Abdusalam Alrmali, BDS, MFDS RCS, MDS
Department of Periodontics & Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA; Department of Oral Pathology, Oral Medicine, and Oral and Maxillofacial Surgery, School of Dentistry, University of Tripoli, Tripoli, Libya.

David T. Wu, DMD
Department of Oral Medicine, Infection, and Immunity, Harvard School of Dental Medicine, Boston, Massachusetts, USA.

Hom-Lay Wang, DDS, MSD, PhD
Graduate Periodontics, Department of Periodontics & Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

Correspondence to:
Dr Hom-Lay Wang, homlay@umich.edu

Appendix



▲ **Appendix Fig 1** Structure of the titanium frame.