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CONE BEAM COMPUTED TOMOGRAPHIC ANALYSIS OF OUTCOMES IN RIDGE AUGMENTATION USING TITANIUM MESH AND TITANIUM REINFORCED PTFE MEMBRANES

Lina Elnakka

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

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Misr International University, July 2011

Virginia Commonwealth University, May 2020

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Abstract

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Objective: The primary goal of this study is to evaluate and compare the average vertical and horizontal bone gain between titanium reinforced polytetrafluoroethylene (Ti-PTFE) and titanium mesh (Ti-mesh) using superimposition of preoperative and postoperative (CBCT). The secondary goal is to evaluate and compare the surgical outcomes between the two techniques.

Methods: A retrospective chart review was completed to assess the clinical and radiographic outcomes of patients who underwent ridge augmentation therapy using either Ti-PTFE or Ti-mesh. Preoperative and postoperative CBCT scans were superimposed using InVivo 3D imaging software. Vertical component of the augmented site (L1) was assessed along a vertical bisecting line, and width (W1-6) was measured in buccolingual dimension at 3 mm intervals along the vertical line with W1 being the most coronal horizontal measurement. Paired t-tests were used to compare measurements pre- and post-operatively at each location and ANCOVA Models determined if the change in bone level differed based on the grafting method. Comparison in the percent of cases with bone gain at L1 and those deemed successes were compared with chi-squared tests. Intraclass correlation coefficient (ICC) analyzed the interrater agreement of measurements on pre and postoperative CBCT scans.

Results: Forty-three ridge augmentation cases with 61 sites were included: 20 Ti PTFE patients with 28 sites (G, N=28), and 23 Ti-mesh patients with 33 sites (G2, N=33). For G1, the average gain in length (L1) was 0.91 ± 1.9 mm which was statistically significant, while in G2 it was 0.6 ± 2.6 mm and not statistically significant. The average gain in width for G1 was 2.1 ± 2.7 mm

and was significant at W1 through W4, while for G2 the average gain in width was 2.49 ± 2.9 mm and was significant at W1 through W6. After adjusting for preoperative bone levels, G1 had significantly greater gains at W1 when compared to G2. More G1 cases demonstrated a gain at L1 than G2 with an average of 1.99 mm versus 2.57 mm. Overall, 60% of the cases showed bone gain in G1 and 69% in G2 with no statistically significant difference. In terms of surgical outcomes, 75% of cases in G1 and 56% in G2 had postoperative complications with no statistically significant difference between both groups. Interrater reliability was excellent with an ICC of 0.9476.

Conclusion: Both ridge augmentation techniques resulted in vertical and horizontal bone gains. No statistically significant difference in terms of bone gain or surgical outcomes between the two techniques. The proposed method can be a useful tool to evaluate accurately the outcomes of ridge augmentation for large alveolar defects using Ti-PTFE or Ti-mesh membranes.

Introduction

Dental implants have proven to be highly successful in the replacement of missing natural teeth.[1] One of the prerequisites for successful implant restoration is adequate bone in the horizontal and vertical dimensions for placement of an appropriate size implant without encroachment on vital structures, as well as the development of a durable, functional, and esthetic restoration.

Periodontists and other dental specialists who plan and or place dental implants are often faced with horizontal and vertical bone deficiencies of remaining alveolar bone at proposed implant sites. The natural response of alveolar bone following extraction of a tooth is increased bone turnover with resultant horizontal and vertical bone resorption. Araujo and Lindhe showed significant alterations in bone of extraction sockets at eight weeks post extraction in Mongrel dogs with vertical bone loss being more pronounced in the buccal wall than the lingual.[2] This was demonstrated through two phases: phase one showed bundle bone resorption and replacement by woven bone while phase two showed bone resorption from the outer surfaces of buccal and lingual walls. The main function of the bundle bone is tooth anchorage, and with tooth removal the bundle bone loses its function. This explains the increased resorption of the buccal bone wall since it's mainly formed of bundle bone compared to lingual bone wall which is formed of bundle and lamellar bone. Bone remodeling continues overtime and approximately two thirds of the bone loss occur in the first three months[3]. Decreases in post-extraction site width have been demonstrated to progress more rapidly than vertical bone loss. The mean

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horizontal loss at 6 months post extraction is 3.8 mm, while the average vertical loss is 1.24 mm, with horizontal loss reaching almost 50% at 1 year. [3,4]

Traumatic extractions as well as difficult extractions requiring bone removal for delivery of the tooth, periodontal disease, and bony pathology requiring excision also contribute to these bony defects that compromise the ability to place a dental implant. [5,6]

These significant defects often require bony augmentation of the proposed implant site prior to placement of the implant to satisfy the above-listed prerequisite for implant placement. Many techniques, whether open or closed, of bone augmentation have been described in literature. These techniques include alveolar ridge split, distraction osteotomy, autogenous or allogeneic block grafts, guided bone regeneration (GBR) using resorbable, non-resorbable membranes or tenting screws, and tunneling approach. [7]

GBR was first introduced in 1959 by Hurley in an experimental study of spine fusion in mongrel dogs. [8] Boyne then used cobalt chrome implants lined with cellulose acetate to augment maxillofacial defects. The cellulose acetate helped contain autogenous hematopoietic marrow and cancellous bone graft in bone defects and prevented ingrowth of soft tissues. [9] Melcher laid the foundations for guided tissue regeneration (GTR) by defining four cells that can populate wound surface: the junctional epithelial cells, gingival connective tissue cells, periodontal ligament cells (PDL) and bone cells. [10] He hypothesized that with adequate selective exclusion of junctional epithelium and gingival connective tissue cells, the periodontal ligament (PDL) and bone cells will repopulate the wound and successfully regenerate lost tissues. In GBR, cell exclusion with a membrane mainly targets rapidly proliferating epithelium and connective tissue cells and guides slowly growing osteoblasts to populate the defect and generate new bone. The application of the GBR concept is guided by the four major biological principles including

primary wound closure with passively approximated wound edges, angiogenesis through

decortication to allow for adequate supply of blood, growth factors and undifferentiated stem

cells, space maintenance for bone growth and stability of the graft with clot stabilization (PASS

principle).[11]

To increase the success of the GBR procedures, membranes should exhibit certain properties.

This includes biocompatibility, space maintenance to allow enough stability for bone

regeneration, cell occlusiveness to prevent ingrowth of soft tissues into bony defects, and clinical

manageability.[12,13] There's a wide variety of occlusive membranes used in GBR procedures,

divided into two main categories of resorbable and non-resorbable. The resorbable membranes

are subdivided into natural polymers as collagen membranes, and synthetic polymers as

polylactic acid (PLA), polyglycolic acid (PGA). Non-resorbable membranes include titanium

mesh, and polytetrafluoroethylene (PTFE) membranes. The PTFE membranes are divided into

two types, expanded PTFE (e-PTFE) and high-density PTFE (d-PTFE). Due to the higher risk of

exposure and infection experienced with e-PTFE, which in turn negatively affects the quantity

and quality of augmented bone, its use has been substituted by d-PTFE, that has smaller pores

than e-PTFE, less than 3 microns. This feature decreases bacterial colonization and allows for

easier removal of membrane rendering it more advantageous when compared to e-PTFE.

Nevertheless, both e-PTFE and d-PTFE membranes have proven to provide adequate cell

occlusiveness and space maintenance properties necessary for GBR. In cases where vertical

ridge augmentation is needed, these membranes fail to maintain adequate space for bone

regeneration due to increased pressure and subsequent deformation. As a result, the need for

better reinforced PTFE membrane was achieved by adding a titanium skeleton. The Ti-

reinforced PTFE (Ti-PTFE) was introduced in 1995 by Jovanovic and Nevins to provide

adequate space maintenance in large vertical bone defects.[14] The titanium skeleton, which comes in different shapes, provides better support, adds stiffness, and adequate space maintenance while maintaining ease of handling and shaping around bone defects.

Another membrane that provides similar characteristics as the Ti-PTFE is the titanium mesh (Ti-mesh). First used by Boyne in augmentation of deficient maxillary edentulous ridges, Ti-mesh has proven to be a successful membrane in GBR procedures.[15] Its rigidity and high mechanical properties facilitate space maintenance for the graft without collapsing. Nevertheless, its plasticity provides ease of handling allowing adaptation to bony contours.[16] In addition, bacterial contamination is minimal due to its smooth surface when compared to more porous spongy architecture of resorbable membranes that act as nidus of infection and microbial colonization.[17]

In large ridge defects and when vertical augmentation is needed, non-resorbable membranes are preferred over resorbable membranes. The most widely used non-resorbable membranes are the Ti-PTFE and Ti-mesh. When Ti-PTFE membranes were compared to titanium meshes in patients requiring vertical bone augmentation, both approaches showed similar results in terms of complications, vertical bone gain and implant stability.[18] On the other hand, in a split mouth study, vertical bone height gained was higher in sites covered by Ti-PTFE versus Ti-mesh sites.[19] Up to this date no study has used cone beam computed tomography (CBCT) superimposition analysis to measure the volume of bone gained after ridge augmentation procedures using Ti-mesh and Ti-PTFE membranes.

The primary goal of this study was to compare the average vertical and horizontal bone gain achieved by using Ti-PTFE and Ti-mesh through the superimposition of preoperative and

postoperative CBCT. The secondary goal is to evaluate and compare the surgical outcomes of

the two techniques.

Methods

In this research we complied with the World Medical Association Declaration of Helsinki and the Code of Medical Ethics of VCU, University Institutional Review Board approved the study protocol, IRB: HM20004398. A retrospective chart review of patients who underwent horizontal and vertical ridge augmentation procedures using Ti-mesh or Ti-PTFE membrane to facilitate implant placement in Graduate Periodontics clinic and Oral and Maxillofacial Surgery (OMFS) clinic between 08/01/2017 and 01/01/2022 was completed. Ridge augmentation procedures using Ti-mesh were performed by OMFS residents while those that used Ti-PTFE as a barrier membrane were performed by periodontal residents. Bone grafts as allografts or xenografts were used separately or in combination under the membranes for space maintenance, membrane support and clot stabilization. Adjunct growth factors were mixed with bone grafts including autologous growth factors like Platelet Rich Fibrin (PRF), or synthetic growth factors as platelet derived growth factor (rhPDGF-BB) or, recombinant human bone morphogenetic protein-2 (rhBMP-2).

Inclusion Criteria

Subject population must fit the following criteria during the time period specified:

1) 16 years of age or older

2) Horizontal and/or vertical ridge augmentation through guided bone regeneration using 50:50 or 70:30 mix allograft/xenograft or autogenous/xenograft particulate material with either Ti-PTFE non-resorbable membrane or Ti-mesh barrier

3) Presence of a pre and postoperative CBCT scan

Exclusion Criteria

Exclusion criteria included patients with simultaneous horizontal ridge augmentation and implant placement or lateral window sinus elevation, those with grafting materials other than particulate bone graft, and those who did not have both a preoperative and postoperative CBCT scan. Patients were not excluded based on their medical history findings or smoking history.

From the treatment record, the following variables were collected and compared for analysis:

1. Types of bone graft and biologics used

2. Dehiscence of the surgical wound, exposure of the graft or membrane requiring removal of membrane or graft material prior to graft maturation

3. Percentage of augmented sites that were suitable to receive implants

Cases were evaluated radiographically before and after alveolar ridge augmentation to assess the gain in bone volume for implant sites on segmental CBCT images. The Ti-PTFE CBCT scans were taken on CareStream (CareStream Kodak 8100 3-D Cone Beam, Carestream Dental, Atlanta, GA) with the following parameters: 90 kilovolt peak (kvp), 2.5 milliamperes (mA), 15.0 seconds (s), and 150 µm voxel size, while Ti-mesh CBCT scans were taken on iCAT (iCAT FLX V10, Imaging Sciences International LLC) with the following parameters: 120 kilovolt peak, 5 milliamperes, 3.71 s, 300 µm voxel size and a FOV of 16 cm x 10 cm. Each case's post-

operative scan was superimposed over the pre-operative scan using InVivo 3D imaging software
(InVivo 6, Anatomage, Santa Clara, CA) to evaluate volumetric bone changes.

CBCT Analysis

CBCT scans captured by the above-mentioned scan machines and saved in the form of Digital
Imaging and Communications in Medicine (DICOM) files were imported into InVivo software
(Figure 1: Pre and postoperative CBCT scans imported to InVivo software (a). Pre and
postoperative CBCT scans after superimposition by InVivo software (b).). Pre and postoperative
CBCT scans were then anonymized to remove patient's information and were given a case
number. Superimposition of scans began with registration of at least four common reproducible
bone and or dental landmarks on pre and postoperative CBCTs, followed by fine manual
orientation of the scans to allow for optimal superimposition. The superimposition was verified
by qualitative visualization of the semi-transparent axial, sagittal, and coronal cross-sectional
slices of the surgical site (Figure 1b). After verifying the superimposition, smooth transitioning
from preoperative to postoperative view of any slice were attained. On the preoperative view, a
line bisecting sagittal or coronal views of the deficient site was drawn to measure the height (L)
of the ridge before augmentation. The height was measured from the base of the mandible or
maxilla to the crest of the ridge (Horizontal and vertical measurement of a maxillary edentulous
site on pre-operative CBCT (a), and on post-operative CBCT after placement of Ti-mesh
membrane (b).). Horizontal lines (W1-6) at 3 mm intervals were drawn across the bisecting line
starting from the base of the bone to measure the width of the deficient site before augmentation
(Fig.Horizontal and vertical measurement of a maxillary edentulous site on pre-operative CBCT
(a), and on post-operative CBCT after placement of Ti-mesh membrane (b). W1 represented the

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most coronal horizontal measurement and W6 represented the most apical horizontal measurement. After recording the preoperative measurements the slice was switched to the postoperative view and the preoperative vertical and horizontal line measurements were altered to measure the dimensional changes noted on the augmented ridge at the same measurement planes. Line measurements were extended to include grafted bone in case of bone gain or reduced if loss of bone was noted (Horizontal and vertical measurement of a maxillary edentulous site on pre-operative CBCT (a), and on post-operative CBCT after placement of Ti-mesh membrane (b). (Horizontal and vertical measurement of a mandibular edentulous site on pre-operative CBCT (a), and on post-operative CBCT after placement of Ti-PTFE membrane (b).. In case of vertical bone gain, the matched horizontal bone gain was measured and represented in postoperative W1 while the corresponding preoperative W1 given a value of "0" as it hasn't existed before ridge augmentation.
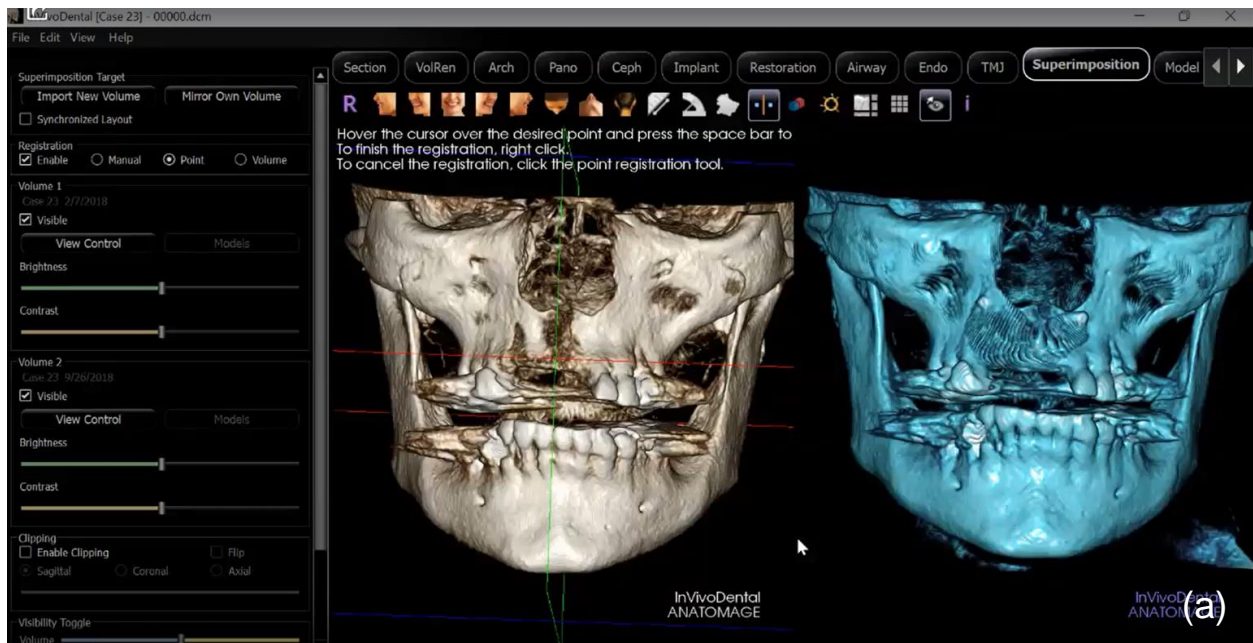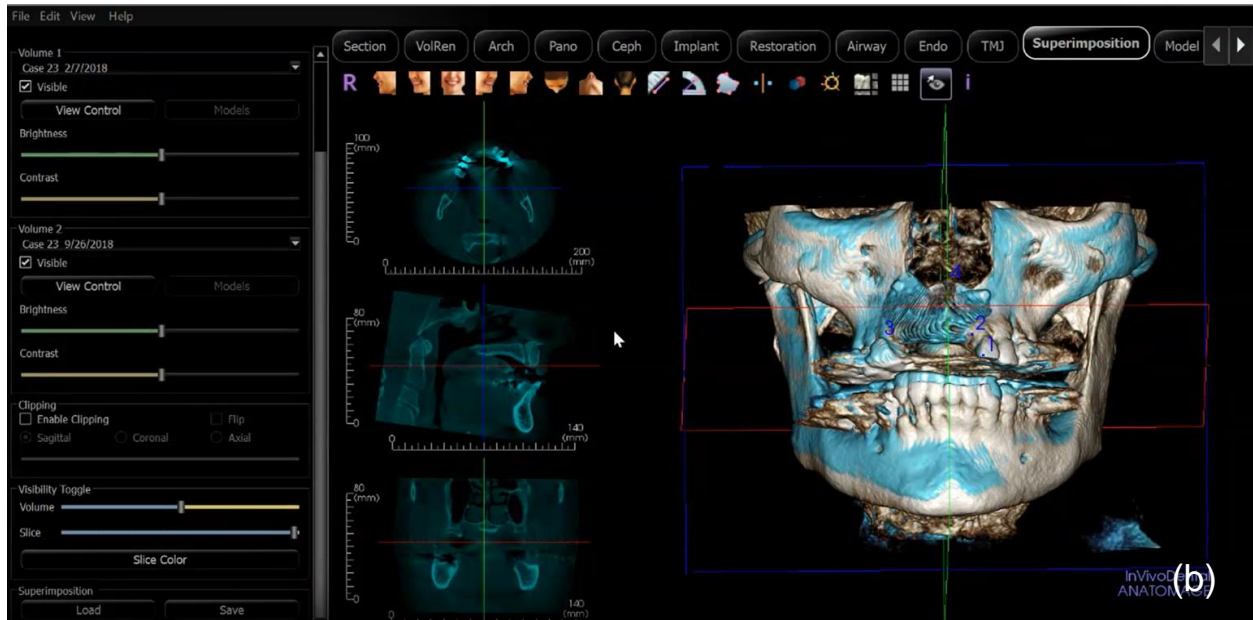
Figure 1: Pre and postoperative CBCT scans imported to InVivo software (a). Pre and postoperative CBCT scans after superimposition by InVivo software (b).
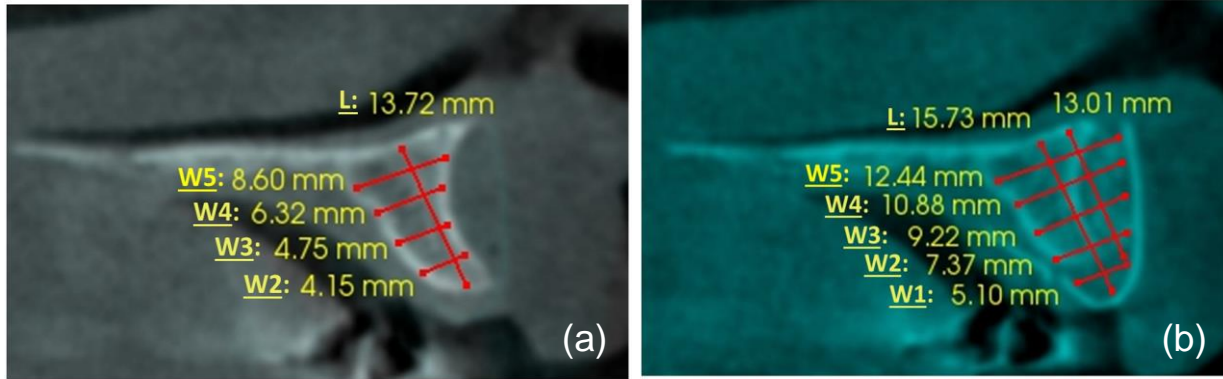
Figure 2: Horizontal and vertical measurement of a maxillary edentulous site on pre-operative CBCT (a), and on post-operative CBCT after placement of Ti-mesh membrane (b).
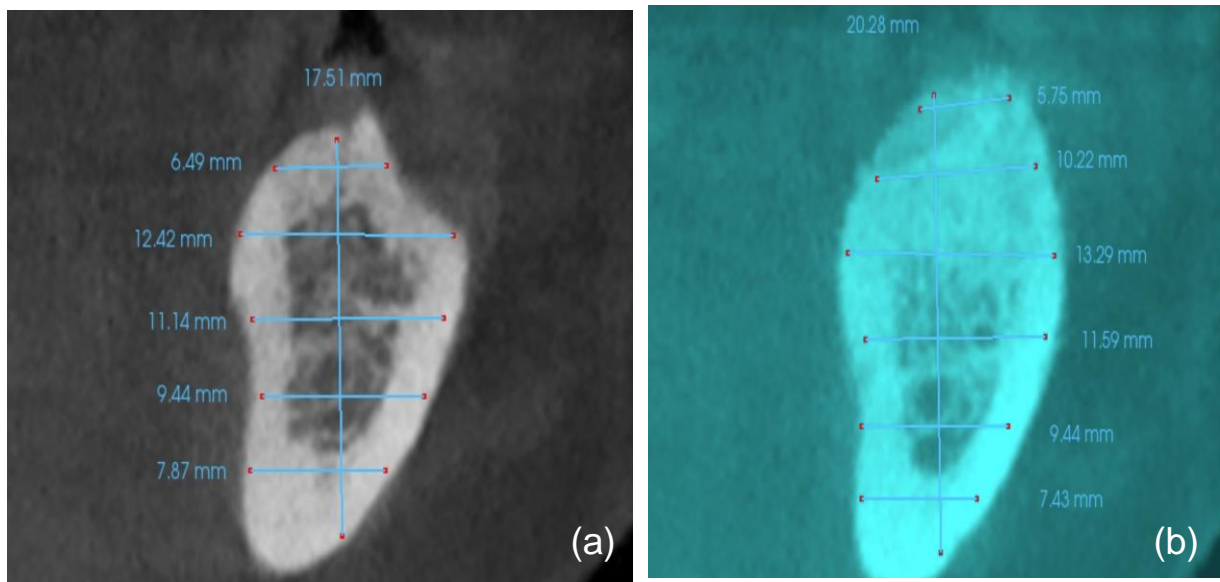
Figure 3: Horizontal and vertical measurement of a mandibular edentulous site on pre-operative CBCT (a), and on post-operative CBCT after placement of Ti-PTFE membrane (b).

Surgical Procedure:

All procedures were performed under local anesthesia with or without intravenous sedation by residents at Virginia Commonwealth University School of Dentistry. The ridge augmentation procedures were performed via a crestal incision over edentulous ridge extending over the surgical area with vertical releasing incisions to allow for adequate access. Full thickness mucoperiosteal flaps were elevated on the buccal and lingual aspects. Grafted sites received

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various mixture of any of the following materials: mineralized freeze-dried bone allograft (FDBA, LifeNet Health, Virginia Beach, VA), cancellous particulate allograft (Puros, ZimVie, Westminster, CO), demineralized bone matrix allograft (Regenavate, ZimVie, Westminster, CO), demineralized bone matrix allograft (Stryker, particulate bovine-derived hydroxyapatite), and xenograft (Bio-Oss, Geistlich Pharma North America, Princeton, NJ). Different biologic materials were mixed with bone and included injectable platelet rich fibrin (i-PRF) and leukocyte platelet rich fibrin (L-PRF) (i-PRF, L-PRF, IntraSpin system, Biohorizons, Birmingham, AL), recombinant human platelet-derived growth factor-BB (rhPDGF bb, Lynch Biologics, Geistlich Pharma North America, Princeton, NJ), recombinant human bone morphogenic protein-2 (rhBMP-2, Medtronic , Minneapolis, MN), and amnion Growth Factor Liquid (AmnioSpark, Salvin Dental Specialities, Charlotte, NC). Titanium screws (Meisinger, Centennial, CO) and (Salvin, Charlotte, NC) were used to secure membranes. Grafts were then covered by either Ti-PTFE membranes, as (RPM™ Reinforced PTFE Mesh, Geistlich Pharma North America, Princeton, NJ) and (Cytoplast Ti-Reinforced d-PTFE Membrane, Osteogenics, Lubbok, TX), or Ti-mesh (Cytoflex Titanium Mesh Membrane, Unicare Biomedical, Laguna Hills, CA). Membranes were fixed using fixation screws. Periosteal releasing incisions on buccal and/or lingual flaps performed to allow for coronal flap advancement and primary closure. 3-0 PTFE horizontal mattress sutures were used to attain primary closure over the crest of the ridge along with simple interrupted sutures. Vertical releasing incisions are sutured using either glycolon or chromic gut resorbable sutures.

Statistical Methods

Paired t-tests were used to compare measurements pre-op and post-operatively at each location. Only cases with bone level at a given location were analyzed. The number of sites decreased

from 33 at W1 to 7 at W6 for Ti-mesh and from 28 at W1 to 6 at W5 for PTFE. There were no observations at W6 for the Ti-PTFE method. ANCOVA Models were used to determine if the change in bone level differed based on the grafting method, while adjusting for the baseline bone level. Comparison in the percent of cases with bone gain at L1 and those deemed successes, and other surgical outcomes and complications were compared with chi-squared tests. Significance level was set at 0.05. SAS EG v.8.2 (SAS Institute, Cary, NC) was used for all analyses. Ti-mesh cases were measured by first rater, Ti-PTFE cases were measured by second rater and a third rater measured randomly 10 cases of Ti-mesh and 10 cases for Ti-PTFE to measure inter-rater reliability.

Results

A total of 43 cases of ridge augmentation were included, 23 cases of Ti-mesh (13 females and 10

males) with age range 16-75 years, and 20 cases of Ti-PTFE (13 females and 7 males) with age

range 40-76 years. Thirty-three Ti-mesh sites were measured by the first rater and 28 Ti-PTFE

sites were measured by the second rater. Random measuring by a third, independent rater

demonstrated excellent interrater reliability with an ICC of 0.9476. Descriptive statistics of

paired t-test comparing between the pre and postoperative measurements of each technique are

provided in Table 1. When comparing the preoperative bone levels, cases treated with Ti-mesh

were significantly larger at W2 through W5. There were also 7 cases treated with Ti-mesh with

an average measurable bone of 5.3mm at W6 preoperatively compared to none of the cases that

were treated with Ti-PTFE. Post-operative values were significantly different at W1 and W2,

with cases treated with Ti-PTFE associated with significantly higher bone levels.

Table 1: Average Bone Levels Pre and Post Operatively by Bone Graft Technique

	Ti-mesh			Ti-PTFE			P-value	
Location	N	Pre	Post	N	Pre	Post	Pre	Post
L1	33	17.5, 6.7	18.2, 6.8	28	19.3, 4.7	20.2, 4.5	0.2334	0.1605
W1	33	2.4, 2.2	4.0, 3.0	28	2.9, 2.6	6.3, 3.0	0.3592	0.0032

							<0.0001	
W2	32	4.2, 2.2	6.9, 2.5	28	6.9, 2.2	8.8, 2.4		0.0042
W3	29	5.7, 2.4	8.6, 2.2	27	8.1, 2.3	9.7, 2.2	0.0003	0.0929
W4	25	6.7, 3.0	9.3, 2.7	17	9.3, 2.8	10.7, 2.1	0.0077	0.0771
W5	15	5.9, 2.8	8.7, 3.0	6	8.9, 2.9	11.1, 2.5	0.0393	0.0736
W6	7	5.3, 2.5	8.0, 2.3	0	- -	- -	- -	- -

*Note: Pre= Pre-operative; Post=Post-operative; P-value from t-test of difference in means between the two methods at each location

For Ti-mesh, the average gain in length (L1) was 0.60mm although this was not statistically significant (p-value=0.2047). There were statistically significant gains in width post-operatively at W1 through W6 (Table 2) (Figure 4). The gains for Ti-mesh ranged from 1.58 to 2.98 and averaged 2.49 (95% CI: 2.00, 2.98). For Ti-PTFE, the average gain in length (L1) was 0.91 which was statistically significant (p-value=0.0189). Additionally, there were significant gains at W1 through W4 (Table 2) (Figure 5). At W5 there was an average gain of 4.36 but with only 7 cases the difference was only marginally statistically significant (p-value=0.0965). Overall, gains for Ti-PTFE ranged from 1.45 to 4.36, with an average of 2.1 (95% CI: 1.58-2.62).

Table 2: Average Paired Differences in Bone Level by Location and Bone Graft Technique

	Ti-mesh			Ti-PTFE		
Location	**Average Gain**	**95% CI**	**P-value**	**Average Gain**	**95% CI**	**P-value**
L1	0.60	-0.35, 1.55	0.2047	0.91	0.16, 1.65	0.0189
W1	1.58	0.1, 3.06	0.037	3.39	1.78, 5	0.0002
W2	2.71	1.48, 3.94	<.0001	1.87	1.09, 2.65	<.0001
W3	2.98	2.19, 3.77	<.0001	1.55	1.02, 2.08	<.0001
W4	2.61	1.86, 3.36	<.0001	1.45	0.41, 2.49	0.0095
W5	2.80	1.8, 3.8	<.0001	4.36	-0.33, 9.05	0.0965

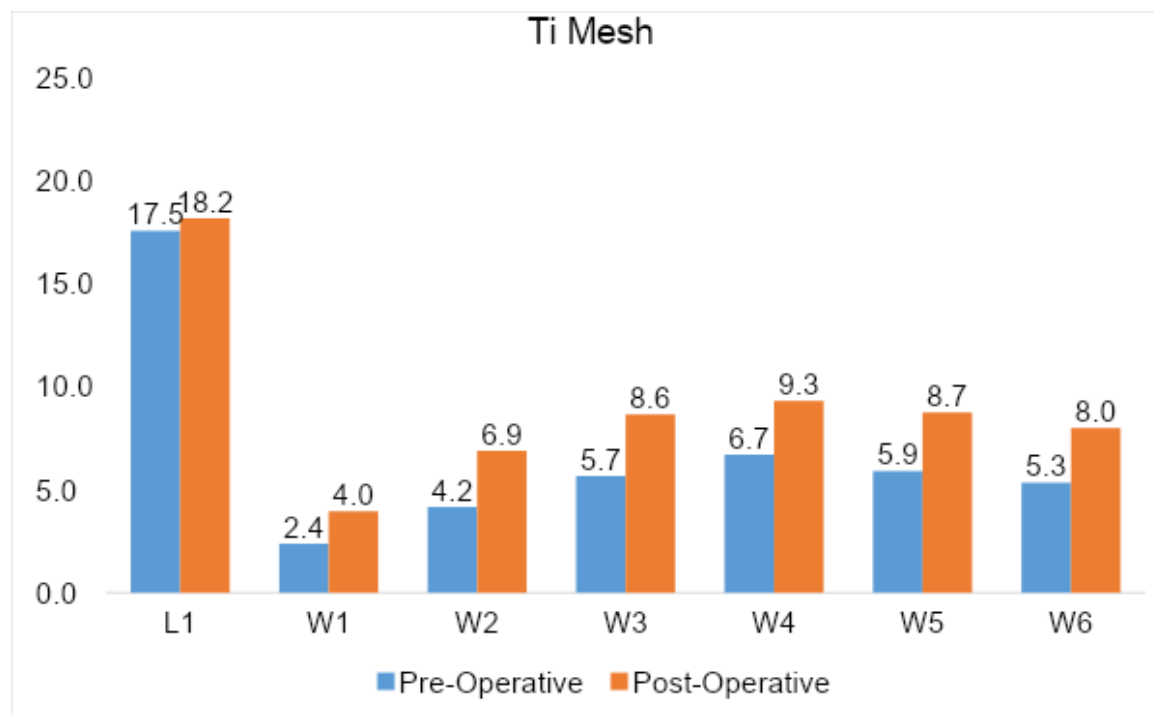|						
W6	2.65	1.47, 3.83	0.0015			
Average Overall (W1-W6)	2.49	2.00, 2.98		2.10	1.58, 2.62	

Figure 4: Preop and postoperative vertical and horizontal measurements for Ti-mesh
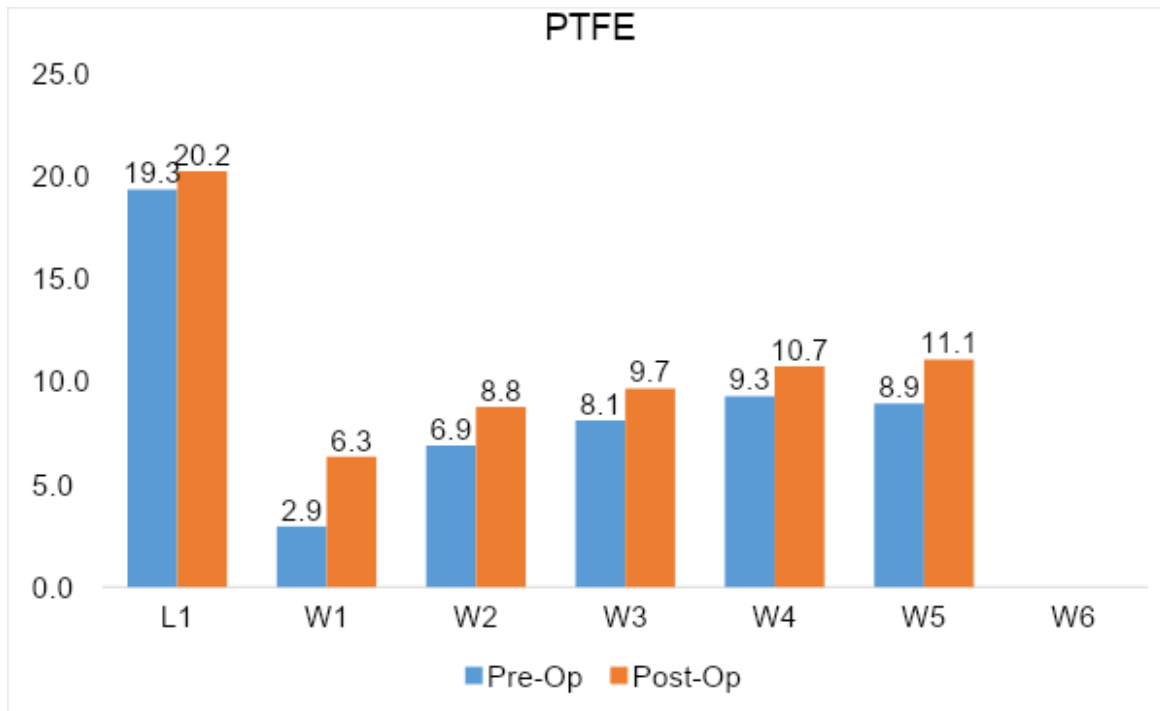
Figure 5: Preop and postoperative vertical and horizontal measurements for Ti-PTFE

ANCOVA models were used to determine if there were significant differences in the gains at each of the locations based on the bone graft method (Table 3) (Figure 6). After adjusting for preoperative bone levels, Ti-PTFE demonstrated significantly greater gains at W1. At W1, for two cases with the same preoperative bone level, a case treated with Ti-PTFE was associated with a 2.5mm greater bone gain than if it were treated with Ti-mesh (p-value=0.0021).

Table 3: Differences in Gain by Technique

	Average Gain (Mean, SE)			
Location	Titanium Mesh	PTFE	Difference	P-Value
L1	0.54 (0.41)	0.99 (0.44)	0.45 (0.61)	0.4588
W1	1.26 (0.52)	3.76 (0.57)	2.50 (0.78)	0.0021

W2	1.79 (0.46)	2.91 (0.49)	1.12 (0.73)	0.1289
W3	2.59 (0.32)	1.97 (0.33)	-0.62 (0.48)	0.2064
W4	2.24 (0.34)	1.98 (0.42)	-0.26 (0.56)	0.6458
W5	2.66 (0.48)	1.79 (0.79)	-0.87 (0.96)	0.3776
W6	2.65 (0.47)	- -	- -	- -

*P-value from ANCOVA model adjusted for preoperative bone level.
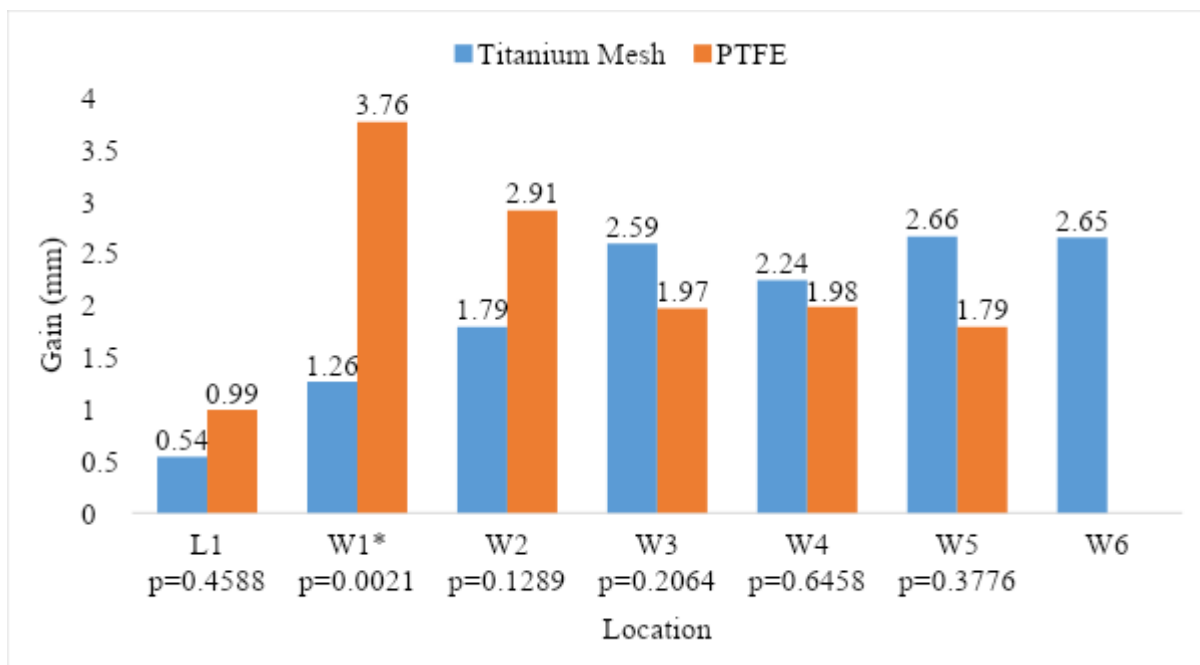
Figure 6: Comparing postoperative vertical and horizontal gains for Ti-mesh and Ti-PTFE

A gain in bone level at L1 was demonstrated for 59% of cases. More Ti-PTFE cases demonstrated a gain at L1 than Ti-mesh, but the difference was not statistically significant (68% vs 52%, p-value=0.1959) (Figure 7a). For cases with some gain at L1, the average gain was 2.3 (95% CI: [1.6-2.8], p-value<0.0001). The average gain was 1.99 (95% CI: [1.5-2.5]) for Ti-PTFE and 2.57 (95% CI: [1.5-3.6]) for Ti-mesh (Figure 7b).

For cases treated with Ti-mesh, 69% showed bone gain compared to 60% of cases treated with Ti-PTFE. This difference was not statistically significant (p-value=0.5401).

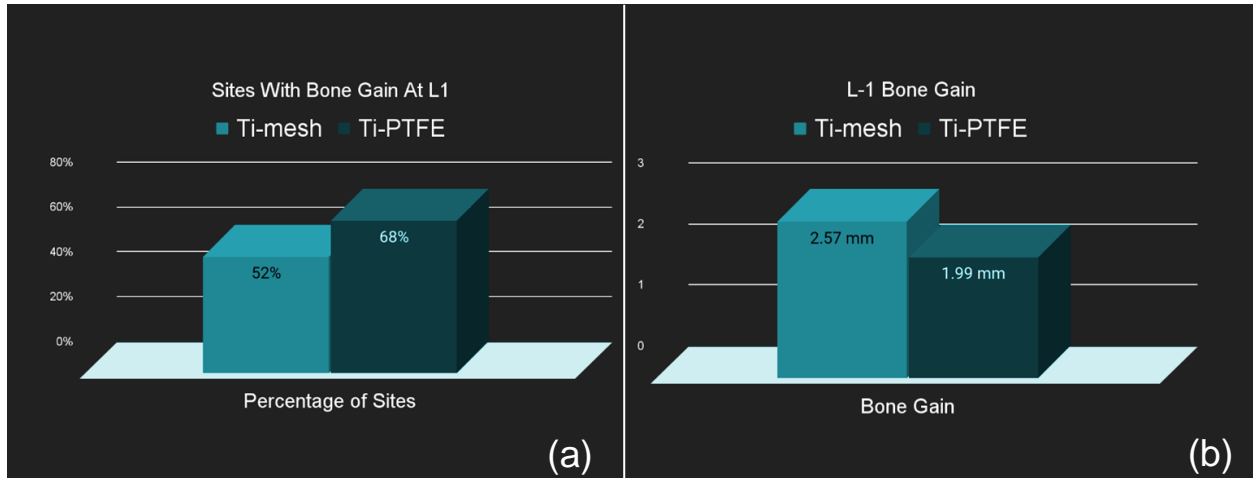Figure 7: Percentage of sites showing vertical bone gain in each technique (a). Average vertical increase in sites that demonstrated vertical bone gain for each technique (b).

Rate of complication presented in cases that experienced barrier exposure or infection of the grafted site was calculated. Fifteen (75%) of Ti-PTFE cases experienced complications compared to 13 (56%) Ti-mesh cases with no statistically significant difference (p=0.3363). Out of the 15 Ti-PTFE cases, 7 cases experienced membrane exposure, 6 cases experienced postoperative infection while 2 cases experienced membrane exposure with infection (p-value=0.5401) (Fig.8Postoperative complications rate in Ti-PTFE cases (a) and in Ti-mesh cases (b). On the other hand, out of the 13 (56%) Ti-mesh cases 11 cases experienced membrane exposure, 1 case experienced postoperative infection while 1 case experienced both membrane exposure with infection (Postoperative complications rate in Ti-PTFE cases (a) and in Ti-mesh cases (b). Overall exposure rate in Ti-mesh cases was 56% and 45% in Ti-PTFE cases with no

statistical significance between the two techniques (p=0.7626) (Membrane exposure rates in Ti-PTFE and Ti-mesh cases).
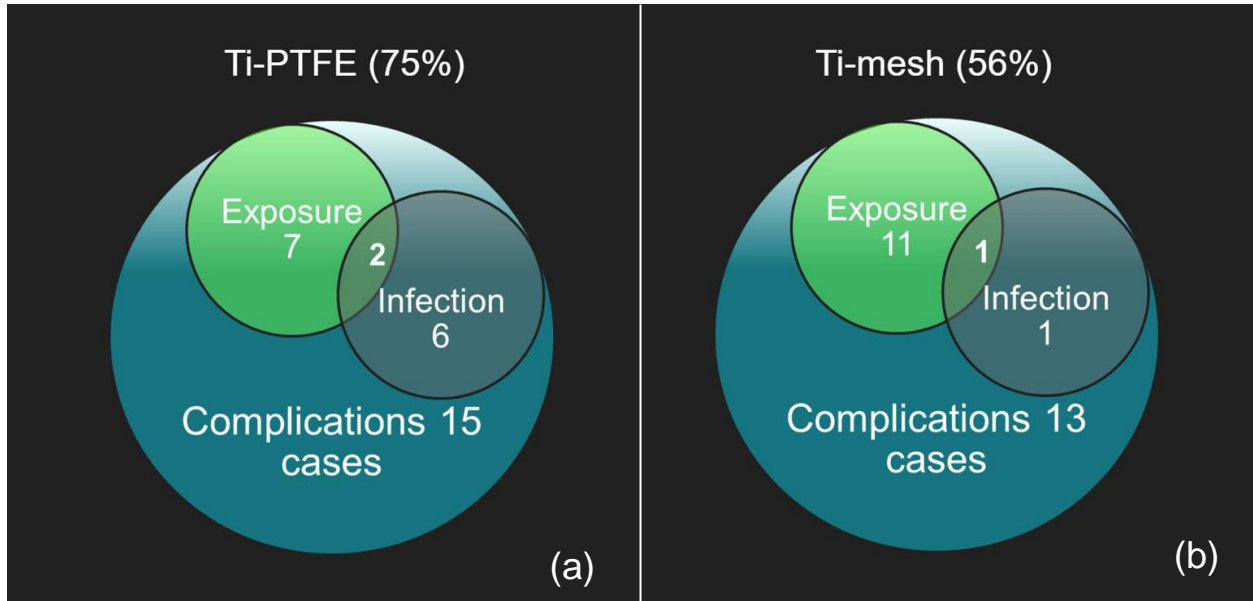
Figure 8: Postoperative complications rate in Ti-PTFE cases (a) and in Ti-mesh cases (b)
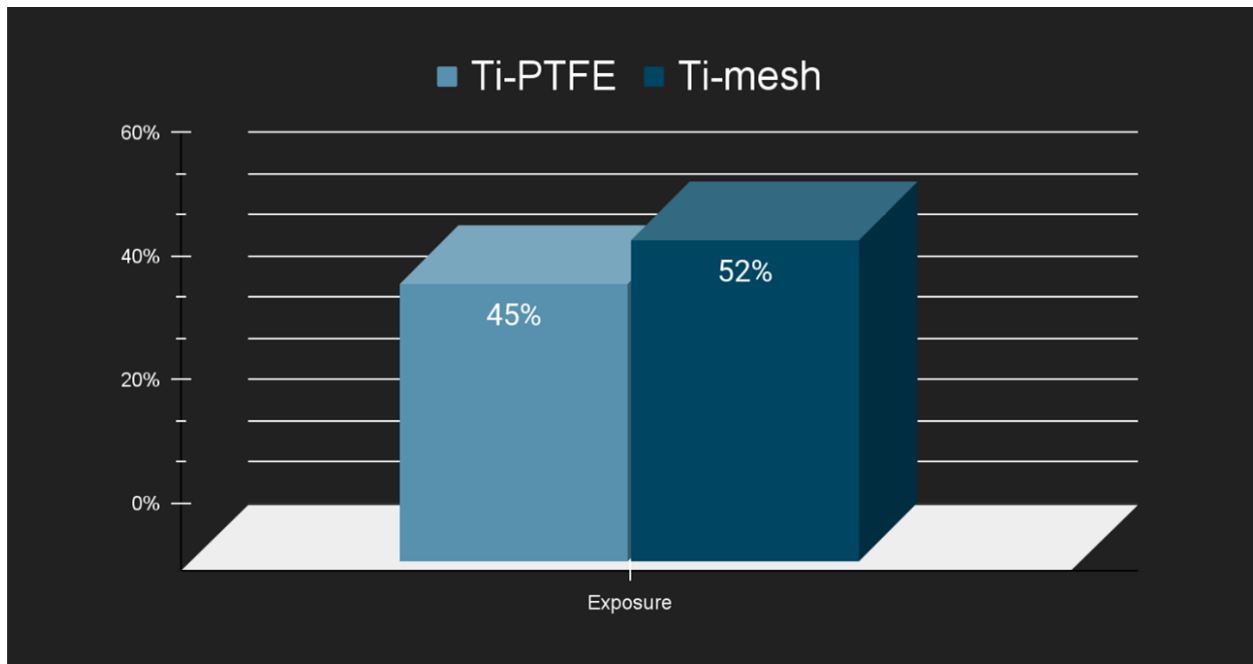
Figure 9: Membrane exposure rates in Ti-PTFE and Ti-mesh cases

In regard to implant placement in ridge augmented sites, 17 (60.71%) implants were placed in sites augmented by Ti-PTFE, while 25 (76%) were placed in Ti-mesh augmented sites which was not statistically significantly different (p=0.2061) (Percentages of augmented sites that received an implant in Ti-PTFE and Ti-mesh cases.).
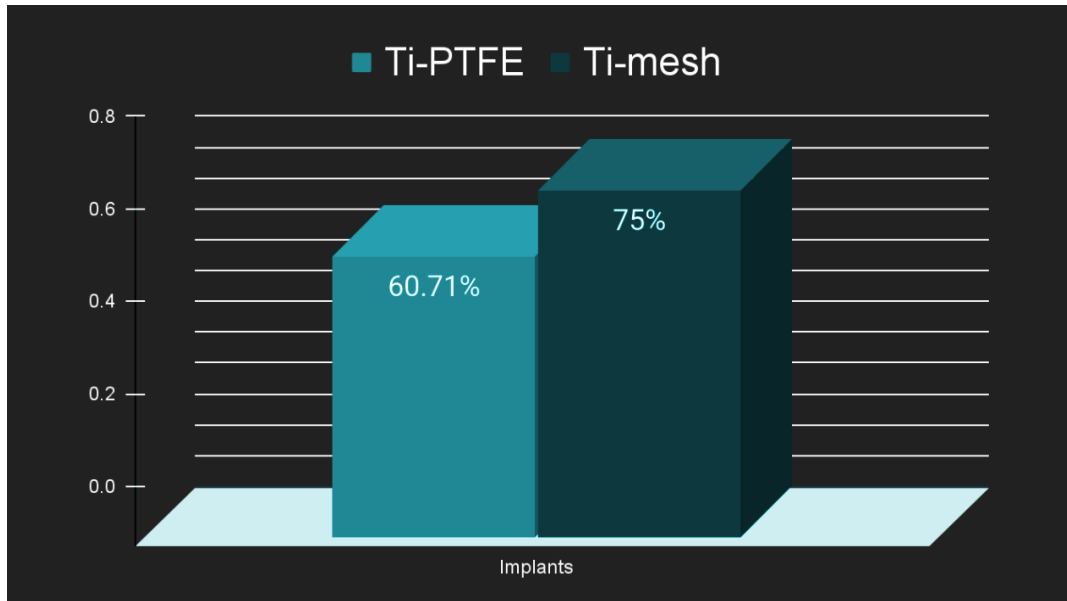
Figure 10: Percentages of augmented sites that received an implant in Ti-PTFE and Ti-mesh cases.

Discussion

In this study we intended to compare the outcomes between two techniques of ridge

augmentation using non-resorbable membranes: the Ti-PTFE and Ti-mesh membranes. These

non-resorbable rigid membranes have been deemed successful in GBR due to their excellent

space maintenance capabilities providing adequate stability of the grafted site. In the present

study, bone gain was noted in 60% of Ti-PTFE cases and 69% of Ti-mesh cases which shows

that both techniques were successful in bone augmentation procedures. Previous studies showed

an average vertical bone gain with Ti-PTFE ranging from 4.2mm to 5.2 mm [19,20,21] through either

clinical measurements at re-opening or CBCT measurements, but none of these studies used the

superimposed CBCT technique. In our study the vertical bone changes in Ti-PTFE ranged from a

loss of 3.5 mm to a gain of 4.1 mm with an average gain of 0.91 mm which was statistically

significantly different from 0 mm. Palkovic reported 5.89 mm in horizontal bone gain when d-

PTFE was used with tenting screws, while Windisch showed a range of 6.5 - 8.5 mm horizontal

gain[22,23]. In the present study, the horizontal bone gain ranged from 1.45 to 4.36mm with an

average of 2.1mm ± 1.9 mm and was statistically significant from W1 through W6.

As for Ti-mesh, previous studies showed a mean vertical bone gain ranging from 1.5 mm to 6.4

mm. [19,24,25] A study by Bahaa showed 2.06-4.12 mm in horizontal bone gain using different

techniques in flap advancement with titanium mesh. [26] In a systematic review evaluating 21

22

studies that used Ti-mesh, the results showed an average horizontal bone gain of 4.3 mm, while a

study by Proussaefs showed an average of 3.75 mm gain. [27,24] In the present study the vertical

bone change (L1) ranged from a loss of 4 mm to a gain of 8.5mm with an average gain of 0.60 ±

2.6 mm that wasn't statistically significant. Horizontal bone gains ranged from 0.58mm to

2.98mm and averaged 2.49 ± 2.9 mm and was statistically significant from W1 through W6.

Horizontal bone measurements were taken at 3 mm intervals starting from the base of the base of

bone. In our analysis we have included the horizontal measurements that were recorded at the

augmented sites (W1-6), as no membrane used in this study augmented deficient ridges past the

W6 horizontal measurement. Furthermore, we noted in our study that not all cases have the full

W1-6 set of horizontal measurements, for example, none of the Ti-PTFE sites had W6

measurement. This is reflected on average horizontal bone measurements where we see a

decrease in pre and postoperative horizontal bone measurements starting at W5 in Ti-mesh cases

and in preoperative measurements at W5 in Ti-PTFE cases. Despite the increased rigidity of the

Ti-PTFE owing to the presence of the titanium skeleton, the titanium skeleton is located in the

inner center of the d-PTFE membrane and doesn't extend to the membrane edges. The less rigid

Ti-PTFE membrane margins may not provide adequate space maintenance at apical sites of the

augmented ridges which makes it prone to compression. On the other hand, Ti-mesh exhibits its

high rigidity properties equally and can provide adequate graft support throughout the membrane

dimensions. That difference may explain why some Ti-mesh sites have W6 horizontal

measurement while none do in the Ti-PTFE sites. Another finding worth mentioning is the low

baseline horizontal measurements of Ti-mesh compared to Ti- PTFE measurements (Figure 4 &

5). Ti-mesh was used to augment more atrophic ridges aiming for larger bone gain. This may

explain the decreased range of horizontal bone gain (0.58mm to 2.98mm) compared to Ti-PTFE

(1.45 to 4.36mm) and the fact that sites augmented with Ti-PTFE would show a greater 2.5mm

gain at W1 than if treated with Ti-mesh after adjusting for preoperative bone levels.

Few studies have compared Ti-mesh to Ti-PTFE membranes. The most recent were a series of

studies by Cucchi that compared the two membranes in terms of vertical bone gain,

histomorphometric analysis and complications. The studies had shown similar results for both

membranes in all tested aspects with an average bone gain of 4.2 mm in Ti-PTFE and 4.1 mm in

Ti-mesh. [18] After 1 year of follow up, marginal bone loss around implants was 0.7 mm and 0.6

mm for the two study groups showing insignificant difference as well as stability and efficacy of

augmented sites. [25] As for the histological and histomorphometric analysis, both membranes

showed similar results when a mixture of autogenous and allogenic bone grafts were used. In a

split-mouth study comparing Ti-mesh and Ti-PTFE in ridge augmentation with simultaneous

implant placement, Maiorana followed up 5 cases up to one year to assess vertical ridge gain.

The results showed a mean vertical bone gain of 4.2 mm for Ti-PTFE and 1.5 for the Ti-mesh. [19]

They attributed the difference in vertical bone gain between the two techniques to membrane

exposure in 2 Ti-mesh cases.

Complications

The main drawbacks of non-resorbable membranes are wound dehiscence and membrane

exposure which may develop into graft site infection. This will jeopardize the integrity of the

bone graft and may lead to its complete loss. The rate of Ti-mesh complications reported in

literature varied widely, ranging from 13% to 33%. [18,28,29] Despite the high risk of exposure, the

large pores of Ti-mesh may allow for spontaneous healing of mucosa over the grafted site. This will help in retaining the Ti-mesh for a longer period if the exposed site was managed properly and no infection developed. The timing of exposure plays an important role in determining the prognosis of the graft. Proussaefs reported only up to 24% bone formation in two cases where exposure occurred in the first two weeks postoperatively with minimal contact of Bio-Oss with bone.[24] Whereas cases that had later exposure (>3 months) haven't compromised formation of new bone.[24] The present study has shown 13 cases (56%) of titanium mesh cases experiencing postoperative complications. The majority of cases (11 cases) experienced mesh exposure without infection which confirms the low rate of infection of Ti-mesh membrane after exposure if site was well maintained owing to the smooth surface that reduces bacterial contamination. [17]

The literature is limited in terms of reporting complications of titanium reinforced high density PTFE (Ti-d-PTFE) compared to reported titanium reinforced expanded PTFE (Ti-e-PTFE). Nevertheless, the smaller pore size, less than 3 microns of Ti-d-PTFE compared to Ti-e-PTFE resists bacterial invasion when membrane is exposed and maintains graft stability. The rate of exposure of Ti- d-PTFE is 21% similar to titanium mesh (15%) as reported by Cucchi with no significant difference. [18] On the other hand, Urban showed only 3% exposure rate with Ti-PTFE membranes. [20] In a cross-sectional study, Ghensi followed 80 complications of Ti-PTFE where he developed a protocol of managing those cases rather than graft removal. The protocol included using chlorhexidine mouthwashes (0.12%) for 30 days, applying 1% chlorhexidine gel twice a day and removing any plaque once a week at the office.[30] In the present study 15 (75%) Ti-PTFE cases experienced postoperative complications with a higher number of infected sites (9 cases) than Ti-mesh (2 cases). The majority cases with infection (6 cases) occurred without

membrane exposure and were noted as an abscess at the grafted site or purulent discharge from adjacent sulci.

Majority of the cases that experienced complications were maintained to 8 and 12 weeks postoperatively to allow for adequate bone maturation before membrane removal. This was done with antibiotic prescription, cleaning exposed sites with cotton tip applicator soaked with chlorhexidine and by frequent recall appointments.

Overall, the rate of exposure in the present study is similar between the two techniques occurring in 45% of Ti-PTFE cases and 52% of Ti-mesh cases with no statistically significant difference. These findings are in agreement with Cucchi's results that demonstrated no difference in the complications rate between the two techniques.[18]

Since membrane exposure can have a negative effect on the ridge augmentation results as demonstrated by Maiorana, further investigation correlating bone gain with membrane exposure was done. [19] Of the 9 (45%) cases of Ti-PTFE that experienced exposure in the present study, 56% of the exposed cases demonstrated bone gain on postoperative measurements. As for Ti-mesh, of the 12 (52%) cases that experienced exposure 50% of them demonstrated bone gain postoperatively. The results can also confirm that exposure of Ti-mesh or Ti-PTFE doesn't mean graft failure or the necessity of graft removal. Maintenance of the exposed membrane could be achieved by the above-mentioned care instructions and bone can mature as seen with the majority of Ti-PTFE and Ti-mesh exposed cases.

In the present study, 17 (60.71%) implants were placed in sites augmented by Ti-PTFE, one of which was deemed a failure at the second-stage surgery. In Ti-mesh augmented sites, 25 (75%)

implants were placed and four of those failed. Failures occurred in two patients with specific circumstances; one patient admitted smoking one pack of cigarettes per day despite denying smoking on her initial exam, the other lost three mandibular anterior implants over the period of four years as a result of unfavorable prosthetic loading with broken prosthesis during COVID and non-compliance with oral hygiene and follow up appointments.

Despite the fact that the end goal of ridge augmentation procedures is implant placement the percentage of implants placed in the present study doesn't represent the ultimate success of cases. This is because not all patients returned to school for completion of treatment and implant placement, whether due to financial reasons, COVID restrictions during the pandemic or pursuing implant placement in another clinic. Furthermore, not all sites that have been augmented received an implant as in cases of implant retained fixed partial dentures and implant retained overdentures. Even though implant placement is the end goal for ridge augmentation procedure, these sites can't be deemed unsuccessful for not receiving an implant.

Differences between results of present study and previous studies

The significant difference in the average vertical and horizontal bone gain between the present study's result and previous studies could be attributed to the fact that the surgeries done in this study were performed by periodontal and OMFS residents in a school setting while in previous studies surgeries were performed by experienced clinicians in a private practice setting. This could also explain the higher rate of postoperative complications in the present study.

Another possible explanation of the measurements difference is the technique used to measure vertical and horizontal bone changes. Previous studies such as Cucchi measured vertical bone

gain clinically by measuring from implant shoulder to the first visible implant bone during initial surgery and during reopening surgery. [26] Similarly, Urban used direct clinical measurement to measure vertical bone in Ti-PTFE cases.[20] He used a UNC-15 probe to measure from the edentulous crest to a horizontal reference line. He used two reference lines to ensure consistent vertical measurements, the first line was an imaginary line connecting between the interproximal bone height of adjacent teeth, and the second line was an imaginary line connecting the proximal tooth bone height to the projected non-resorbed alveolar crest of an edentulous area in case of distal edentulism. On the other hand, Windisch in his study evaluating Ti-PTFE membranes had used both direct clinical measurements as well as CBCT measurements. Direct clinical measurements were used when ridge augmentation with simultaneous implant placement was feasible while CBCT measurements were used when staged approach was indicated. In the case of staged approach augmented sites were measured on pre and postoperative CBCT scans with using adjacent teeth as a reference to calculate bone gain vertically and horizontally.[24] The present study relied on pre and postoperative CBCT measurements for accurate representation of edentulous ridge horizontal and vertical dimensions. With CBCT superimposition, the planes of measurements remain unaltered when switching from preoperative to postoperative view of the superimposed slice. This ensures that the pre and postoperative measurements represent the most accurate bone dimensional changes after ridge augmentation surgery. Using the base of the bone opposed to the crest of the ridge as the starting point for horizontal measurements at 3 mm intervals provides accurate reproducible measurement planes independent of crestal bone changes, whether gain or loss of bone. This technique is more accurate in measuring dimensional changes of the edentulous ridge compared to direct clinical measurement or non-superimposed

CBCT measurements.

Limitations

One of the limitations in this study is the short follow up after ridge augmentation procedure. The time difference of the majority of preop and postop CBCT was 5-7 months. No measurements were done to evaluate stability of bone graft before and after implant placement in cases that have received implants. This could be done in a follow-up study.

Despite the high accuracy of CBCT compared to periapical or panoramic x-rays, presence of metal artifacts from restorations, bridges, or implants created challenges in the superimposition step as well as recording vertical and horizontal measurements. The presence of teeth in preop CBCT or fixations screws in postop CBCT affected the accuracy of measurements in some cases.

Having Ti-mesh and Ti-PTFE CBCT scans taken by two different machines with different settings may be another limitation. However, pre and post-op scans were captured on the same machine and any bias would affect both measurements equally. Moreover, despite Carestream and i-CAT having different exposure as well as voxel size parameters, these variations did not make significant difference in measurements.

Another major limitation is the inconsistency of grafts and biologic agents used within cases of the same technique or between the two techniques since Ti-PTFE ridge augmentations were performed in the Graduate Periodontics clinic and Ti- mesh ridge augmentations performed in the OMFS clinic. For example, within the Ti-mesh cases rh-BMP2 was used in 9 cases (39.1%)

while L-PRF was used in 3 cases (13%). While in Ti-PTFE one case (4.76%) has received rh-PDGR and 7 cases (33.33%) received a mixture of i-PRF and L-PRF. Latest consensus of the American Academy of Periodontology on biologics concluded that the use of autologous blood products (ABP) as PRF, rh-PDGF, rhBMP-2 with bone grafts didn't yield higher clinical or radiographic outcomes compared to cases without. Nevertheless, the use of ABP improved wound healing and decreased the risk of wound dehiscence. [31] The consensus encouraged clinicians to use biologic in medically compromised patients, defects with decreased predictability as in large vertical ridge defects, shortening healing timeframe and in patients with history of complications and failure of earlier treatments. [32]

Future studies may expand on the present study's findings and further investigate the effect of different variables on dimensional changes of the augmented ridge. Correlating between the amount of bone gain and the materials used for grafting, or between the amount of bone gain and site of ridge augmentation whether maxillary, mandibular, anterior, or posterior, could provide valuable insights that may be useful in anticipating the results of ridge augmentation procedures using Ti-mesh or Ti-PTFE. In addition, correlating between the radiographic and surgical outcomes and patient's health history and active medications may be another area to investigate.

Conclusion

This study has shown that the use of Ti-PTFE or Ti-mesh membranes in alveolar ridge augmentation procedures to prepare alveolar ridge for implant placement was successful in increasing horizontal dimensions of alveolar ridge. For vertical bone augmentation, Ti-PTFE was more successful than Ti-mesh with a statistically significant average gain of 0.91 mm versus non-significant 0.6 mm. The average horizontal width gain was statistically significant with both Ti-PTFE and Ti-mesh with 2.1mm and 2.49 mm average gain. No significant differences were found between percentage of sites that demonstrated bone gain of each technique, with 60% of Ti-PTFE cases and 69% Ti-mesh cases showing bone gain. Postoperative complications also did not differ significantly between the two techniques, 75% in Ti-PTFE cases versus 56% in Ti-mesh cases. The proposed method can be a useful tool to evaluate accurately the outcomes of ridge augmentation for large alveolar defects using Ti-PTFE or Ti-mesh membranes.

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