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VOLUMETRIC CHANGES IN EDENTULOUS ALVEOLAR RIDGES FOLLOWING AUGMENTATION WITH REINFORCED POLYTETRAFLUOROETHYLENE MESH

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ABSTRACT

Volumetric Changes in Edentulous Alveolar Ridge Sites Using Reinforced Polytetrafluoroethylene Mesh

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Introduction: The four foundational tenets of guided bone regeneration (GBR) include primary closure, angiogenesis, space maintenance and blood clot stability. Technological advancements in membrane design for GBR applications have improved rigidity for improved space maintenance through titanium reinforcement. Manufacturers have also focused their design efforts on enhancement of biocompatibility and fluid diffusion in order to promote predictable primary wound closure. Fluid diffusion plays a key role in providing nutrient flow from the graft and underlying bone to the gingival flap that covers the membrane-graft complex. Historical approaches to GBR have employed many types of membranes, including resorbable membranes and non-resorbable membranes with either a total absence of pores, the presence of micropores, or a macropore design. The ultimate goal of a membrane is to promote optimal hard tissue regeneration through adequate nutrient diffusion, while maintaining space and excluding soft tissue ingrowth. **Objectives:** This study will quantify volumetric changes in hard and soft tissues on edentulous ridges following GBR using a non-resorbable, titanium-reinforced polytetrafluoroethylene mesh designed with 0.66mm macropores. **Methods:** Fourteen subjects requiring GBR prior to dental implant placement will be enrolled. Bone augmentation surgery will be performed using a standardized approach. Volumetric

change will be assessed using 3D reconstruction of the edentulous area. Baseline CBCT imaging will be compared to follow-up CBCT imaging captured 6 months after surgery to evaluate hard tissues. Baseline intraoral scans will be compared to 2-4 week and 4 months scans following dental implant placement to evaluate soft tissue change. **Results:** This long-term clinical study is pending approval by the WRNMMC Institutional Review Board. **Conclusion:** This study will supplement the body of literature by providing evidence for the regenerative potential of a titanium-reinforced PTFE mesh with a macropore design.

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LIST OF ABBREVIATONS

ABBM	Anorganic Bovine Bone Mineral
DFDBA	Demineralized Freeze-Dried Bone Allograft
d-PTFE	Dense Polytetrafluoroethylene
e-PTFE	Expanded Polytetrafluoroethylene
FDBA	Freeze-Dried Bone Allograft
GBR	Guided Bone Regeneration
GTR	Guided Tissue Regeneration
NHANES	National Health and Nutrition Examination Survey
PCN	Penicillin
PTFE	Polytetrafluoroethylene
RPM	Reinforced PTFE Mesh

CHAPTER 1: Review of the Literature

INTRODUCTION

According to data analyzed from the National Health and Nutrition Examination Survey (NHANES), there has been an increase in the prevalence of dental implants from 0.7% in 1999-2000 to 5.7% in 2015-2016. Assuming continuation of this trend, dental implant prevalence could rise to 17-23% by the year 2026.[1] With growing demand for dental implant therapy, an increased need for new and innovative ways to grow bone in atrophic ridges has developed. If a deficiency is present, proper development of the site is necessary to create an adequate bone volume that will promote success of the dental implant and future prosthesis. There are various methods to augment bone volume, including the use of growth factors, particulate graft materials, distraction osteogenesis, guided bone regeneration (GBR), and revascularized autogenous bone grafts.[2] In the field of Periodontics, GBR is a commonly employed procedure to correct osseous defects on edentulous ridges. The four foundational tenets of GBR include primary closure, angiogenesis, space maintenance and blood clot stability.[3] The improving predictability of such procedures can be attributed to technical advancements and the capacity of new materials to meet the four aforementioned tenets.

After tooth extraction, osseous resorption is an inevitable part of the natural healing process. Using linear and subtraction radiography techniques on stone models, Schropp et al. demonstrated that following extraction of a tooth without ridge preservation, approximately 50% of the width of the alveolar ridge was lost over 12 months.[4] This bone loss occurred rapidly, with the majority of loss occurring in the first three months. Proper ridge preservation results in approximately 1.4 mm less horizontal

resorption when compared to extraction alone.[5] In the field of dentistry today, ridge preservation is not always utilized due to a host of patient and provider related factors. The lack of universal adoption of ridge preservation as a clinical standard has contributed to an increased need for GBR procedures to correct deficient alveolar ridges before implant surgery is considered.

An implant placed into a deficient ridge faces a myriad of potential complications. In such a scenario, surgeons are often likely to place the implant in the area with the greatest bony volume rather than in the location that satisfies the ideal restorative plan. If a dental implant is placed without consideration of the restorative outcome, the prosthesis may be more susceptible to complications, or potentially non-restorable. Additionally, if an implant is placed at a site that does not offer circumferential osseous support, implant threads may become exposed to the oral environment in the long term. Such exposure can lead to plaque retention, bacterial invasion, inflammation, infection, and ultimately, implant failure. While grafting can be done at the time of implant placement to overcome some of these challenges, predictability and long term success is better supported by placing implants into native or fully healed bone. Therefore, it is critical to preserve ridge dimensions and minimize alveolar resorption after extraction. Moreover, proper planning will provide the dental team with the necessary information to decide whether GBR before implant placement will provide the most ideal outcome for the patient.

GUIDED BONE REGENERATION (GBR)

GBR involves procedures that attempt to regenerate lost periodontal structures through a differential tissue response. The term GBR is often used interchangeably with *ridge*

augmentation and *ridge preservation*. Indications for GBR include the presence of bony defects resulting from trauma, periodontal disease, or atrophy from long-standing edentulism. While shorter or narrower implants can be a solution for the deficient ridge, surgical complexity and risk increases when implants are placed in close proximity to vital structures, such as the inferior alveolar nerve (IAN), maxillary sinus floor, or nasal floor.[6]

More than 30 years ago, Buser et al. presented a new surgical protocol for ridge augmentation using an expanded polytetrafluoroethylene (e-PTFE) barrier membrane in conjunction with fixation screws to provide adequate space maintenance for bone regeneration. In modern approaches to GBR, various barrier types are used to aid in blood clot stability, space maintenance and epithelial exclusion, including e-PTFE, polyglactin, polylactic acid, calcium sulfate, amnion-chorion, pericardium, and collagen. In Buser's pioneering approach, the e-PTFE membrane and screws were left undisturbed for 9 months before surgical re-entry when dental implants were placed after removal of the hardware. Buser proposed four fundamentals for predictable success in GBR procedures: (1) achievement of primary soft tissue closure without dehiscence, (2) use of an appropriate barrier membrane, (3) stabilization and close adaptation of the membrane to the surrounding bone, and (4) creation and maintenance of a secluded space to allow for osseous regeneration.[7]

BONE GRAFTING MATERIAL

Although the original model for guided tissue regeneration (GTR) in natural teeth involved only the use of a barrier membrane, the combination of a membrane with a bone graft has become a more widely accepted practice for regeneration procedures. The use of

autografts, allografts, xenografts and alloplasts offers an additional benefit to the overall regenerative process in supporting space maintenance and blood clot stability.

An autograft is defined as bone harvested from a second surgical site in the same patient, including the mandibular ramus, mandibular symphysis, tori, exostoses, anterior iliac crest, and the calvarium.[6] Although autografts are assumed to have the greatest regenerative capacity, disadvantages include a finite quantity of available bone, a variable rate of resorption, and a second surgical site that increases patient morbidity. In a murine study of GBR in 60 mandibles using autogenous block grafts with or without e-PTFE membranes, the non-membrane group displayed significantly more bone resorption. The authors attributed the resorption to a more rapid revascularization of the autogenous graft in the absence of a membrane.[8] Misch published a case series of 50 autogenous block grafts without the use of barrier membranes, demonstrating 100% success and a resorption rate with a range of 0-25%.[9] Rocchietta et al. treated 10 patients with intraoral block grafts and autogenous particulate graft with an e-PTFE barrier membrane. Eleven sites out of 12 healed uneventfully, and the mean gain in vertical bone growth was 5.03 mm.[10]

An allograft is defined as a graft from a donor of the same species as the recipient, but not genetically identical. Available in mineralized or demineralized particulate and block formulations, human allograft is widely used for ridge preservation following tooth extraction, regeneration in natural teeth, sinus elevation procedures, and GBR. When comparing the regenerative potential of freeze-dried bone allograft (FDBA) and demineralized freeze-dried bone allograft (DFDBA) in the literature, both materials have demonstrated success. In a study by Wood and Mealey, forty extraction sites were grafted

with either FDBA or DFDBA, and 32 core biopsies were taken at the time of dental implant placement. The results showed that while both materials were effective in maintaining alveolar ridge dimensions, DFDBA displayed a significantly greater percentage of vital bone at 38.42% versus 24.63% for FDBA.[11] Assessing the success of dental implants placed in non-native bone, Nevins et al. reported a 72-month survival rate of 97.5% for 526 dental implants placed in sites regenerated with either FDBA, DFDBA or autografts.[13] Feuille et al. evaluated the use of FDBA in conjunction with a titanium reinforced e-PTFE barrier for twelve patients needing ridge augmentation prior to implant therapy. The authors reported a mean alveolar ridge width increase of 3.2 mm. The clinical and histologic findings of this study demonstrated that FDBA in conjunction with an e-PTFE barrier could provide a predictable way to augment deficient alveolar ridges.[12] Lyford et al. used freeze-dried cancellous block allografts in five deficient sites finding a 2-4 mm gain in ridge width upon surgical re-entry. However, 1-2 mm of surface resorption was noted in three of the sites, providing evidence that block autografts can vary in predictability.[14]

Xenografts are transplants from a donor of a different species. Bovine, porcine, and equine sources have been widely used in dentistry for regenerative applications, particularly in regions of the world where the availability of allografts is limited. A purported advantage includes a longer graft remodeling time that results in extended space maintenance. A systematic review and meta-analysis of various GBR procedures demonstrated that the use of particulate anorganic bovine bone mineral (ABBM) with a collagen membrane ultimately resulted in an implant survival rate of 98.34%. The authors

concluded that ABBM was effective in providing sufficiently regenerated bone for dental implant placement.[15]

Synthetic graft materials, known as alloplasts, have a long history of use with limited success in the regenerative realm. The literature consensus conveys that alloplasts do not provide the same predictable osteoconductive foundation seen in xenograft and allograft materials. The unpredictable nature of alloplast healing has proven to be problematic in implant dentistry. In a study of 12 patients, GBR with bioactive glass and a titanium reinforced e-PTFE membrane resulted in failed implant attempts in 33% of patients due to inadequate ridge augmentation. Histologic examination revealed connective tissue encapsulation of most of the residual graft particles, and the authors concluded that bioactive glass with an e-PTFE membrane was unable to succeed in a consistent manner.[16]

Barrier Membranes

Membranes used during regenerative procedures serve four main purposes: (1) epithelial exclusion, (2) graft containment, (3) clot stabilization, and (4) space maintenance. Derived from human, animal, or synthetic sources, resorbable membranes have the advantage of breaking down naturally and eliminating the need for a secondary procedure to remove the membrane. In contrast, resorbable membranes degrade rapidly when exposed to the oral environment, resulting in the inability to achieve ideal performance. Another clinical challenge is that resorbable membranes are more flexible and have the tendency to collapse, failing to maintain space in an ideal manner. Non-resorbable membranes, typically fabricated from expanded or dense polytetrafluoroethylene (e-PTFE/d-PTFE), are generally used when a more rigid material is desired or when

primary closure cannot be achieved (e.g., after tooth extraction). Non-resorbable membranes can be designed with perforations for nutrient and fluid diffusion or be completely occlusive. When even more rigidity is required, these non-resorbable membranes can also be fabricated with reinforced titanium. Newer advances, such as the reinforced PTFE mesh (RPM), combine circular macropores with a titanium framework for space maintenance, and PTFE mesh for cell exclusion. Although such improvements in membrane design offer new options for the clinician, technique sensitivity can limit success. Non-resorbable membranes have historically been associated with a high prevalence of exposure and flap dehiscence. Once exposed, the membrane and graft are susceptible to bacterial colonization and epithelial invasion, leading to possible infection and failure. Advancements in membrane design have focused on improving pore design to encourage natural nutrient flow and limit the likelihood of exposure and flap dehiscence.

TITANIUM MESH

To prevent membrane collapse and provide an even greater rigidity than is offered by non-resorbable membranes, titanium mesh has become a viable option. The use of titanium mesh for reconstruction dates back to 1985, when Dr. Boyne contoured mesh over edentulous ridges in 15 human subjects, and followed them for 3-10 years.[17] Sumi et al. described three cases in which a titanium mesh was hand-trimmed and applied to the surgical site to restore the desired shape of a new alveolar crest. Autogenous bone was harvested from the retromolar area and placed between the mesh and the recipient site. After a period of 6 to 9 months, the site was surgically accessed and displayed a mean gain of 3.5 mm in ridge width.[18] Pieri et al. enrolled 16 human subjects who were treated

with customized titanium mesh in osseous defects spanning 19 edentulous sites. Autogenous bone was harvested and combined with anorganic bovine bone mineral, while the mesh was fixated with at least three titanium mini-screws. Nine months following the procedure, the mesh was removed and a total of 44 dental implants were placed among the subjects. Of the 19 sites, only one mesh had to be removed due to premature exposure. Computed tomography scan analysis revealed a 3.71 mm and 4.16 mm mean gain in bone growth vertically and horizontally, respectively. Of the 44 implants placed, there was a cumulative survival rate of 100% and a success rate of 93.2%.[19] A retrospective study by Louis et al. evaluated 44 human subjects who experienced procedures using titanium mesh for vertical ridge augmentation. Nearly 200 implants were placed in 36 of the 44 subjects with an overall success of 97.72%. The rate of mesh dehiscence was 52.27% with seven subjects requiring early mesh removal because of an infection.[20] Another retrospective study analyzed factors associated with post-operative complications after grafting with titanium mesh. The author reported mesh complications in seven of 27 sites, representing a mesh dehiscence rate of 26%. None of the sites required premature removal and 69 implants were placed 4 to 11 months after surgery.[21] Titanium mesh has been widely accepted as a viable option for application in GBR procedures. Potential disadvantages include the technique sensitivity of trimming the mesh at the time of surgery. Hand trimming creates the potential for sharp edges and flap perforation, as well as the possibility of less than ideal adaptation to the underlying ridge.

POROSITY

Perforations of barrier membranes have been examined in order to determine whether such a design allows for accelerated revascularization and bone formation. The foundational science supports the idea that barrier pores allow the passage of fluids, oxygen, and nutrients that are essential for healing by enhancing blood circulation and reestablishment of the microcirculatory system.[22,23] Zellin et al. examined the influence of membrane porosity with e-PTFE membranes on bone growth. Three murine groups with membrane porosities measuring < 8μm, 20-25μm, and 100μm were evaluated at four time points (6, 12, 18, and 24 weeks). While the two groups with the largest pore size performed well by the 6-week mark, the group with the smallest pore size lagged in bone formation. The 8μm group required an additional 6 weeks of healing to match the bone growth achieved in the other groups, and also showed a decrease in the rate of soft tissue integration.[24] These findings suggest that membranes with an extremely small pore size may have a negative impact on clinical healing. The theoretical justification for strategic pore sizing in membrane design is to block cells that interfere with osteogenesis, but allow nutrient flow and capillary ingrowth. Hence, a fully occlusive barrier would impede vascular ingrowth, nutrient diffusion and ultimately, bone formation.[25] In a direct comparison examining the impact of pore size on regenerative outcomes in a canine model, Gutta et al. evaluated two titanium mesh membranes (0.6 mm and 1.2 mm pore size) and one resorbable membrane (1 mm pore size). The author reported that the 1.2 mm macropore membrane facilitated greater bone regeneration than the other groups. Given these findings, it is important to highlight the importance of the space maintenance achieved by the rigid titanium mesh as compared to the less rigid resorbable collagen

membrane. Moreover, the fact that the titanium mesh with the largest pore size performed best suggests that regeneration was maximized by both the inherent rigidity and the nutrient diffusion provided by the larger pores.[26]

With the understanding that macropore design alone may enhance bone regeneration, an important clinical question involves whether the addition of a bone graft would also enhance outcomes. In a canine model examining regeneration, Sverzut et al. compared results among the following groups: (1) no barrier/no bone, (2) a bone graft alone, (3) a microporous membrane alone, (4) a microporous membrane with a bone graft, (5) a laser- perforated membrane, and (6) a laser-perforated membrane with a bone graft. The authors reported that the combination of the perforated membrane with a bone graft led to an increase in regenerated bone volume compared to the other treatment groups. These results support the idea that the addition of a graft to GBR with perforated membranes is clinically beneficial.[27]

CHAPTER 2: Materials and Methods

STUDY DESIGN

In this descriptive, prospective case series, the purpose is to measure volumetric changes after guided bone regeneration with RPM and FDBA. Measurements will be completed utilizing CBCT and intraoral digital scans at four time points, including the initial presentation, 6 months after guided bone regeneration at the time of implant placement, 2 to 4 weeks after implant placement, and 4 months after implant placement.

Providers in the Periodontics Department at the Naval Postgraduate Dental School will screen suitable adult candidates who require guided bone regeneration prior to dental implant placement. Each qualified subject will have an approved treatment plan for dental implants, and the need for ridge augmentation prior to implant placement will be confirmed by review of a CBCT scan. Additional inclusion criteria include male and female military health care beneficiaries 18 years or older that will remain in the National Capital Region for at least 14 months following the initial surgical procedure, and the presence of a bone deficiency with at least three natural teeth adjacent to the area. Additionally, if the patient presents with two potential sites in different dental arches (mandible or maxilla) requiring grafting and implant placement, both sites may be included. Exclusion criteria include patients under the age of 18, patients that will not be available for 14 months following the initial surgical procedure, female patients who are pregnant or nursing, current smokers, patients with uncontrolled systemic disease, patients that are allergic to any medications or materials necessary for the study, patients with poor oral hygiene, patients with an active infection manifesting as

lymphadenopathy, and patients who decide not to proceed following a discussion of the risks and benefits of the procedure.

Following informed consent, baseline intraoral scans of the surgical field will be made with the OmniCam digital scanner for comparison to scans acquired 2 to 4 weeks after implant placement, and 4 months after implant placement. A 3D model of the ridge defect will be created from the patients CBCT using software in the 3D Medical Applications Department, and later compared to a CBCT taken 6 months following augmentation surgery. Following anesthesia, full thickness flap reflection will be completed to expose the deficient site. Cortical perforations will be completed using a high-speed handpiece and round carbide bur in order to create bleeding in areas of dense cortical bone. An appropriately sized RPM membrane will be selected and trimmed for adequate site adaptation. Hydrated FDBA will be adapted to the deficient ridge and covered with the contoured RPM membrane. The barrier will be secured with either tacking screws or periosteal strap sutures based upon the surgeon's preference and the unique clinical presentation of each patient. Passive, tension-free flap closure will be obtained through periosteal release and PTFE sutures. A 7-day course of amoxicillin (or clindamycin for PCN-allergic patients) will be prescribed in addition to medication for pain control. Patients will be given post-operative oral hygiene instructions and prescribed 0.12% chlorhexidine gluconate oral rinse to substitute for home hygiene measures during the initial healing period.

CHAPTER 3: Results

This long-term clinical study is pending approval by the Walter Reed National Military Medical Center Institutional Review Board. A total of 14 subjects will be enrolled. CBCT data will be analyzed using a paired t-test or the Wilcoxon signed rank test, and a repeated measure analysis of variance (ANOVA) will be utilized for comparative analysis of volumetric changes in digital scans. Additionally, descriptive statistics will be provided.

CHAPTER 4: Discussion

The goal of this study is to measure and analyze volumetric changes in hard and soft tissue following guided bone regeneration. The RPM should yield positive results, as it has the potential to uphold the four ideal functions of a barrier membrane—epithelial exclusion, graft containment, clot stabilization, and space maintenance. With the added design features of titanium reinforcement and larger pore size, the clinical performance is expected to be more than adequate. With advances in 3D technology, a universal effort should be made to standardize how volumetric changes are measured and reported in the literature. As described by Naenni et al., baseline bone width is inversely correlated with the obtained bone width gain, indicating that a thinner alveolar process at baseline has a statistically higher probability of gaining more bone volume.[28] For this reason, historical publications that merely report linear gains with a manual probe, without a description of baseline bone width, do not give a truly comprehensive analysis of volumetric changes. As proposed in this study design, hard and soft tissue comparisons with 3D reconstruction of CBCT and intraoral scans will be a more accurate representation of what is achievable in GBR, and enhance clinical decision-making in the field of Periodontics.

CHAPTER 5: Conclusions

This study will supplement the body of literature by providing evidence for the regenerative potential of a titanium-reinforced PTFE mesh with a macropore design.

REFERENCES

1. Elani H, Starr J, Da Silva J, Gallucci G. Trends in Dental Implant Use in the U.S., 1999–2016, and Projections to 2026. *Journal of Dental Research* 2018, Vol. 97(13) 1424–1430

2. Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. *Clin. Oral Impl. Res*. 17 (Suppl. 2), 2006; 136–159

3. Wang HL, Boyapati L. "PASS" principles for predictable bone regeneration. *Implant Dent*. 2006 Mar;15(1):8-17.

4. Schropp L, Wenzel A, Kostopoulos L, Karring T. Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study. *Int J Periodontics Restorative Dent*. 2003 Aug;23(4):313-23.

5. Iasella JM, Greenwell H, Miller RL, Hill M, Drisko C, Bohra AA, Scheetz JP. Ridge preservation with freeze-dried bone allograft and a collagen membrane compared to extraction alone for implant site development: a clinical and histologic study in humans. *J Periodontol*. 2003 Jul;74(7):990-9.

6. Chiapasco M, Tommasato G, Palombo D, Scarnò D, Zaniboni M, del Fabbro M. Dental implants placed in severely atrophic jaws reconstructed with autogenous calvarium, bovine bone mineral, and collagen membranes: A 3- to 19-year retrospective follow-up study. *Clin Oral Impl Res*. 2018; 29:725–740

7. Buser D, Brägger U, Lang NP, Nyman S. Regeneration and enlargement of jaw bone using guided tissue regeneration. *Clin Oral Implants Res*. 1990 Dec;1(1):22-32. doi: 10.1034/j.1600-0501.1990.010104.x.

8. De Marco A, Jardini M, Lima L, Revascularization of Autogenous Block Grafts with or Without an e-PTFE Membrane. *INT J ORAL MAXILLOFAC IMPLANTS* 2005;20:867–874

9. Misch CM. Comparison of intraoral donor sites for onlay grafting prior to implant placement. *Int J Oral Maxillofac Implants*. 1997 Nov-Dec;12(6):767-76.

10. Rocchietta I, Simion M, Hoffmann M, Trisciuoglio D, Benigni M, Dahlin C. Vertical Bone Augmentation with an Autogenous Block or Particles in Combination with Guided Bone Regeneration: A Clinical and Histological Preliminary Study in Humans. *Clin Implant Dent Relat Res*. 2016 Feb;18(1):19-29.

11. Wood R Mealey B. Histologic Comparison of Healing After Tooth Extraction With Ridge Preservation Using Mineralized Versus Demineralized Freeze-Dried Bone Allograft. *J Periodontal*. 2012;83:329-336

12. Feuille F, Knapp CI, Brunsvold MA, Mellonig JT. Clinical and histologic evaluation of bone-replacement grafts in the treatment of localized alveolar ridge defects. Part 1: Mineralized freeze-dried bone allograft. *Int J Periodontics Restorative Dent*. 2003 Feb;23(1):29-35. PMID: 12617366.

13. Nevins M, Mellonig JT, Clem DS 3rd, Reiser GM, Buser DA. Implants in regenerated bone: long-term survival. *Int J Periodontics Restorative Dent*. 1998 Feb;18(1):34-45.

14. Lyford RH, Mills MP, Knapp CI, Scheyer ET, Mellonig JT. Clinical evaluation of freeze-dried block allografts for alveolar ridge augmentation: a case series. *Int J Periodontics Restorative Dent*. 2003 Oct;23(5):417-25.

15. Wessing B, Lettner S, Zechner W. Guided Bone Regeneration with Collagen Membranes and Particulate Graft Materials: A Systematic Review and Meta-Analysis. *Int J Oral Maxillofac Implants.* 2018 January/February;33(1):87–100.

16. Knapp CI, Feuille F, Cochran DL, Mellonig JT. Clinical and histologic evaluation of bone-replacement grafts in the treatment of localized alveolar ridge defects. Part 2: bioactive glass particulate. *Int J Periodontics Restorative Dent*. 2003 Apr;23(2):129-37. PMID: 12710816.

17. Boyne PJ, Cole MD, Stringer D, Shafqat JP. A technique for osseous restoration of deficient edentulous maxillary ridges. *J Oral Maxillofac Surg*. 1985 Feb;43(2):87-91.

18. Sumi Y, Miyaishi O, Tohnai I, Ueda M. Alveolar ridge augmentation with titanium mesh and autogenous bone. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2000 Mar;89(3):268-70.

19. Pieri F, Corinaldesi G, Fini M, Aldini NN, Giardino R, Marchetti C. Alveolar ridge augmentation with titanium mesh and a combination of autogenous bone and anorganic bovine bone: a 2-year prospective study. *J Periodontol*. 2008 Nov;79(11):2093-103.

20. Louis PJ, Gutta R, Said-Al-Naief N, Bartolucci AA. Reconstruction of the maxilla and mandible with particulate bone graft and titanium mesh for implant placement. *J Oral Maxillofac Surg*. 2008 Feb;66(2):235-45.

21. Her S, Kang T, Fien MJ. Titanium mesh as an alternative to a membrane for ridge augmentation. *J Oral Maxillofac Surg*. 2012 Apr;70(4):803-10.

22. Rakhmatia YD, Ayukawa Y, Furuhashi A, Koyano K. Current barrier membranes: titanium mesh and other membranes for guided bone regeneration in dental applications. *J Prosthodont Res*. 2013 Jan;57(1):3-14.

23. Milstein DMJ, Mathura KR, Lindeboom JAH, Ramsoekh D, Lindeboom R, Ince C. The temporal course of mucoperiosteal flap revascularization at guided bone regeneration- treated implant sites: a pilot study. *J Clin Periodontol.* 2009; 36: 892–897.

24. Zellin G, Linde A. Effects of different osteopromotive membrane porosities on experimental bone neogenesis in rats. *Biomaterials*. 1996 Apr;17(7):695-702.

25. Marouf HA, El-Guindi HM. Efficacy of high-density versus semipermeable PTFE membranes in an elderly experimental model. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2000 Feb;89(2):164-70.

26. Gutta R, Baker RA, Bartolucci AA, Louis PJ. Barrier membranes used for ridge augmentation: is there an optimal pore size? *J Oral Maxillofac Surg*. 2009 Jun;67(6):1218-25.

27. Sverzut CE, Faria PE, Magdalena CM, Trivellato AE, Mello-Filho FV, Paccola CA, Gogolewski S, Salata LA. Reconstruction of mandibular segmental defects using the guided-bone regeneration technique with polylactide membranes and/or autogenous bone graft: a preliminary study on the influence of membrane permeability. *J Oral Maxillofac Surg*. 2008 Apr;66(4):647-56.

28. Naenni N, Lim H, Papageorgiou SN, et al. Efficacy of lateral bone augmentation prior to implant placement: A systematic review and meta-analysis. *J Clin Periodontol*. 2019;46(Suppl. 21):287–306.