

HORIZONTAL RIDGE AUGMENTATION IN IMPLANT DENTISTRY

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MECHANISM OF ALVEOLAR BONE LOSS

Whenever teeth are lost, the maxillary and mandibular alveolar processes undergo significant structural and histological changes. The specific changes that occur have been investigated in animals and humans.^{1,2}

The amount of bone loss and factors associated with it was well described and studied by Kingsmill and Carlsson. Approximately 25% alveolar bone loss occurs after the first year post extraction, mainly during the first 3 months and 40-60% volume loss after the first 3 years. Largely, along the bucco-lingual dimension and mainly due to resorption of the buccal bone. Many factors may play a role in accelerating or decelerating the rate of bone loss. Functional factors that include presence or lack of mechanical stress, for example, absence or presence of dentures and the extent of applied force. Anatomical factors such as original size of the mandible, original depth of tooth sockets, local bone quality, proportion of extrinsic tooth fibers, age and availability of bone cells, quality of the soft tissues, local blood supply, and muscle attachments. Inflammatory factors include trauma inflicted at extraction, pre-existing/residual infection, periodontal disease, mucosal inflammation, local inflammatory mediators, and denture hygiene. Systemic factors include age and gender, skeletal status,

bone regulatory hormones, and dietary calcium.³⁻⁶ It is essential to preserve the original form of alveolar bone in order to achieve a good functional and esthetic result following implant placement in the edentulous jaw. **(Figure 1)**

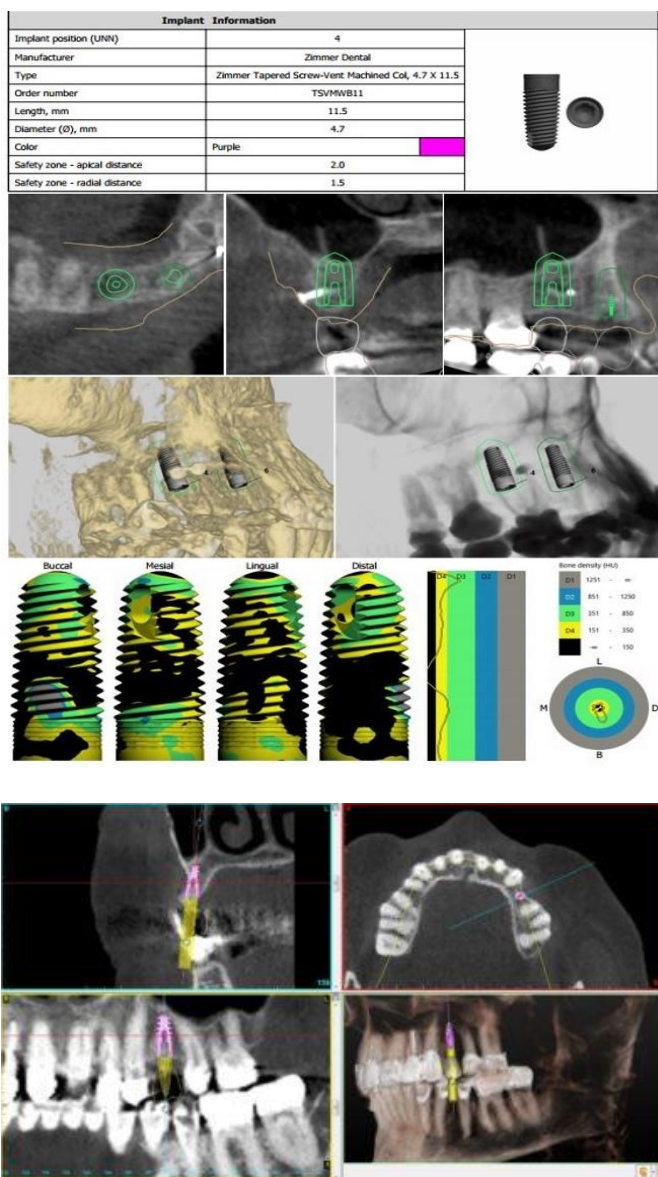


Figure 1: Post extraction changes showing decrease in the 3D structure of the extraction socket, primarily along the bucco-lingual dimension mainly due to resorption of the buccal bone.

DIAGNOSIS AND TREATMENT PLANNING

The degree of horizontal and vertical bone loss following tooth loss can be measured in multiple ways from clinical evaluation to radiographic evaluation including the 2D panoramic radiograph and the 3D cone beam computed tomography (CBCT). Since the advent and refinement of the CBCT, there is perhaps a shift toward the exclusive utilization of the CBCT for dental implant planning and

execution.^{7,8} Although panoramic radiography generally can be used effectively in some implant cases, there are still instances in which CBCT is indicated. It can be beneficial to have 3D images preoperatively in cases when guided surgery is planned, when there is great risk of violating vital structures, or when there is the possibility of needing bone augmentation. CBCT more accurately predicts the size of the dental implant and the need for bone grafting. Surgeons should continually re-evaluate the need for 3D imaging as the radiation exposure from CBCT is decreased and 2D imaging is displaced by CBCT in the future.⁹ **(Figure 2A-B)**



INITIAL MANAGEMENT

To counter the tissue changes that occur soon after tooth extraction, different techniques for socket preservation have been recommended. These range from “atraumatic” flapless tooth extraction maximizing socket healing and minimizing socket disturbance to packing the resulting alveolar socket with different grafting materials, with barrier membranes or without. To date there is no consensus on the effectiveness or superiority of flapless vs. flapped surgery during tooth extraction.^{7, 8, 10} **(Figure 3 A-D)**

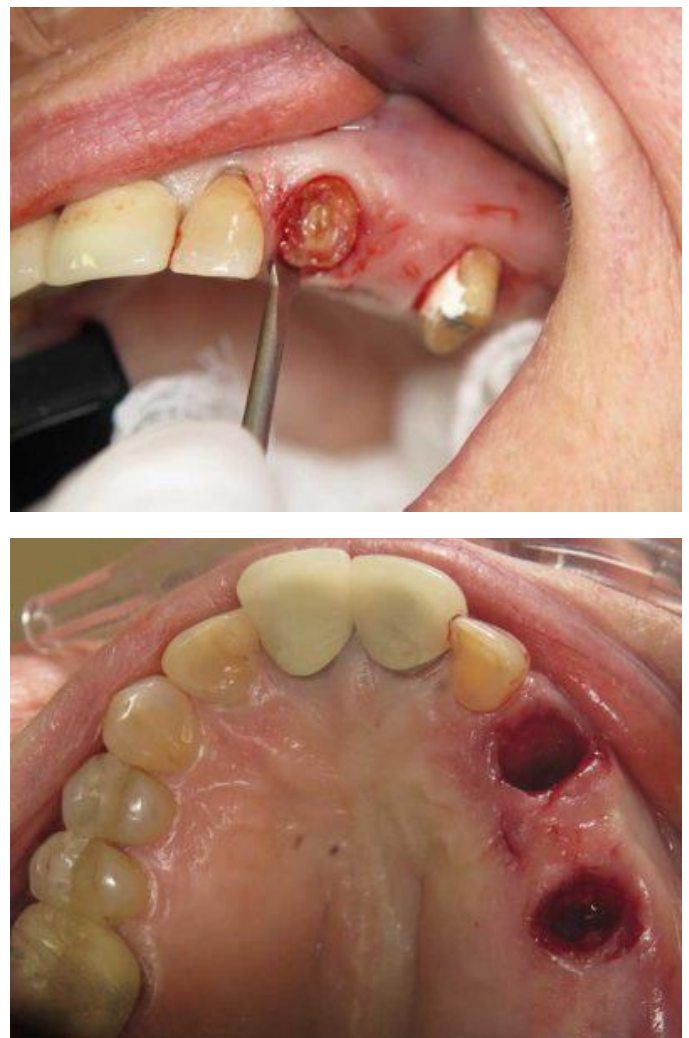


Figure 3: A (top), B (bottom), Flapless tooth extraction with minimal bone exposure and preservation of soft tissue architecture.

Previous human and animal studies have shown that using different grafting material may aid in decreasing the dimensional changes associated with tooth extraction but did not

Figure 2: A (top), B, (bottom), Use of 3D technology in dental implant treatment planning. This allows the surgeon to perceptually plan implant placement with greater accuracy.

significantly alter the physiological resorption process.^{10,11}

Aimetti performed a randomized controlled trial to evaluate the difference in 3D changes between grafted alveolar sockets and those without grafting over a 12-month period. He used collagenated bovine-derived bone (DBBM-C) and covering collagen membrane to graft the alveolar sockets. Pre and post-operative images of the socket were superimposed. He concluded that the use "of a slow-resorbing graft with a secured covering collagen membrane may prove effective not only in limiting post-extraction crestal ridge bone loss but also in improving alveolar ridge shape and dimensions with the advantage to simplify later implant insertion in the aesthetic zone".¹²



Figure 3: C (top), D (bottom), Socket preservation using graft covered with a bioresorbable membrane then secured with Gore-Tex suture.

Over the years, dental implants have proved to be a great way of rehabilitating partially or fully edentulous patients, with great predictability and safety margins. Dental implants have cumulative survival rates ranging between 89.5% and 92.7% after 10–27 years of function.¹³

It is prudent to mention that simply placing an implant in the jaws is by no means a guarantee for success. There must be careful planning involved. An implant must be placed in a "solid foundation." That foundation—alveolar bone—must be of sufficient strength and volume to withstand the forces transmitted to it via the implant placed. To facilitate implant placement we must reconstruct the deficient alveolar ridge.

Thus, many bone regenerative techniques have been suggested and evaluated, depending on the structure of the bone defect whether it is horizontal, vertical or a combination. Lateral augmentation procedures are predictable and safe, with reported implant survival rates of 87%–95% for simultaneous and 99%–100% for staged approaches.^{14,15} On the contrary, vertical ridge augmentation interventions are less predictable and are associated with a higher frequency of complications.¹⁶ We will focus on the different techniques of horizontal ridge augmentation.

DIFFERENT TECHNIQUES FOR HORIZONTAL RIDGE AUGMENTATION

Horizontal, vertical and combination ridge augmentation can be completed with various types of bone augmentation materials: autografts, allografts, xenografts, and alloplasts. Currently, autogenous bone is considered to be the "gold standard" because of its inherent osteogenic, osteoconductive and osteoinductive nature. It also is found to be associated with faster healing times and integration. Implant placement in patients with

an atrophic mandible or maxilla is becoming more prevalent. Atrophy or bone loss can be due to periodontal disease, trauma, or post extraction resorption. This loss can be substantial enough to prevent the implant placement, and therefore bone augmentation may become necessary.¹⁷ **(Figure 4)**

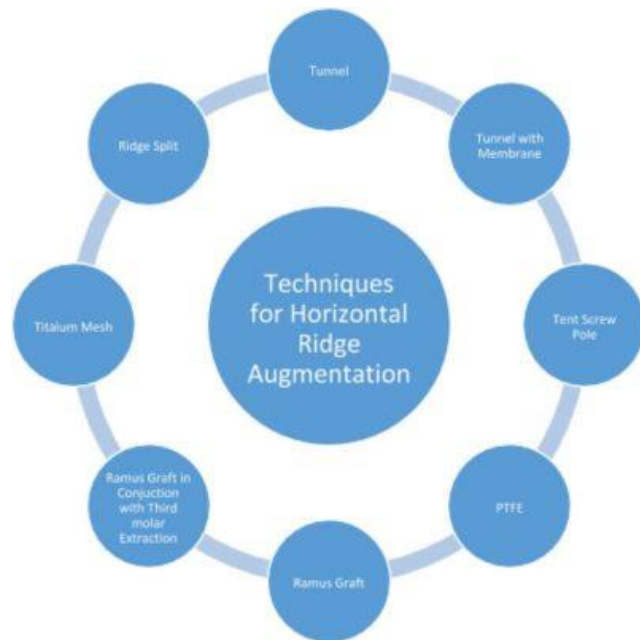


Figure 4: Techniques for Horizontal Ridge Augmentation.

TUNNEL AND TUNNEL WITH MEMBRANE TECHNIQUE

The tunnel technique for completing a horizontal ridge augmentation was first suggested by Kent et al. in the early 1980s with the utilization of nonresorbable hydroxylapatite.¹⁸ Initial analysis of this minimally invasive technique indicated favorable outcomes in terms of lateral ridge stability.¹⁸ Studies conducted in the later 1980s, however identified barriers to graft stability in the lateral direction including the formation of a fibrous capsule.¹⁹ Block et al. identified an increase in long-term lateral ridge stability of the posterior mandible, however with the addition of autogenous cancellous bone to nonresorbable hydroxylapatite.¹⁹

Variations to the original tunnel technique include the same approach, but with the addition of a bioresorbable membrane. Block identified greater gains in posterior mandibular ridge width with the use of a resorbable collagen membrane over a bovine particulate graft, and minor resorption two years after the grafted site was restored.²⁰ Similar results were observed when applied to the anterior maxilla.²¹

Indications

The main indication for a horizontal ridge augmentation is to increase lateral ridge dimensions of a deficient alveolar ridge for future implant placement.²² This includes achieving widths sufficient enough to provide support for an implant of appropriate diameter in regards to desired implant location.²² Surgically, this may be achieved with an open, or closed technique. Indications and limitations of the closed technique will be discussed here. The tunnel, or closed technique is indicated for augmentation of narrow mandibular or maxillary anterior and posterior alveolar ridges.¹⁸⁻²¹

Complications

Complications associated with open approaches, including membrane exposure, and swelling that exposes the graft site and non-tension-free closure, to name a few, have led to the increase in use of the tunnel technique for most cases.²² The main surgical limitation of this approach is a lack of ridge visibility, localization of grafting material, and the requirement for delicate subperiosteal, indirect placement of a membrane that is properly sized (if used) and grafting material at the desired location.²³ It does, however, allow for completion in a clinical setting under local anesthesia, which minimizes patient morbidity.²⁰

Tunnel Technique

Advantages/Disadvantages

The tunnel technique is a minimally invasive procedure that has many advantages over open techniques. These advantages include superior outcomes with better preservation of keratinized gingiva, and decreased incidence of post-operative complications such as less surgery recovery time, bleeding, wound dehiscence, requirement for prolonged systemic antibiotic courses, postoperative visits, bone loss, and patient discomfort.^{22, 23} Disadvantages include poor localization and incorrect positioning of grafting material with subsequent diffusion into adjacent tissues (cited mainly at the anterior maxilla), inadequate ridge height achievement, and a lack of direct vision of the graft recipient site.²⁴

Post-operative

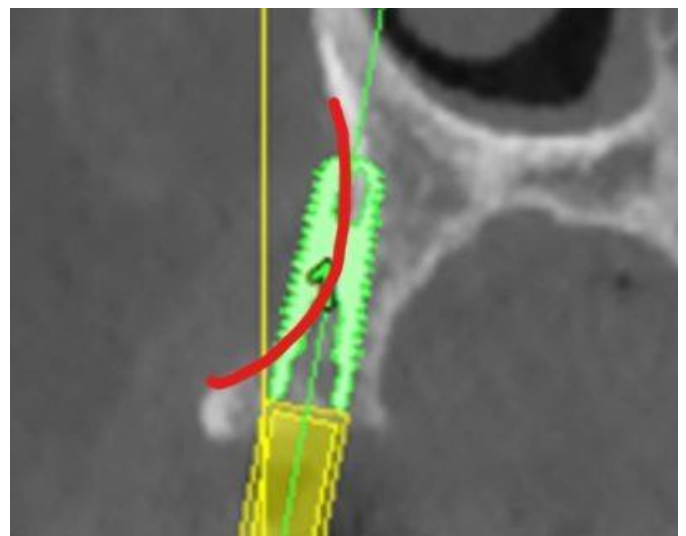
Post-operatively, patients are placed on antibiotics and analgesics.²⁰ Graft sites are left to heal free from all mechanical manipulation for 4-6 months.²² Cone-beam computed tomography is then obtained at the 6-month visit to allow graft site assessment for implant placement, which is typically 6-9 months after ridge augmentation.²² Patients may return for assessment 1 week, 1 month, and 6 months post-operatively, while some clinicians prefer 1 month, followed by 3-month interval follow-up visits.^{22, 23}

Technique

The tunnel technique is performed via a vertical incision made just inferior to the mucogingival margin approximately 1cm distal to, or at the mesial line angle of the tooth anterior to the proposed graft site.^{20, 22} A #7 or #9 periosteal or freer elevator is utilized for subperiosteal dissection to create a tunnel that is confined to the desired graft site.²² Care should be taken to avoid damage to surrounding vital structures. Subperiosteal dissection planes should not extend further than the external oblique ridge, or posteriorly

than the retromolar pad if the posterior mandibular alveolus is to be grafted.²⁰ Following the creation of the subperiosteal tunnel, graft material is carefully injected with a modified tuberculin syringe.²² (see Figure 6) The site is then closed with resorbable sutures and left for 4 to 6 months.²² No prosthesis, chewing, or manipulation of the site should ensue during this healing period.²⁰ Cone-beam computed tomography is obtained also during this range for assessment of integration.²² Implant placement proceeds 6 to 9 months post-placement of the graft.²⁰

Similar to the standard tunnel technique, the tunnel with membrane technique employs a bioresorbable membrane as an adjunct. The membrane functions as a means for physical containment of the grafting material, and to tent out dissected tissue in the subperiosteal plane.²⁰ After dissection, a soft surgical stent or foil from chromic gut suture packaging can be utilized to approximate tunnel size.²⁰ This guide is used to trim the bioresorbable membrane, which is then folded along its long axis, with the resulting convex portion positioned superiorly during insertion.²⁰ The membrane is advanced with cotton forceps, and results in a subperiosteal tunnel that is tented out.²⁰ Particulate grafting material can then be packed manually, and the site is closed with resorbable interrupted sutures and left for 4 to 6 months.²⁰ The follow-up course then follows that of the standard tunnel technique. **(Figures 5A-B, 6, 7A-B)**



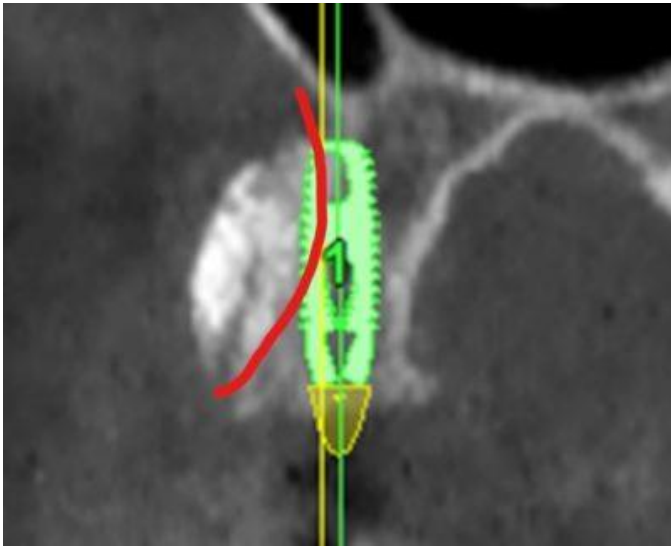


Figure 5: A (top), B (bottom), Pre and post horizontal ridge augmentation of the maxillary incisor region via tunnel technique.

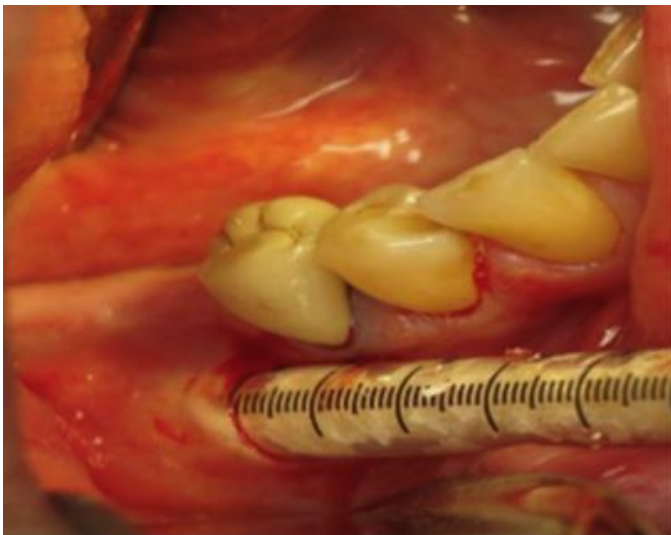


Figure 6: Graft material carefully is injected with a modified tuberculin syringe into the subperiosteal tunnel created.

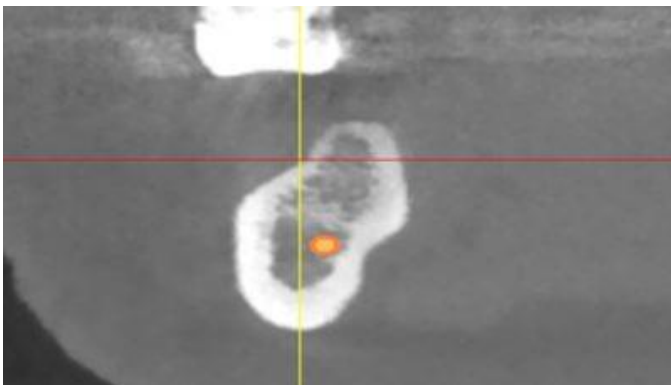


Figure 7: A (top), B (bottom), Pre and post horizontal ridge augmentation of the mandibular parasymphysis region via tunnel technique.

Tent Screw Pole Technique

In 1993, Fugazzotto reported on the use of titanium screws in combination with particulate allografts covered with Gore-Tex Augmentation Material to successfully increase the bucco-lingual dimension of an atrophic mandibular ridge prior to implant placement.²⁵ In 1994, Hempton and Fuguzzotto repeated the same technique, however, it was in combination with the use of an expanded polytetrafluoroethylene membrane with similar results.²⁶ The tent screw pole technique has since been continued to be used with high success rates for augmentation of atrophic ridges with minor alterations including the use of resorbable and non-resorbable membranes, and the use of demineralized freeze-dried bone allografts with particulate bovine-derived hydroxyapatite, to name a few.²⁵⁻²⁸ The use of membranes to contain particulate grafts has been shown to decrease site dehiscence, and to achieve greater graft consolidation, especially on flatter surfaces.^{27, 28}

The tent screw pole technique is indicated for augmentation of atrophic alveolar ridges with flat surface defects, although it has been successfully implemented for ridge

augmentation in all quadrants.^{27, 28} Additionally, "C" shaped defects commonly located at the anterior maxilla require careful placement with differing screw exposure lengths to follow the contour of the defect, which is more technically difficult to achieve.²⁷ (see Figure 8a) During placement at mandibular sites, release of the mylohyoid muscle from its attachment has been cited as a critical step to reducing dehiscence by decreasing tension during closure.²⁸ This technique, however, is limited surgically by the requirement for direct access for screw placement perpendicular to the apico-occlusal plane.^{25, 26, 28} This technique also is surgically limited considering anatomical variations of alveolar contours, and the requirement for shorter screws to not perforate the maxillary sinus.

As previously mentioned, the tent screw pole technique is better suited for flat surfaces compared to other augmentation techniques.²⁷ This is due to the addition of a membrane in combination with retention screws, which allows containment and localization of graft particles that otherwise could diffuse from the site.^{27, 28} Although it may still be used for augmentation of "C" shaped alveolar defects, the use of a lesser invasive technique that produces similar results is more beneficial, such as the tunneling technique.^{27, 28} Additional advantages to the tent pole technique are that it may be performed as an outpatient procedure minimizing cost and recovery for the patient, no second surgical site for obtaining graft or graft site morbidity, and a high success rate for large defect spanning one single missing tooth.²⁶⁻²⁸ **(Figures 8A-E)**

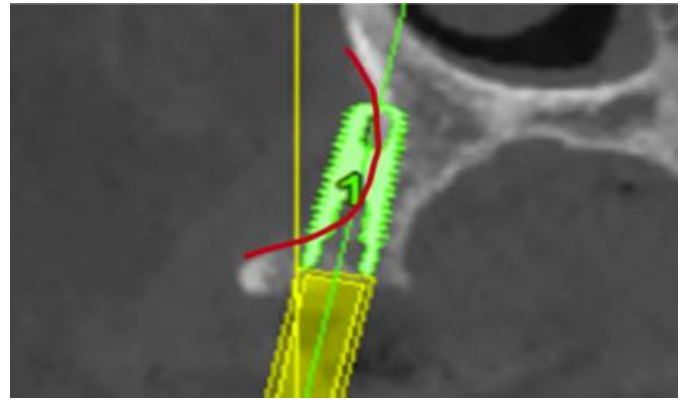


Figure 8A: Pre-op CBCT showing deficient maxillary alveolar ridge prior to augmentation using tent pole screw technique.



Figure 8B: Area of deficient maxillary alveolar ridge exposed.



Figure 8C: Tent screws are placed sufficiently apart in a vertical orientation to allow for tenting of mucosa.



Figure 8D: Bone graft particulate packed around screws.

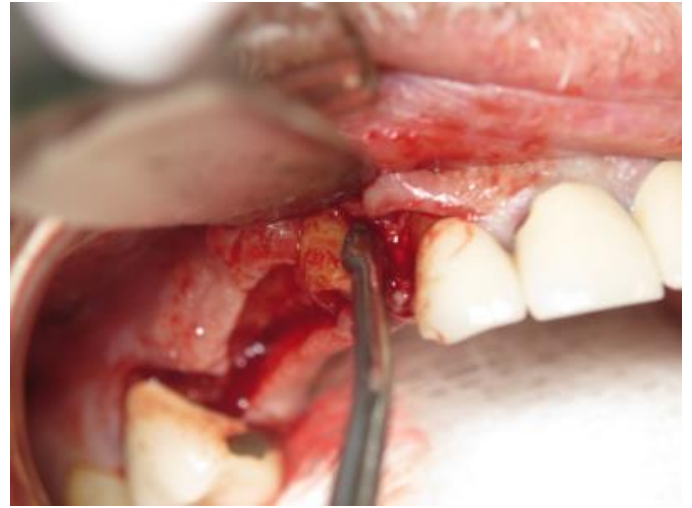


Figure 9B: Atraumatic technique utilized minimizing trauma to surrounding bone.



Figure 8E: Bioresorbable membrane placed to contain bone graft particulate.

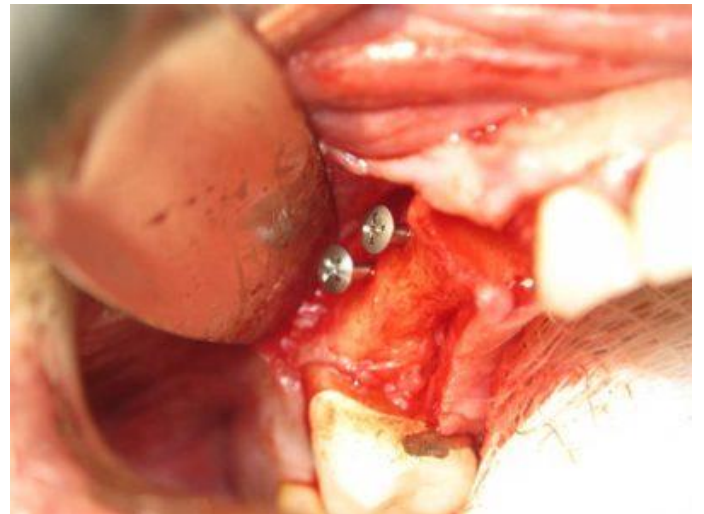


Figure 9C: Tent screws are placed sufficiently apart in a horizontal orientation to allow for tenting of the mucosa.



Figure 9A: Canine area to be augmented via tent screws.



Figure 9D: Bone graft particulate packed around screws.



Figure 9E: Area of previously grafted area exposed showing gain in alveolar width.

Disadvantages to this technique include the expense and complexity when compared to simpler, equally effective techniques that are better suited for certain situations, including “C” shaped defects.²⁷ The follow-up process also complicates this technique by requiring subsequent removal of non-resorbable membranes and screws typically 4 to 5 months after placement, prior to implant placement.^{27, 28} In cases spanning two or more missing teeth, Le et al described a greater risk for and higher incidences of wound dehiscence secondary to increased tension upon closure.²⁸

Following completion of the tent screw pole technique for ridge augmentation, patients may be placed on a five day antibiotic regimen with use of chlorhexidine mouth rinse for 10 days.²⁷ The graft site is allowed to heal for 4 to 5 months free of tension and mechanical stimulation from chewing and prosthesis

placement.²⁷ Cone-beam computed tomography may be utilized after this healing period to assess adequate graft consolidation, after which screws are removed, and implant placement is completed.²⁶

Ridge access for the tent screw pole technique is achieved via reflection of a full-thickness mucoperiosteal flap, facilitated by a crestal incision with vertical releases.²⁷ Reflection of soft tissue should be extended to expose the entire alveolar deficiency where grafting is planned, taking into account and avoiding vital structures. In the case of mandibular ridge augmentation, rate of dehiscence is decreased by releasing the mylohyoid muscle from its attachment.²⁸ The graft recipient site may be notched in preparation for screw placement. Titanium self-drilling screws are then placed in the alveolar ridge deficiency, perpendicular to the apico-occlusal plane.²⁵ (see Figure 8C) The amount of screw exposure depends on the alveolar deficiency, and on the amount of desired ridge width.²⁷ For example, Deeb et al. reported a high success rate of augmentation utilizing two to four broad head, polished neck 1.5mm wide tenting screws with a range of 3mm-6mm exposure in 35 patients.²⁷ After screw placement, particulate grafting material is carefully placed to fill the defect to the surface of the screws.²⁷ (see Figure 8D) Small particle size mineralized allograft material has been associated with a high success rate, and may be combined with particulate bovine hydroxyapatite.²⁶⁻²⁸ A Bio-resorbable or non-resorbable membrane may be placed overlying the graft site, and may or may not be fixed with retention screws as in an open procedure.²⁷ (see Figure 8E) In the case of the open polytetrafluoroethylene method, the graft site is covered with a fitted PTFE membrane and retained with tenting screws although this method has been reportedly associated with increased postoperative complications.²⁷ Tension free closure is facilitated by a periosteal release, and secured with sutures. Postoperative antibiotics are prescribed, and the graft is allowed to heal in the absence of mechanical stimulation from chewing or

prosthetic devices. Screws may be removed after 4 to 5 months, followed by implant placement given adequate consolidation of the graft.²⁸ The tent screw pole technique yields predictable results at 4 to 5 months and a low rate of infection, wound dehiscence, and loss of grafting material if tension free closure is obtained.^{27, 28}

Polytetrafluoroethylene Membrane Technique

The use of membranes for the healing of bone defects was first reported in the late 1950s and early 1960s for orthopedic procedures.^{29, 30} The application of barrier membranes for healing of defects in the oral cavity, however was examined by Nymann and Karring in the early 1980s, who demonstrated the efficacy of physical membrane barriers in preventing soft tissue ingrowth and competition of nonosteogenic cells.³¹ Schenk et al., then reaffirmed these findings by providing histologic explanations to the pattern and sequence of bone healing in association with barrier membranes in 1995.³² It was confirmed that there is a normal pattern of bone growth beneath expanded polytetrafluoroethylene (e-PTFE) membranes in the canine mandible that was histologically supported to be normal bone.³² The use of membrane barriers specifically for the purposes of lateral or horizontal ridge augmentations prior to implant placements was reported in 1988 by Buser et al.³³ This clinical study including ridge augmentation on 40 partially edentulous patients identified three main complications associated with use of a PTFE membrane. These included soft tissue dehiscence and membrane exposure, displacement of the membrane during closure, and collapse of the membrane during healing resulting in reduced volume of the graft.³⁴ It also was reported at this time that essential to success of a graft is implementing lateral releasing incisions to reduce tension during closure, using retention screws to maintain membrane integrity, obtaining adequate membrane adaptation to

surrounding bone, and utilizing autogenous bone to better support the membrane.²⁹

Polytetrafluoroethylene (PTFE) membranes are versatile in their use for ridge augmentations. They have been applied to block grafts with success as demonstrated by Buser et al., and utilized to successfully localize particulate grafts as demonstrated by Buser and Deeb et al.^{22, 34, 35} Buser et al., reported better outcomes when implementing vertical releasing incisions to decrease tension upon closure, and noted important surgical modifications to the GBR technique including adding miniscrews to support and maintain the membrane, and ensuring close adaptation of the membrane to surrounding bone.³⁴ Considering its higher degree of procedural complexity and cost when compared to alternative options for ridge augmentation, such as the tunneling technique, the use of PTFE might be more favorable in certain situations. This idea was proposed by Deeb et al., who compared the use of the open PTFE technique with the tunneling and tent screw pole techniques.²² Similar ridge width gains were reported between the standard tunnel and tunnel in combination with PTFE techniques at six months post-operatively.²² The addition of PTFE did however provide better results for augmentation of flat surfaces due to its ability to successfully localize and prevent migration of particulate grafting materials.²² It can therefore be assumed that the use of PTFE is better suited for horizontal augmentation of the posterior mandible and maxilla.

Buser et al., and Antoun et al., reported that membrane application consistently prevents ingrowth of soft tissue and leads to decreased resorption, thereby resulting in predictable width augmentation.^{34, 36} Specifically, both reported similar gains in mean augmentation of 3.6 mm and 3.7mm at 6 months in forty and five patients, respectively.^{34, 36} Buser identified three main benefits of membrane application including its function as a bioinert physical barrier to prevent soft tissue ingrowth,

its role in stabilization of graft and blood clot, and its ability to preserve the graft to minimize resorption.³⁴ Compared to seven augmentations performed with onlay grafts placed in the absence of a membrane, Antoun reported minimal complications and less resorption associated with the presence of a PTFE membrane in five patients.³⁶ He did however identify a major drawback being the time consumption associated with adaptation and placement of the e-PTFE membrane.³⁶ Similarly, Deeb et al., reported predictable and successful augmentation outcomes using an open PTFE technique, however with a higher incidence of post-operative complications including site dehiscence (52% incidence, 31 patients, $p = 0.0033$), graft loss (12%, 31 patients, $p = 0.0256$), more post-operative visits ($p = 0.0043$) and additional use of antibiotics ($p = 0.0017$) compared to the standard tunnel technique.²²

Patients are provided with post-operative antibiotics and chlorhexidine mouth-rinse for seven and ten days.^{22, 34, 36} Graft sites are allowed to heal free from tension and mechanical stimulation for 6 months, at which time they are evaluated for consolidation and stability via cone beam computed tomography (CBCT).²² Implants may then be placed, and restored after four months of integration.^{22, 36}

Expanded polytetrafluoroethylene (e-PTFE) membranes may be utilized in an open or closed manner for ridge augmentation. This technique is initiated by a full thickness crestal incision with vertical releases, followed by debridement of fibrous tissue from the proposed graft site.³⁴ A PTFE membrane is trimmed to fit the graft site, and secured on the palatal or lingual surface with one titanium screw.²² Particulate grafting material is then carefully packed at the site, and covered by folding the PTFE membrane over which is secured to the buccal or facial alveolar bone with two titanium screws.²² (see Figure 10C) A minimum of three titanium screws should be used to prevent lateral shifting of the

membrane.²² Post-operative antibiotics may be prescribed for 1 week, and extended in duration if infection develops.^{22, 36} The graft is allowed to heal free of all tension for 6 months, at which time the site is evaluated for graft consolidation via CBCT.^{22, 34} Titanium screws are removed at this time, and implant placement may proceed given graft consolidation and stability.^{22, 34-36} Implants are allowed to integrate for 4 months, and restored if stable.³⁶ **(Figure 10A-D)**



Figure 10A: Post exposure of alveolar deficiency. PTFE membrane has been outlined and palatal portion placed subperiosteally.



Figure 10B: Bone graft particulate placed.

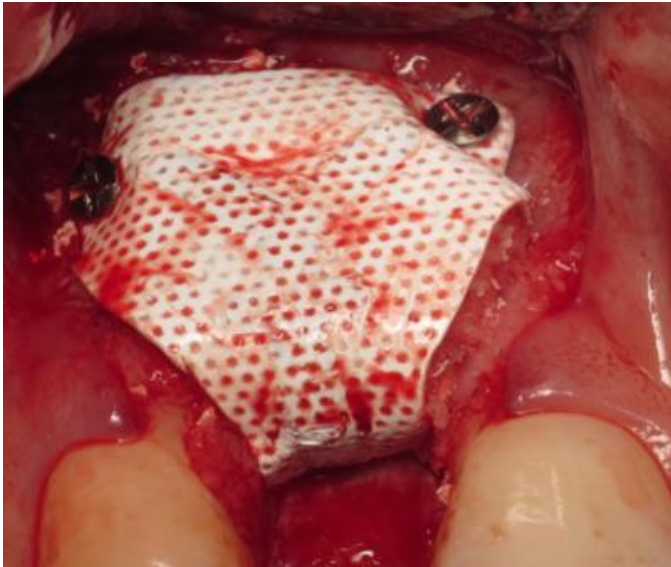


Figure 10C: PTFE membrane secured over the bone graft with 2 tracking miniscrews.

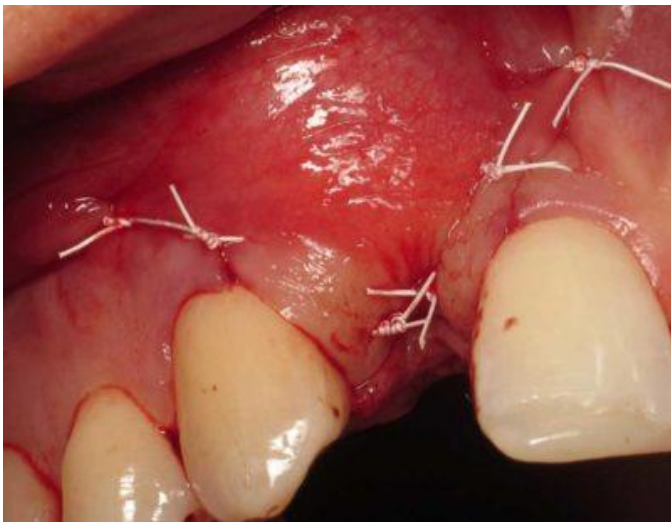


Figure 10D: Tensionless closure accomplished with the use of releasing incisions and PTFE interrupted sutures.

RAMUS GRAFT AND RAMUS GRAFT DURING THIRD MOLAR EXTRACTION

The use of autogenous grafts obtained from the ramus for the purpose of augmenting an atrophic ridge was described by Wood and Moore in 1988 as an alternative to decrease donor site morbidity, and procedural complications associated with procedures such as iliac crest grafts.³⁷ These grafts were placed without fixation, although rigid fixation to lateral ridges to obtain a greater horizontal dimension is common. Chacon et al., described

the use of resorbable screws for autogenous graft fixation in an animal model, reporting excellent graft stability.³⁸ Quereshy et al., compared resorbable vs. non-resorbable screw fixation and reported similar integration and survivability of graft sites.³⁹ Utilizing histologic and Cone-beam computed tomography examination, Spin-Neto et al. observed that the efficacy of autogenous ramus block grafts is superior to fresh-frozen allogenic block bone grafts, coinciding with the “gold standard” use of autogenous bone for onlay grafts.^{40, 41} The harvest of ramus bone can be performed as a standalone procedure, or utilized during third molar extraction. The combination of ramus grafts during third molar extraction is typically implemented for younger patients who have traumatically lost, or who were born with absent dentition since the need for augmentation typically coincides with the need for third molar removal.⁴² Alterations to both techniques include the addition of a membrane, or the combination of ramus graft with allogenic grafting materials to fill voids between the donor and recipient site, to name a few.⁴³

Ramus bone harvesting for onlay grafting prior to implant placement has been used with success to augment narrow or irregular anterior and posterior maxillary and mandibular ridges.³⁹⁻⁴² Little differences have been reported in terms of resorption and complications in any location, although the risk of damage to the neurovascular bundle does exist for both techniques.^{40, 41, 43} Ramus grafts are indicated for situations when the GBR technique cannot be used, and are ideal when used in combination with third molar removal given dual access to extraction and grafting site.⁴³ Ramus grafts require broad, intimate contact between the graft and recipient site to insure union.⁴² Obtaining this may be complicated by bony irregularities between the graft and recipient site (i.e. maxillary concavities), but may be achieved via graft or recipient site modifications or via the addition of an allograft and membrane.⁴³ Surgical limitations also include difficult access due to

patient positioning, a small vertical dimension of occlusion, and physiologic variations of neurovascular bundle positioning that may result in post-operative deficits.⁴² Following placement, Misch recommends a healing period of 4 months minimum for maxillary sites, and 5-6 months minimum for mandibular sites.⁴² The increase in healing time for mandibular sites is due to denser cortical bone and to insure union of the graft.⁴²

In terms of long-term stability, autogenic grafts have reportedly obtained superior results when compared to allogenic grafts. Spin-Neto et al., reported statistically significant differences in bone resorption, with allogenic grafts experiencing greater degrees of resorption at a 6-month follow up assessment of 26 patients (13 allogenic) via cone-beam computed tomography.⁴⁰ Autogenic grafts provide predictable increases in bone volume and are classified as the "gold standard" for ridge augmentation.³⁹ Ramus grafts are advantageous over allogenic and extraoral techniques for many reasons, including the absence of an extraoral scar, greater degrees of integration with less resorption, decreased proximity of donor and recipient site, decreased anesthesia time, shorter integration times and decreased incidence of donor site infection and postoperative complications when compared to extra-oral grafting techniques.⁴² Misch reported no increase in incidence of neurosensory deficits, infections, or alveolar osteitis associated with facial cortex osteotomies.⁴² With successful, tension-free closure dehiscence, infection, and graft exposure is minimal.⁴³ Potential disadvantages include damage to the neurovascular bundle if the osteotomy is extended to the inferior ramus below the level of the inferior alveolar canal.⁴²

Obtaining ramus grafts in the absence of third molar removal allows for extension higher on the ramus, where cortical bone is thicker. This provides bone widths of approximately 4mm, compared to reported widths of 2.7mm to

3.5mm when obtained in combination with third molar extraction.⁴³ Although considered "gold standard" for horizontal ridge augmentation, autogenic grafts do create an additional surgical site to obtain, whereas allogenic grafts do not. The creation of a second surgical site for autogenic graft may be justified, however by the significantly lesser degree of resorption.⁴⁰ Obtaining ramus grafts in combination with third molar removal is advantageous for younger patients with congenitally missing (mainly anterior) dentition or as a result of trauma. This is an ideal procedure when there is an unerupted or impacted mandibular third molar due to the dual access via one incision.⁴³ The need for ridge augmentation in younger patients typically coincides with the requirement for third molar removal, and combining these procedures decreases surgical procedures while combining access to both extraction and grafting site with one incision.⁴² Regardless of technique used, ramus grafts weaken the mandible at the site of the osteotomy, which increase the risk of post-operative fracture of the mandible.⁴²

Following placement of a ramus graft to recipient site, postoperative antibiotics are prescribed for a duration of 5 days while chlorhexidine mouth rinse is prescribed for a duration of 10 days.⁴³ Patients are allowed to heal for 4 months minimum for maxillary recipient sites and 5-6 months minimum for mandibular recipient sites.⁴² No removable prosthetics are to be placed during the healing period, and transmucosal pressures over the graft site should be minimized by avoiding chewing over the area.⁴² Implant placement is completed following CBCT assessment of graft union.

Recipient sites are first evaluated for proposed graft size and prepared via full thickness mucoperiosteal buccal or facial flaps over the crestal ridge and debridement of connective and granulation tissue.³⁹ The grafting site is accessed via an oblique-sagittal incision made distal to the third molar so as to follow the

contour of the ramus, and extended with the addition of a vertical releasing incision.³⁹ This releasing incision facilitates achievement of adequate reflection for direct visualization of the graft site.³⁹ Osteotomy of the desired onlay graft is completed with a fissure bur under copious irrigation at the anterior border of the ramus approximately 4mm mesial to the external oblique ridge. (see Figure 11A)

This osteotomy is made through the cortex, to the depth of bleeding bone, and may be extended to the distal aspect of the first molar.³⁹ Osteotomy width and height is dictated by desired graft size. The block is then green-stick fractured off with a spatula osteotome along the sagittal cut, followed by rounding of sharp corners and removal of the cancellous portion with a large round bur.³⁹ The block graft is trimmed to fit the recipient site to ensure broad, intimate contact.⁴³ Pilot holes are then placed through the graft and into the recipient site to the desired position. Fixation of the graft to the recipient site is achieved with either resorbable or non-resorbable screws.^{39, 42} Two screws minimum should be placed to reduce graft mobility.⁴³ (see Figure 11D, E) To ensure a flush surface and decrease irritation from screw heads, a round bur may be used to generate a countersink in the graft prior to screw placement.⁴³ (see Figure 11B) Voids or gaps between the graft and recipient interface may be filled with bone chips from the graft site, allogenic material, or may be compensated for by preparing the recipient site with a round bur.^{39, 43} Greater quantity of bone width may be obtained with the addition of a barrier membrane.⁴³ Attention should be shifted to ensuring tension free closure by scoring the periosteum at the flap base. No tension should remain at the base, medial/lateral aspects, or crestal positions of the flap. Postoperative antibiotics and chlorhexidine mouth rinse are prescribed, and patients are allowed to heal for 4 months minimum for maxillary recipient sites and 5-6 months minimum for mandibular recipient sites.⁴² Contact sports should be avoided for

approximately 8 weeks to avoid fracture at the osteotomy site.⁴² Implant placement is completed following CBCT assessment of graft union.^{39, 42, 43}

When combining third molar removal and ramus grafts, the recipient site is prepared in the same manner as the standard ramus graft technique. A full thickness mucoperiosteal envelope flap with a distal buccal or hockey stick release is utilized for impacted third molar exposure.⁴³ Anterior extension may be utilized to facilitate improved access and closure.⁴³ The ramus graft may be obtained before or after removal of a third molar based on surgeon preference. If the third molar is impacted, obtaining the ramus graft before removal may provide better access to the impacted dentition.⁴² Extraction of the third molar should be performed as atraumatically as possible. Proximal and distal osteotomies are performed at the lateral aspect of the ramus to desired size with a fissure bur under copious irrigation, and removed with an osteotome or dental elevator.⁴³ The graft is then placed at the recipient site in the same manner as the traditional ramus graft. Ramus grafting as a standalone procedure or in combination with third molar extraction prior to implant placement has provided excellent results with minimum graft resorption, sequestration, dehiscence, infection, and graft exposure.⁴³ **(Figure 11 A-H)**



Figure 11A: Obtaining ramus graft immediately after removal of third molar with minimal bone troughing.



Figure 11B: Shaping the bone block and creating a counter sink for the screw head.



Figure 11E: Particulate bone graft placed around the block grafts.



Figure 11C: Exposure of the maxillary alveolus to be grafted. Note the deficient lateral incisor regions.

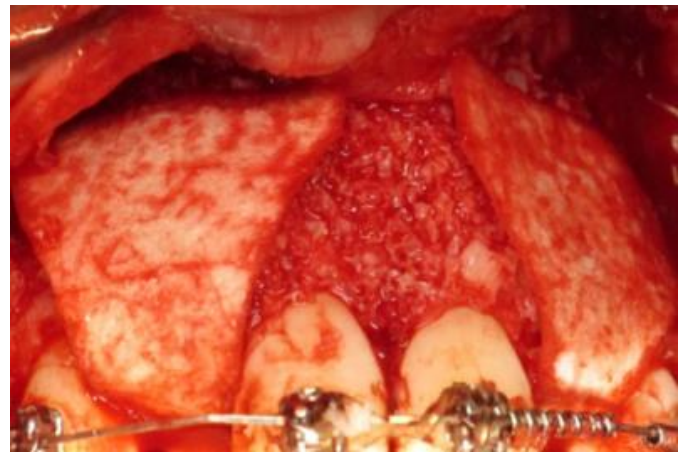


Figure 11F: Placement of bioresorbable membrane over the block grafts.

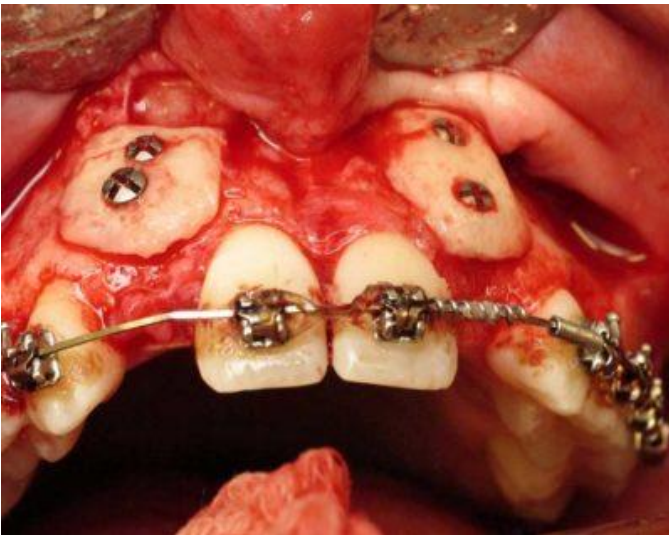


Figure 11D: Securing the grafted ramus block grafts with two miniscrews to avoid rotational movement of the graft. Note: it is recommended to place two screws even if there is sufficient immobility at time of graft placement obtained with one screw.



Figure 11G: Post closure with PTFE sutures.

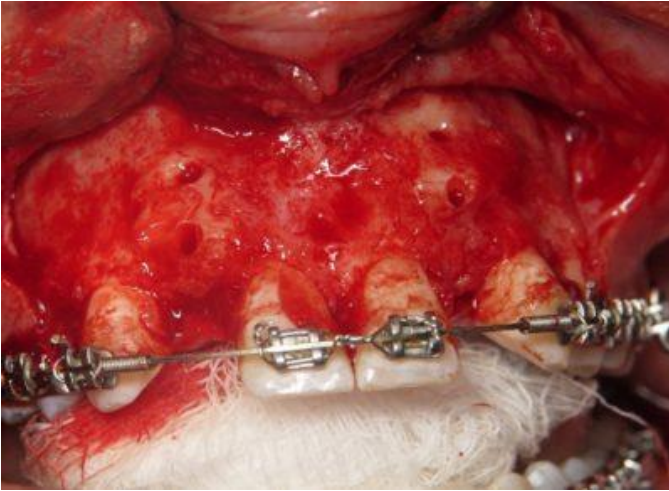


Figure 11H: Post exposure of the graft 4-6 months later. Note the gain in horizontal alveolar width.

TITANIUM MESH TECHNIQUE

The use of titanium mesh in oral and maxillofacial surgery was first utilized by Boyne to successfully reconstruct large maxillofacial discontinuity defects in 1969.⁴⁴ Malchiodi implemented the use of titanium mesh in 1998 for lateral ridge augmentation in 25 patients to combat a common problem associated with non-rigid membrane placement, which is subsequent collapse and decrease in augmented space.⁴⁵ An average of 5.20mm to 6.10mm in lateral gain was reported, along with failure of only 3 of 125 implants placed.⁴⁵ Histologic analysis indicated complete integration of autologous graft particles with surrounding bone, and no reported resorption of the grafting material.⁴⁵ Maiorana et al., reported similar findings in 2001 using iliac cancellous bone and anorganic bovine bone to augment atrophic maxillas in 14 patients.⁴⁶ Histologic examination of these sites showed the presence of vessels within regenerated bone, indicating graft integration and vitality.⁴⁶ Both previously mentioned studies resulted in successful implant placement with little resorption.^{45, 46} Her et al., also reported success using titanium mesh for ridge augmentation in 27 sites, and 100% integration of 69 implants at 6 to 24 month follow-up.⁴⁷

Titanium mesh should be used when there is a specific final ridge shape one is attempting to achieve for implant placement. For example, if there is a requirement for a curve to a lateral ridge, such as in the maxillary canine region, a titanium mesh would be beneficial since it can be shaped to follow the alveolar contours.⁴⁷ Its use is limited, however to regions with adequate keratinized soft tissue to obtain tension-free closure.⁴⁷

Disadvantages to using titanium mesh include its requirement to be removed along with its screws, which exposes patients to more surgical procedures compared to augmentations performed with bioresorbable membranes.^{46, 47} This method also requires adequate presence of keratinized tissue that is thick and wide enough to provide tension-free closure and prevent wound dehiscence.⁴⁷ This would decrease one's ability to achieve tension-free closure in regions where there is insufficient soft tissue, and would predispose the wound to dehiscing.⁴⁷ Her et al., reported the presence of 1-2mm of soft tissue over augmented sites that may be removed at the time of implant placement. In the event that this soft tissue is not completely removed, however, implant placement and positioning in relation to final restoration emergence profile may be skewed.

Advantages of titanium mesh include reportedly less exposure rates, the ability to custom mold a desired augmentation, and its wide application for any shape defect.⁴⁴⁻⁴⁷ Since it is able to be adjusted to fit any shape, titanium mesh may be applied in any location with success.^{45, 47, 48} Additionally, there is the ability to treat post-operative mesh exposures by trimming the mesh in the affected area and allowing that region to re-mucosalize as opposed to possible complete removal of e-PTFE membranes.⁴⁷ Her et al., reported that the mesh present in the titanium allows faster than previously believed migration and growth of osteogenic cells,

possibly due to its effect of increased blood clot stabilization.⁴⁷

After placement, titanium mesh barriers are left to heal for 4-7 months along with an initial post-operative course of antibiotics.⁴⁷ If there is dehiscence and mesh exposure, it may be trimmed at 2mm from the exposure margins with a round burr as described by Her et al.⁴⁷ Trimming the mesh facilitates closure, and doesn't greatly affect augmentation outcomes.^{44, 45, 47}

The titanium mesh technique is initiated by reflecting a full thickness mucoperiosteal flap with vertical releasing incisions. The recipient site is prepared by debriding fibrous tissue, and perforating the recipient cortex multiple times with a round burr until bleeding is reached.⁴⁷ Titanium mesh is then fit to the site and formed to define a desired width.⁴⁷ (see Figure 12B) Placement of grafting material may proceed, as Her et al., described, in two manners: placement of particulate graft followed by fixation of the titanium mesh with retention screws, or fixation of the titanium mesh with retention screws followed by placement of particulate graft via a "trap door" which is then also secured with a retention screw.⁴⁷ Tension-free closure is obtained with apical undermining, or possible graft repositioning with split thickness periosteal releasing incisions.⁴⁷ Grafts are left to heal for a range of 4-7 months, after which the titanium screws and mesh are removed and implants placed.^{45, 47, 48} (see Figure 12D) If there's a layer of soft tissue overlying augmented hard tissue, it also may be removed at the time of implant placement.⁴⁷ The use of titanium mesh for ridge augmentation has provided excellent results with minimal complications. **(Figure 12A-D)**

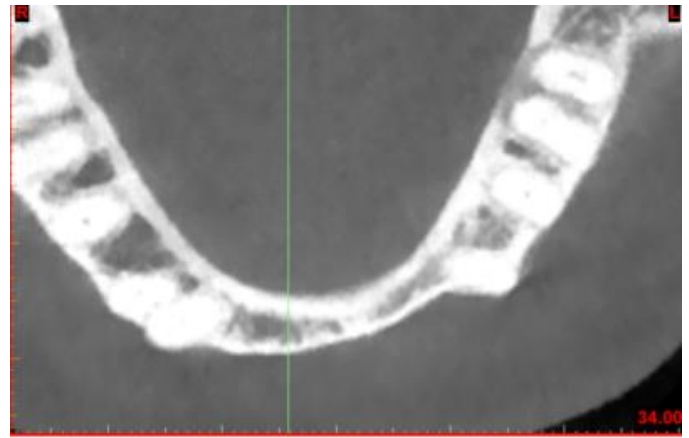


Figure 12A: Pre-op CBCT axial view showing deficient alveolar ridge in the anterior mandible in need of augmentation.

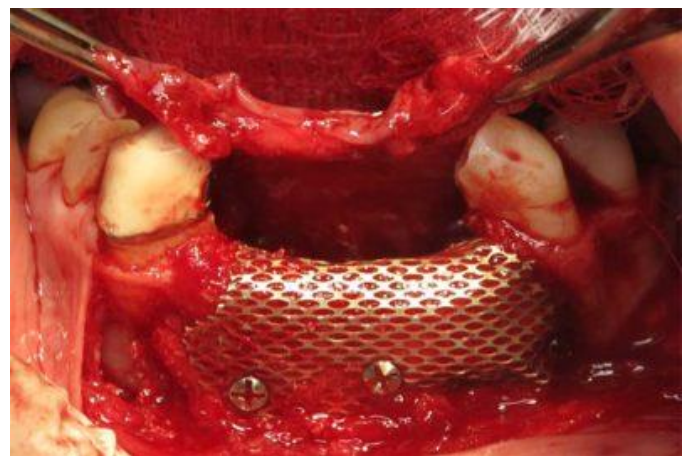


Figure 12B: Placement of bone graft particulate contained in place with use of titanium mesh. Titanium mesh is secured with the use of miniscrews.

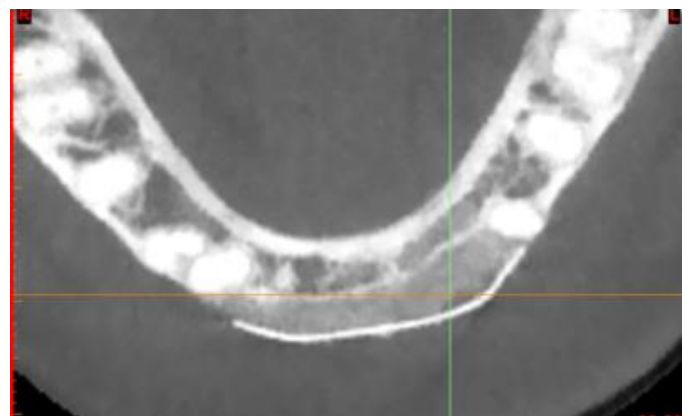


Figure 12C: Post-op CBCT axial view showing augmented alveolar ridge and titanium mesh in place.



Figure 12D: Augmented alveolar ridge post titanium mesh use.

RIDGE SPLIT TECHNIQUE

The concept of gaining horizontal bony mass of atrophic maxillary and mandibular ridges through expansion of buccal/facial and lingual/palatal cortical plates was first applied by Tatum in the 1970s.⁴⁹ This was accomplished with the use of a root form Omni implant system that functioned with utilization of tapered channel formers and D-shaped osteotomes that expanded atrophic alveolar ridges.⁵⁰ This concept was advanced by Simion in 1992, who reported successful ridge width gains and successful immediate implant placement following establishment of a longitudinal green-stick fracture in the alveolar ridge.⁵¹ This green-stick fracture technique yielded gains of 1mm-4mm, with greater gains reported in the maxilla.⁵¹ Modifications to the ridge split technique were established throughout the 1990s and well into the 21st Century. Pikos, for example reported use of a closed flap during ridge splitting 1992, while Scipioni reported the use of partial thickness flaps in 1994 to preserve periosteum and therefore maintain alveolar bone blood supply.^{50, 52} The latter clinical study implemented a large sample size and longer follow-up visits that yielded results indicating a high success rate of implant survival, solidifying the use of partial thickness flaps during ridge splitting.^{50, 52}

This was further supported by Brushi et al., who reported a 95.7% success rate in 490 posterior maxillary implants utilizing a similar technique with a partial thickness flap.⁵³ Additional alterations include grafting the split alveolar ridges as demonstrated by Smiler's "sandwich technique," Vercellottis use of piezosurgery and platelet-rich plasma, and Blus and Szmukler-Moncier's use of ultra-sonic surgery for ridge splitting, to name a few.⁵⁰

The ridge split technique has been described as the most surgically complex and technique sensitive method for horizontal ridge augmentation by many.^{50, 54, 55} Tolstunov describes five surgical principles that are essential to the ridge-split procedure, including utilization and maintenance of a vascular bone flap, placement of particulate grafts in a "sandwich" manner (if needed), establishment of osteo-mobilization between split cortical plates, recognizing differences between maxillary and mandibular bone densities, and recognizing osteo-condensation that can contribute to increase implant survival and osteo-integration.⁵⁰ Although success has been obtained with placement in both the maxilla and mandible for single or multiple missing teeth or complete edentulous ridges, Bravi et al., demonstrated site and technique specific outcomes by analyzing data from 1,715 implants that were placed using the ridge split technique.⁵⁶ This study noted that 60 of the 73 reported implant failures were located in the posterior maxilla.⁵⁶ It was concluded that implants placed at the anterior and posterior maxilla have a decreased survival rate due to poor bone quality and a decreased level of primary implant stability.⁵⁶ Additional pertinent findings were reported by Bravi, including decreased failure rates associated with tapered compared to parallel implants, and increased failure rates associated with implants wider than 4mm or shorter than 15mm.⁵⁶ The ridge split technique is best suited, as described by Tolstunov, for ridges that have experienced mild-to-moderate resorption of medullary bone.⁵⁰ This is in contrast to ridges that have previously experienced complete loss of

cancellous bone secondary to traumatic odontectomies and subsequent bone avulsion.⁵⁰ With this in mind, Tolstunov explains ridge parameters that favor use of the ridge split technique, including alveolar thickness of 3mm to 5mm for the experienced surgeon, and 4mm to 5mm for the novice surgeon.⁵⁰ The ridge split technique also may be used for ridges of adequate width, however, that require expansion of an associated labial concavity that poses esthetic concerns following implant placement.⁵⁰ Due to differences in bone density, the ridge split surgical technique differs between the maxilla and the mandible, which will be discussed shortly. Additionally, there are two approaches to this technique, including the one- and two-staged alveolar ridge split procedures.

Advantages of the Ridge Split Technique

The main advantage of the ridge split technique is the high degree of success in horizontal ridge augmentation associated with proper execution.^{54, 55} It is a versatile technique that may be performed as a single- or two-staged approach with multiple modifications available for each. The single-stage approach is beneficial when adequate buccal cortical bone is available (minimum 1.5-2mm thick) to minimize plate fracture.⁵⁰ As articulated by Bravi's review of 1,715 implants placed using the ridge split technique and followed over a 10 year period, there are few complications, and the majority of which were associated with implants placed at the posterior maxilla.⁵⁶ Another advantage of the ridge split technique is that tension-free closure is not a requirement, unlike the majority of alternative horizontal ridge augmenting techniques, to achieve favorable outcomes. Tolstunov explains that "healing by secondary intention is emphasized" in the ridge split technique due to volume expansion that essentially inhibits tension-free closure.⁵⁰ As previously stated here and extensively demonstrated during its evolution the horizontal ridge width gains, wide application,

and few complications associated with the ridge split technique make it an excellent choice for augmenting the atrophic maxillary or mandibular alveolar ridge.

Disadvantages of the Ridge Split Technique

The main disadvantage of the ridge split technique is the technical sensitivity associated with successful establishment of a corticotomy, and management of the associated buccal plate.⁵⁰ The overzealous or inexperienced surgeon can fracture the buccal plate during expansion, or compromise its only blood supply by stripping the periosteum during second-stage surgery. These complications would result in unequal ridge expansion, and cause bony irregularities that may prevent implant placement.⁵⁰ Additionally, it could be challenging to achieve a minimum cortical plate thickness of 1.5mm, as Scipioni proposed, in ridges that are <5mm thick.⁵² During single-stage ridge augmentation, it also can be challenging to maintain a partial-thickness or limited full-thickness open flap without completely fracturing the buccal plate, resulting in compromised periosteum integrity and subsequent necrosis of the fragment.⁵⁰ Lastly, consideration must be given to implant width so as to not over-expand the alveolar ridge leading to fracture, and implant length to achieve adequate primary stability in the presence of a mobilized buccal plate (in the case of single-stage placement).⁵⁰ Complications with the latter may be minimized by placing mini-screws to aid in buccal plate immobilization.⁵⁰

Following completion of the single-stage technique, patients are instructed to complete a 5 to 7 day course of antibiotics and Chlorhexidine mouth rise.⁵⁰ However, after first stage of the two-stage approach, patients are instructed to implement a 2-3 day post-op use of Chlorhexidine mouth rinse only.^{50, 54, 55} Following the first stage of a two staged alveolar ridge split approach, patients are

returned 4 to 5 weeks for the second stage procedure, which includes splitting and grafting of the previously placed corticotomies.⁵⁰ Tolstunov recommends use of post-operative antibiotics following this stage, which includes a five-day antibiotic regimen of amoxicillin (500mg) or clindamycin (300mg) three times a day.⁵⁰ Assessment of the widened alveolar ridge proceeds 4 to 6 months post-single stage surgery or post-second stage of the two stage surgery via CBCT interpretation, at which time implants may also be placed.^{50, 54, 55} In cases where a non-resorbable membrane was placed, patients may be returned ideally 2 to 3 weeks post-placement for removal.⁵⁰

Single Stage Approach to the Ridge Split Technique

The single-stage approach to the ridge split technique is initiated with a mid-crestal incision extended to the alveolar ridge crest, and maintenance of the buccal periosteum.⁵⁰ The latter, for example may be achieved with use of a partial thickness flap, or a limited open full-thickness flap.⁵⁰ No corticotomies are utilized for the single-stage approach.⁵⁰ This is followed by splitting and expanding the alveolar ridge using a series of chisel osteotomes that are tapped into the bone to create progressive buccal plate expansion and displacement.⁵⁰ (see Figure 13AB) Care must be taken here to not fracture the buccal plate, disrupt the periosteum, or perforate vital structures (i.e. the maxillary sinus, inferior alveolar nerve canal, or mental nerve).⁵⁰ In the case of maxillary augmentation, osteotomes should be utilized in a parallel spatial orientation in relation to the palatal cortical plate to minimize buccal thinning or unfavorable fracture.⁵⁰ These complications also may be minimized with use of a piezoelectric tip or small saw to lengthen the buccal plate toward adjacent dentition (if present), in the oblique direction.⁵⁰ The result of cortical plate expansion should yield a muco-osteoperiosteal flap including the buccal plate, its intact periosteum and overlying

gingival mucosa.⁵⁰ This ensures maintenance of a blood source to the buccal plate, and aids in preventing necrosis of the plate.^{50, 55} The site may then be grafted with the surgeons preferred material.^{50, 55} In longer alveolar ridges, the use of fixation pins or retention screws prior to grafting aids in preventing collapse of the expanded buccal plate.⁵⁰ A bio-resorbable, or non-resorbable membrane is implemented for particulate graft retention.^{50, 54, 55} The site is then allowed to heal via secondary intention, or may be closed if primary closure is obtainable.⁵⁰ Follow-up proceeds as previously discussed.

The two-stage approach to the ridge split technique is initiated with a mid-crestal incision extended to the alveolar ridge similar to the single-stage approach described above, however with reflection of full-thickness mucoperiosteal buccal flap with vertical releasing incisions.⁵⁰ Two vertical and two horizontal connecting peripheral corticotomies extending through the cortex and to bleeding medullary bone are performed with either a thin fissure bur, or piezoelectric tips to create a rectangular door-shaped buccal outline.^{50, 54} Apical horizontal corticotomies are placed at a distance of 8mm to 12mm from the alveolar crest.^{50, 54} Once corticotomies are completed, the buccal flap is repositioned and the first stage is considered complete. The patient is then returned 4 to 5 weeks after, and stage 2 is initiated.⁵⁰ Site exposure is achieved via minimal reflection of a closed full-thickness flap, or a split-thickness flap with vertical incisions similar to that of the single-stage approach. Extreme care should be taken to preserve the overlying buccal plate periosteum at this point.⁵⁰ The previously placed crestal corticotomy is then localized, which is where use of chisel osteotomes is performed as in the single-stage approach. Placement of tapered implants is then performed at 4-6 months post-second stage, and restored 4 months after.⁵⁴ The ridge split method, although very technique sensitive has a good rate of success, and a low rate of complications and drawbacks including low graft and implant failure, good

long-term stability, and a low rate of infection. (**Figure 13A-F**)

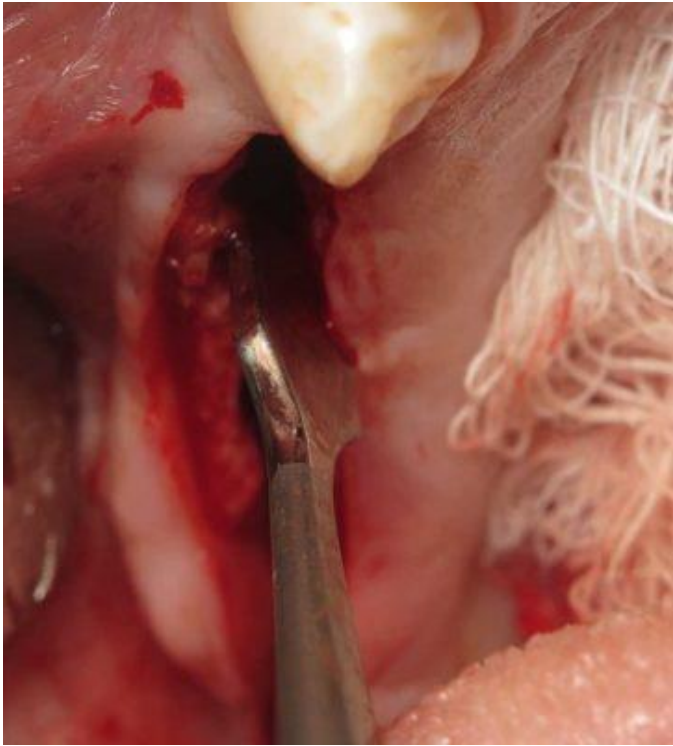


Figure 13A: Separated cortical plates of the alveolar ridge divided by the ridge-split procedure.

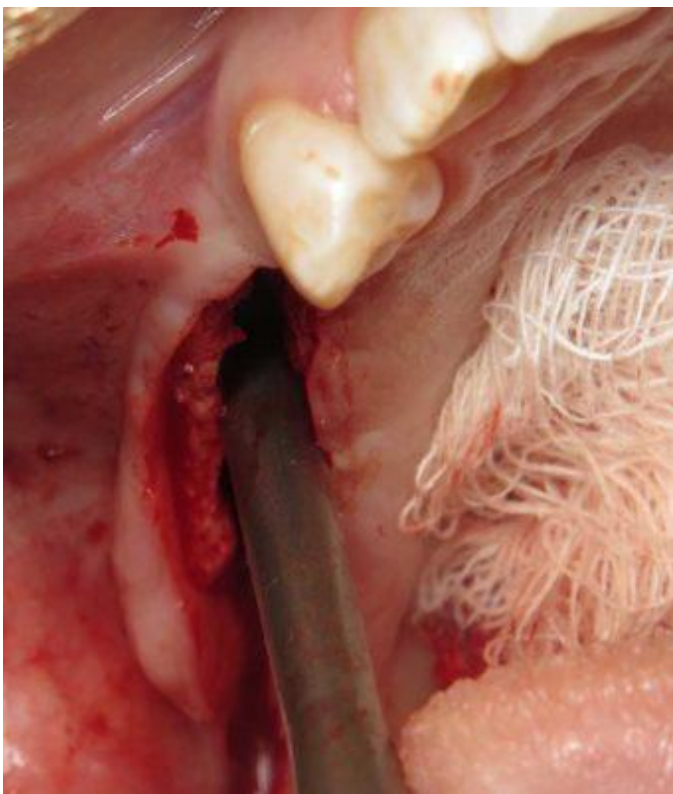


Figure 13B: Progressive tapping with chisel osteotomes creating a "greenstick" fracture of the alveolar ridge.

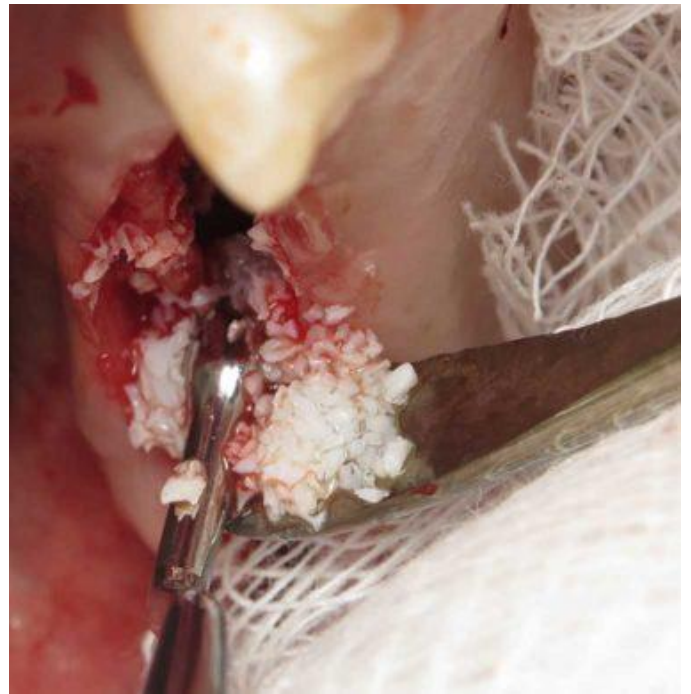


Figure 13C: Packing of bone material into the divided ridge in a bottom-up fashion with light compression until completely filled.

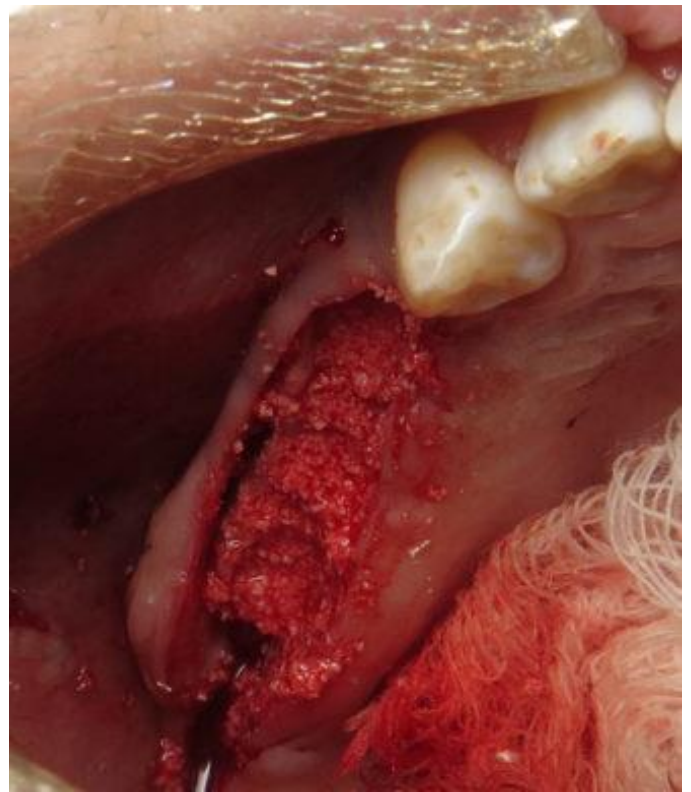


Figure 13D: Packing of bone material into the divided ridge in a bottom-up fashion with light compression until completely filled.

CONCLUSION

"Share your smile with the world. It's a symbol of friendship and peace." Christie Brinkley

For many individuals their smile is a unique feature that distinguishes them from those around them. When a patient undergoes tooth extraction there are physical changes that occur to the socket. This event, however, may be associated with significant emotional distress to the patient. Reconstructing a patient's smile begins with reconstruction of the alveolus. It is important to restore the alveolus to its near pre-op condition in order to be able to withstand the mechanical stresses brought about by an implant prosthesis.

Alveolar bone deficit often has a substantial horizontal element of bone loss. Many techniques are present in the literature to help augment the alveolar ridge. We focused on horizontal ridge augmentation which can be grouped into two main categories. **(Table 1)**

Closed Techniques	Open Techniques
Tunnel	Tent Screw Pole
Tunnel with a membrane	PTFE
	Ramus Graft
	Ramus Graft in Conjunction with Third Molar Removal
	Titanium Mesh
	Ridge Split

Table 1: Techniques used to augment the alveolar ridge.

Alveolar bone augmentation and concurrent implant surgery procedures allow clinicians to reconstruct alveolar bone deficiencies,



Figure 13E: The placement of a bioresorbable membrane after bone grafting.



Figure 13F: Closure via secondary intention with 3.0 or 4.0 chromic suture.

preserve the three dimensional structure of the alveolar socket, and to replace missing teeth with implant prostheses in a prosthetically driven position with natural appearance and function. In order to obtain a predictable outcome one must follow certain rules to maximize the desired biologic result. The importance of diagnosis and treatment planning cannot be over emphasized. A careful clinical, radiologic and systemic review of the patient must occur in order to maximize success and decrease the potential for failure. We presented some of the most commonly accepted and utilized methods. All methods are reasonable and have shown acceptable success rates. These methods need to be dictated by surgeon experience and patient selection.

No matter what part of the body is to be reconstructed it should begin with accurate diagnosis followed by thoughtful treatment planning, leading to near perfect execution of the surgical treatment. In addition, postoperative follow-up, and appropriate implant loading are all important factors that lead to success of the proposed and executed treatment.

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