An Updated Decision Tree for Horizontal Ridge Augmentation: A Narrative Review

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Horizontal ridge augmentation is a common surgical procedure performed prior to or simultaneously with implant placement, depending on the extent of the ridge deficiency. Many horizontal augmentation surgical options have been developed, spanning a wide range of materials and techniques. Given the numerous permutations available, the most suitable strategy to regenerate ridge width for an individual case often confounds clinicians. Based on an extensive review of the literature, this article provides up-to-date technique selection guidelines, in the form of a decision tree, for predictable horizontal bone augmentation dependent on the amount of bone gain needed. Int J Periodontics Restorative Dent 2022;42:341–349. doi: 10.11607/prd.5031

Bone remodeling inevitably occurs after tooth extraction and may result in the loss of enough alveolar ridge volume to complicate future implant placement. Ridge augmentation techniques are frequently needed to prepare deficient edentulous sites for implant placement. There has been a steady outpouring of research into materials and methods for implant site development, and a large variety of augmentation procedures have been proposed to regenerate bone horizontally. As the combinatorial options for grafting seem infinite, clinicians require up-to-date, evidence-based guidelines to help them select the most appropriate surgical protocol for each patient. To address this need, the present authors analyzed pertinent literature to revise and validate their previously published decision tree addressing horizontal ridge augmentation; the previous guidelines selected therapy based on the available buccolingual bone width at the edentulous site (> 3.5 mm, < 3.5 mm, or 4.0 to 5.0 mm). This newly revised decision tree selects a regenerative technique based on the amount of horizontal bone gain desired (< 3.0 mm, 3.0 to 6.0 mm, or ≥ 6.0 mm) that fits what clinicians intended to accomplish for the regeneration. This is also in line with how most published articles tend to quantify bone gain rather than...
presenting the ridge width. With the development of this decision tree, the authors aim to assist clinicians, as straightforward as possible, in choosing an optimal surgical approach for horizontal bone augmentation (Fig 1).

The Decision Tree

Ridge Deficiency

Minor ridge deficiency: < 3.0 mm of horizontal bone augmentation required

For ridges requiring < 3 mm of augmentation, a variety of treatment approaches can be performed to achieve predictable bone gain: guided bone regeneration (GBR), protected bone augmentation with titanium mesh, autogenous or allogenic block grafting, ridge splitting, and subperiosteal tunneling. Alternatively, the practitioner may opt to place a smaller-diameter implant to avoid bone augmentation entirely. Depending on the surgeon’s experience level, either simultaneous horizontal bone augmentation with implant placement or delayed implantation following bone grafting can be predictably performed (Fig 1). Figure 2 presents a case of implant placement with simultaneous horizontal bone augmentation (< 3 mm) of a ridge deficiency.

Moderate ridge deficiency: 3.0 to 6.0 mm of horizontal bone augmentation required

Sites that require 3.0 to 6.0 mm of horizontal bone augmentation can be predictably reconstructed with GBR, protected bone augmentation with a titanium mesh, block graft, or ridge splitting. A subperiosteal tunnel surgical design may not be a viable option in this category based upon current evidence (Fig 1). Figure 3 presents a case requiring moderate lateral ridge augmentation that was treated with GBR and delayed implant placement.

Severe ridge deficiency: ≥ 6.0 mm of horizontal bone augmentation required

Sites that require at least 6 mm of horizontal bone gain may be treated reliably with one of three options: GBR, protected bone augmentation with a titanium mesh, or block grafting. Proposed treatments such as ridge splitting or subperiosteal tunneling are not predictable enough for rebuilding a large volume of bone, based on current evidence (Fig 1). Figure 4 presents a case that required extensive ridge augmentation with GBR, utilizing particulate allograft and a titanium-reinforced dense polytetrafluoroethylene (d-PTFE) membrane, which was chosen for its enhanced space-creating ability.

Review of Treatment Modalities and Literature

GBR and protected bone augmentation

GBR utilizes membranes (nonresorbable or resorbable) in conjunction with bone fill materials (autograft, allograft, xenograft, or alloplast) to promote cell occlusivity, create a protected space for augmentation, and encourage osteogenesis. It is based on the principles of guided tissue regeneration, which was first described by Nyman et al in 1980. GBR capitalizes on the different cell migration rates of nonosteogenic and osteogenic cells; it compartmentalizes the rapidly migrating epithelial and connective tissue cells from the targeted bone regeneration area with an occlusive membrane, allowing the slower-migrating osteogenic cells to populate the surgically created space. In a rat model, Dahlin et al performed GBR using PTFE membranes and demonstrated complete bone healing after 6 weeks. In 12 patients, Buser et al employed GBR using nonresorbable expanded PTFE (e-PTFE) membranes and observed 1.5 to 5.5 mm of new bone formation after a healing period of 6 to 10 months. Despite their success in bone regeneration, nonresorbable membranes have two major disadvantages: They require surgical retrieval after healing and tend to have a higher rate of membrane exposure, leading to potential infection and graft failure. Resorbable membranes, typically made from collagen, were formulated to tackle these concerns. Zitzmann et al compared resorbable collagen membranes to e-PTFE barriers for the treatment of exposed threads in simultaneous implant placement and GBR cases. The average bone fill was 92% for the collagen membrane group and 78% for the e-PTFE group.

A systematic review of simultaneous implant placement with GBR reported an average width gain...
Fig 1 A proposed surgical decision tree for horizontal bone augmentation based upon the amount of bone gain needed (< 3.0 mm, 3.0 to 6.0 mm, and ≥ 6.0 mm). GBR = guided bone regeneration; d-PTFE = dense polytetrafluoroethylene.
Fig 2  Implant placement with simultaneous GBR in a case requiring minor ridge augmentation (< 3 mm) at the mandibular left side. (a) The occlusal view of the edentulous site showed a minor buccal concavity. (b) The relationship between the buccal concavity and the implant was noted immediately after placement. (c) The alveolar defect was grafted with allogenic particulate bone (inner layer: cancellous bone allograft; outer layer: cortical bone allograft) and covered with a pericardium membrane. (d) Occlusal view of the site 6 months postaugmentation. Buccal bone regeneration was seen upon flap reflection of the healed site. (e) Occlusal and (f) radiographic views at 7 years posttreatment.

Fig 3  GBR was performed using a resorbable membrane with delayed implant placement in a case necessitating moderate horizontal bone augmentation (3.0 to 6.0 mm) at the maxillary right side. (a) Flap elevation of the site revealed a buccal concavity and limited ridge width; a hopeless second molar was extracted at this time. (b) The ridge was grafted with cortical particulate allograft. (c) The bone graft was covered with a pericardium membrane, and the site was secured with chromic gut sutures. (d) Five months posthealing, implants were placed into the wide regenerated ridge.
of 2.7 mm (95% CI: 2.3, 3.0) and a maximum width gain of 5.7 mm (95% CI: 4.69, 6.68) using a combination of bioabsorbable membrane, particulate xenograft, and bone morphogenetic protein. Another systematic review on GBR found an overall weighted mean horizontal bone gain of 3.7 ± 1.2 mm. The horizontal gain was significantly higher for mixtures of autogenous bone with allogeneic or xenogeneic grafts (4.5 ± 1.0 mm) compared to those using synthetic materials alone (2.2 ± 1.2 mm). Wessing et al published a systematic review evaluating GBR with or without simultaneous implant placement and noted an overall mean horizontal bone gain of 2.27 ± 1.68 mm, regardless of the type of bone graft used. Based on these findings, GBR may be performed predictably at the time of implant placement when the ridge needs only minor augmentation (3 mm); this would reduce the overall treatment time and be more acceptable to the patient. Use of a resorbable membrane avoids the need for a second surgery, and it could be applied along with autogenous, allogeneic, or xenogeneic grafts (or a combination thereof), as there are no appreciable differences in efficacy between those materials. An alloplast, however, might result in less bone gain because of its faster resorption rate compared to other grafts.

A systematic review determined that the average width gain from staged horizontal bone augmentation (ie, delayed implant placement) was 3.90 mm (95% CI: 3.52, 4.28). A greater gain in bone width, close to 6 mm, was recorded by Urban et al after staged GBR. In their first case series, Urban et al treated defects with synthetic resorbable membranes overlying particulate autogenous bone with or without anorganic bovine bone-derived mineral; this method yielded an average bone gain of 5.6 ± 1.5 mm, and histologic analysis showed new bone formation intermixed with bovine bone mineral particles. The authors’ later case series followed patients treated with collagen membranes and a combination of particulate autogenous and xenogeneic bone grafts, and this protocol generated an average augmentation width of 5.7 ± 1.4 mm after a 9-month healing period.

Titanium mesh is another material commonly used for bone augmentation, as its rigidity allows it to maintain space extremely well. The mesh is designed with noticeably large pores (in the millimeter range) to allow for adequate blood supply to the underlying graft and therefore is not cell occlusive. Although it is used in the same manner as a membrane for space creation, a titanium mesh does not meet the criteria for GBR, which must involve the physical separation of fast-moving epithelial cells from slower-migrating osteoprogenitor cells (compartmentalization). Ridge reconstruction with a titanium mesh is considered as “protected bone augmentation” rather than GBR. Protected bone augmentation using titanium mesh appears to augment bone laterally by about 4 to 6 mm. Malchiodi et al reported data from 25 patients who received titanium mesh—driven horizontal augmentation, and the average gain in bone width was 5.65 mm (range: 5.20 to 6.10 mm). Troeltzsch et al observed that titanium mesh improved space-making compared to collagen membranes, resulting in an additional 1 mm of width augmentation (4.5-mm mean horizontal bone gain for the titanium mesh group vs 3.5 mm for the collagen membrane group). Another systematic review indicated similar results, showing an average width gain of 4.5 mm when titanium meshes were combined with autogenous and xenogeneic bone grafts.

Per the present analysis, staged GBR or protected bone augmentation with titanium meshes may be predictable approaches for cases that require up to 6 mm of horizontal bone augmentation. Moreover, when longer-lasting materials (such as xenografts) are combined with the grafting material and improved space-making devices (such as titanium-reinforced d-PTFE membranes), either technique could be used to grow 6 mm of bone (Fig 4).

**Block Grafting**

Block grafts have autogenous, allogeneic, or xenogeneic origins. Autogenous block grafts can be harvested from intraoral or extraoral sites. Common intraoral donor sites include the mandibular symphysis, the mandibular ramus, and the maxillary tuberosity. Extraoral donor sites include, but are not limited to, the iliac crest, tibia, and skull. Gultekin et al compared the regenerative potential of autogenous iliac
block grafting to that of GBR in patients with atrophic maxillae; they found that patients who received iliac block grafts gained statistically significantly more bone width (6.52 mm) compared to those in the GBR group (5.31 mm).14 A systematic review by Sanz-Sánchez et al reported an average horizontal bone gain of 4.3 mm (95% CI: 4.0, 4.8) with the use of block grafts.1 The major disadvantages of autogenous block grafting are the increased operating time, limited tissue availability, donor site morbidity, patient discomfort, and potential wound exposure with its related complications. Despite the drawbacks of autogenous block grafting, systematic reviews have noted that it produces 1 mm of additional bone gain compared to methods that employ particulate grafting materials.4,24 Troeltzsch et al reported a weighted mean width gain of 4.5 ± 1.2 mm after autogenous block grafting, which is higher than that seen after augmentation with particulate bone (3.7 ± 1.2 mm).4 Autogenous block grafts also may show a greater initial bone gain (4.2 mm) compared to GBR using particulate matter (3.6 mm).24 Developed to bypass some of the disadvantages of autogenous block grafting, allogeneic and xenogeneic blocks are widely available, but their effectiveness remains uncertain; there exist a limited number of publications on the matter, most of which are pilot studies with a short-term follow-up.25,26

Ridge Splitting and Ridge Expansion

Bruschi and Scipioni introduced ridge splitting for horizontal augmentation in 1990.27 This process involves making a crestal incision to the ridge and, if warranted, adjunct vertical incisions at the mesiobuccal and distobuccal aspects of the edentulous site. A greenstick

Fig 4  GBR was performed using a d-PTFE membrane with delayed implant placement in a case necessitating extensive horizontal bone augmentation (> 6 mm) at the anterior maxilla. (a) Flap elevation of the site uncovered a ridge with an absent labial plate and very thin residual bone. (b) The site was augmented with cortical particulate allograft that was covered by a titanium-reinforced d-PTFE membrane secured with pins. (c) A second membrane (collagen) was laid over the d-PTFE barrier. (d) Significant bone width gain was detected after 6 months of healing. (Images courtesy of Dr Lorenzo Tavelli, Harvard School of Dental Medicine, Boston, Massachusetts, USA).
fracture is then produced by separating the buccal ridge from the intact palatal/lingual plate with a chisel or other instrument, and then filling the newly formed gap with graft material.27 Ridge splitting usually allows for simultaneous implant placement; however, it is important to stabilize the buccal plate and secure it with ligature/fixation screws as needed.28 A 5-year survival rate of 86.2% to 98.8% has been reported for augmentation by ridge splitting with immediate implant placement in the maxilla.29,30 A systematic review described a weighted width gain of 3.2 ± 12 mm (range: 2.0 to 4.0 mm) using the ridge splitting approach.6 However, complications have been reported, such as unideal implant positioning (eg, too buccally placed), sequestration of the bony plates, more severe buccal bone remodeling, and higher rates of implant failure.28 A randomized clinical trial (RCT) investigated the effects of different particulate grafting materials and sizes on horizontal augmentation after ridge splitting.7 When a slow-absorbing bone graft (hydroxyapatite) was used, the average alveolar width gain was 3.52 to 4.40 mm. Width augmentation was improved by the use of graft particles with a diameter 1 to 2 mm relative to particles 0.25 to 1 mm in diameter (width gain of 4.4 mm vs 3.52 mm, respectively). Based on these outcomes, the authors of the RCT recommended slower-resorbing, larger-particle (> 1 mm) bone materials for use in ridge splitting procedures.7 The present authors’ review of the literature indicates that ridge splitting can be used to gain up to 6 mm of bone width (Fig 1). Ridge splitting can predictably augment minor bony defects (< 3.0 mm); if moderate ridge reconstruction (3.0 to 6.0 mm) is expected, a staged ridge splitting approach is preferred. This treatment modality will not be able to rectify cases with extensive expansion demands (> 6 mm).

Subperiosteal Tunneling

Minimally invasive surgery has been advocated for both soft and hard tissue augmentation in order to minimize surgical trauma. Several groups have reported bone grafting via subperiosteal tunneling, a minimally invasive flap design.5,9,31 Early pioneers of this method, Block and Degen, utilized a subperiosteal route to place particulate human mineralized bone at 13 deficient mandibular posterior sites and reported that the heated dimensions of the grafted ridges were sufficient for placement of implants with a diameter of 3.25 mm or wider.31 However, no direct measurements of the alveolar width gain or histologic evidence were disclosed.31 Nevins et al8 conducted a case series with 12 patients (maxillary sites) using tunneling with different grafting combinations: group A comprised allograft + collagen membrane + recombinant human platelet-derived growth factor-BB (rhPDGF-BB); group B comprised anorganic bovine bone graft (ABBG) + collagen membrane + rhPDGF-BB; and group C comprised ABBG/mineralized collagen bone substitute alone. CBCT scans showed the average bone gain of groups A, B, and C to be 5.1 mm, 4.9 mm, and 8.4 mm, respectively. However, three implants in group A required removal, and two implants in group C could not be placed.8 Histologic evaluations showed that groups A and B had newly formed bone surrounding the remaining graft particles, while group C showed more fibrous encapsulation of the graft particles and limited bone formation.8 In 2017, Lee introduced the Subperiosteal Minimally Invasive Aesthetic Ridge Augmentation Technique (SMART): A subperiosteal pouch was surgically created at the site of interest, and a mixture of bovine xenograft and rhPDGF-BB was inserted into the pouch.9 The author reported an average horizontal bone gain of 6.47 mm based on CBCT assessment.9 Recently, a case report detailed the use of subperiosteal tunneling a d-PTFE membrane and allograft into position for augmentation of a thin ridge (3 mm) at a lateral incisor site.32 After ridge reconstruction, an implant with a 3.5-mm platform was placed without dehiscence.32 A more recent publication presented three cases utilizing a novel technique for horizontal bone augmentation, using a customized bag made from collagen membrane that was filled with xenograft and inserted into a subperiosteal pouch.33 However, no direct measurements were obtained from either study.32,33 Subperiosteal tunneling may minimize surgical trauma, but only short-term reports or studies without data...
quantiﬁcation exist to support its application. Despite a reported average bone gain of 5 to 8 mm, as evaluated by CBCT, further validation of true bone regeneration using this technique would be highly welcome. Therefore, subperiosteal tunneling may be used with caution and limited to sites that require < 3 mm of lateral bone augmentation.

Other Alternatives: Narrower-Diameter Implants

Long-term survival of implants placed in regenerated bone is comparable to that of implants placed in native bone. A systematic review concluded that implants placed in sites simultaneously augmented with GBR exhibited similar survival rates (95.5% to 100%) to those placed in pristine bone (97.3% to 100%) in the long term. Benic et al found comparable bone-level stability of implants placed in regenerated and native bone; the marginal bone level measured 1.3 ± 0.5 mm for the GBR group and 1.6 ± 0.9 mm for the native bone group. It is important to keep in mind that most of the studies tracking implant stability do not directly measure or consider buccal-lingual dimensional changes in bone over time. Is a horizontally regenerated ridge more prone to resorption (perhaps apical to the crest) than untouched bone, and would this negatively affect implant esthetics or implant/prosthetic success? Is the surgeon comfortable with performing regenerative techniques? To side-step bone regeneration completely, placement of a narrower-diameter implant that allows for at least 1.8 to 2 mm of sound buccal and palatal/lingual bone around the implant is a practical treatment choice.

Conclusions

There are myriad permutations of methods and materials used for horizontal bone augmentation, and it is important to consider the strength of evidence for each approach regarding average bone gain and/or histologic analysis, as well as the surgeon’s comfort level with performing a certain procedure. This article updates the decision guidelines for horizontal bone augmentation based on the bone gain needed for ideal implant placement and the current evidence available. As more bone gain is required, fewer predictable options remain. For edentulous ridges requiring more extensive width enhancement (> 6 mm), GBR, protected bone augmentation with titanium mesh, or extraoral autogenous block grafting are the most dependable methods.

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