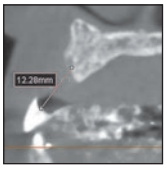
An Updated Decision Tree for Vertical Bone Augmentation



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Vertical bone augmentation (VBA) procedures for dental implant placement are biologically and technically challenging. Systematic reviews and meta-analyses of studies on VBA have failed to identify clinical procedures that provide superior results for treatment of the vertical ridge deficiencies. A decision tree was developed to guide clinicians on selecting treatment options based on reported vertical bone gains (< 5 mm, 5 to 8 mm, > 8 mm). The choice of a particular augmentation technique will also depend on other factors, including the size and morphology of the defect, location, and clinician or patient preferences. Surgeons should consider the advantages and disadvantages of each option for the clinical situation and select an approach with low complications, low cost, and the highest likelihood of success. Int J Periodontics Restorative Dent 2021;41:11–21. doi: 10.11607/prd.4996

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When an implant-supported prosthesis is planned, the clinician must evaluate bone volume for implant placement. The success of implant procedures and maintenance of long-term stability are directly related to the quality and quantity of the supporting bone. When the residual ridge lacks the adequate bone for implant placement, bone augmentation procedures are often indicated.

Osseous regeneration primarily originates from the surrounding bone walls. As such, the morphology of a bone defect should influence the choice of material or technique. Sites with fewer surrounding osseous walls and more pronounced atrophy are more demanding and require materials and/or techniques that offer greater biologic activity and regenerative capacity. Vertical bone augmentation (VBA) is more biologically and technically challenging than horizontal bone augmentation. In addition, VBA outside the osseous contour (eg, flat ridge) is more difficult to achieve than repair of vertical intraosseous defects. Intraosseous defects have a higher regenerative capacity with better space maintenance and graft stability. As such, VBA of intraosseous defects can be predictably accomplished using bone substitutes and coverage with a barrier membrane or protective mesh.

Techniques for VBA outside the osseous boundary include guided bone regeneration (GBR), titanium mesh (TM), block grafts (BGs), interpositional grafts (IGs), distraction osteogenesis (DO), and orthodontic extrusion (OE).

Techniques for VBA

Guided Bone Regeneration

GBR utilizes a barrier membrane to occlude soft tissue cells and allow slower-growing bone cells to repopulate the defect and regenerate bone.[1]

Maintainable barrier function is desired with membranes used in GBR for VBA. Absorbable collagen membranes can be used for small amounts of vertical bone gains. Cross-linking the collagen prolongs degradation time, improves barrier function, and has been shown to provide greater vertical gains than non–cross-linked membranes.[2] Graft materials and tenting screws can improve space maintenance during graft healing. Dense polytetrafluoroethylene (d-PTFE) provides a nonresorbable membrane option, and titanium reinforcement (TR) of the d-PTFE membrane improves space maintenance. Vertical bone gains may also be improved with membrane fixation using tacks or screws.[3] Healing time requirements are typically 6 months but may be longer for larger defects.

Titanium Mesh

TM is a metal matrix that acts as a form-stable scaffold, used with particulate bone graft to vertically direct bone ingrowth. The mesh lattice allows passage of nutrients, cells, and vascular ingrowth. This feature may offer an advantage when using exogenous chemotactic growth factors.[4,5] Although some studies include TM in the GBR category, this material is not cell-occlusive and therefore does not fulfill the true definition of GBR; the term "protected bone regeneration" has been proposed. The mesh is formed to size and shape or can be customized using CAD/CAM technology. It is secured to the ridge with screws for graft stability. Healing time requirements are typically a minimum of 6 months.

Block Grafts

Autogenous BGs may be harvested from various donor sites. Intraoral BGs from the mandibular symphysis or ramus are mostly cortical, as is calvarial bone harvested from the outer table of the skull. The iliac crest is a source for large quantities of corticocancellous bone, making it useful for the reconstruction of significant vertical defects. Although there are reports on the use of allograft, xenograft, and alloplast blocks, they lack the regenerative capacity for significant VBA and their clinical evidence is limited,[6] but the use of growth factors could improve their incorporation.[7] Autogenous BGs have short healing requirements of approximately 4 months.

Interpositional Graft

An IG is placed following the preparation of osteotomies in the ridge to completely separate an osteoperiosteal segment attached to a soft tissue pedicle. The bone segment is elevated away from the basal bone and then secured with a plate. The space between the basal bone and bone segment is highly osteoconducive and may be filled with autogenous bone or bone substitutes in block or particulate forms. The vertical movement of the bone segment can be limited by the soft tissue pedicle. This technique does not correct any horizontal ridge deficiency or transverse discrepancy with the opposing arch. The healing time is approximately 4 months.

Distraction Osteogenesis

DO is similar to IG in that osteotomies are prepared in the ridge to completely separate an osteoperiosteal segment attached to a soft tissue pedicle. A distraction device that transports the osseous segment in a gradual and measured manner is then attached to the bone, allowing bone regeneration to occur between the separated bone segments. Incremental separation of the bone segments occurs at a rate of approximately 1 mm per day. Thereafter, during the consolidation phase, new bone forms between the separated bone segments in 6 to 10 weeks. A unique feature of DO is the simultaneous lengthening of surrounding soft tissues so that vertical movement of

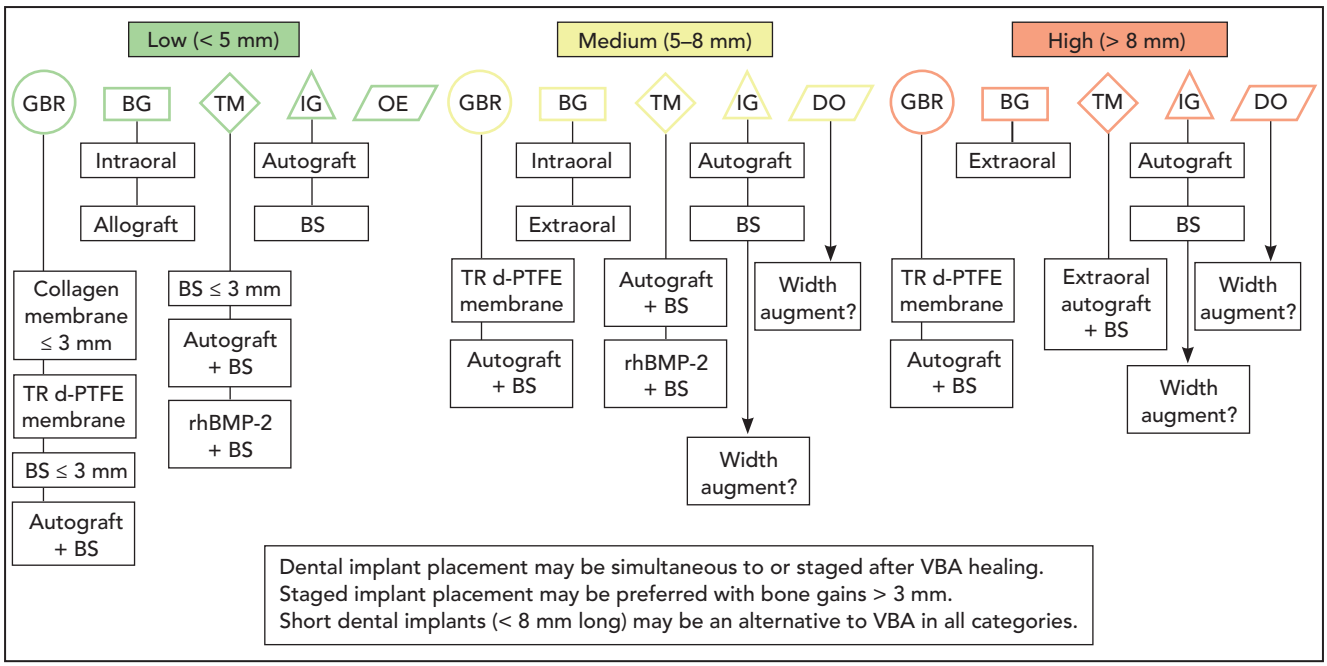

Fig 1 *Decision tree for extraosseous vertical bone augmentation (VBA) of the maxilla and mandible. BS = bone substitute (allograft, xenograft, alloplast).*

the bone is not limited by the mucosal attachment.[8]

Orthodontic Extrusion

OE offers a nonsurgical approach to gain additional vertical bone height and establish a more favorable gingival profile.[9,10] This technique is especially useful in the esthetic zone. Vertical increase of the interproximal bone can improve the support of the interdental papilla to enhance gingival esthetics. The hopeless tooth is erupted approximately 1 to 2 mm per month and then retained in the desired position for 2 to 3 months. The hopeless tooth is then extracted for implant placement.

Decision Tree

Although a previous decision tree for vertical bone augmentation was proposed by Plonka et al,[11] it did not discuss all available techniques and concluded that guided bone regeneration was the preferred treatment method in every deficient situation. The proposed decision tree is based on the amount of extraosseous VBA needed for implant placement. The augmentation gains are stratified into low (< 5 mm), medium (5 to 8 mm), and high (> 8 mm). It is important to note that the three categories for VBA are guidelines (Fig 1) based on bone gains in published studies. There are a range of gains for various techniques, graft materials, clinicians, and patients. The color designation (green, yellow, and red) reflects the increasing difficulty in achieving predictable and complication-free outcomes with greater bone gains. Experienced surgeons may be able to utilize a particular technique and achieve exceptional results. There are also local and systemic patient factors that may negatively influence wound healing and compromise outcomes.

Low VBA (< 5 mm)

Small VBA gains may be accomplished using GBR, TM, BG, IG, or OE (Fig 2). For GBR, collagen membranes may be considered for gains up to approximately 3 mm.[2,3] A nonresorbable membrane, such as TR d-PTFE, may be preferred when vertical augmentation requirements approach 5 mm.[12–15] A TR d-PTFE membrane may also be recommended with simultaneous dental implant placement.[13]

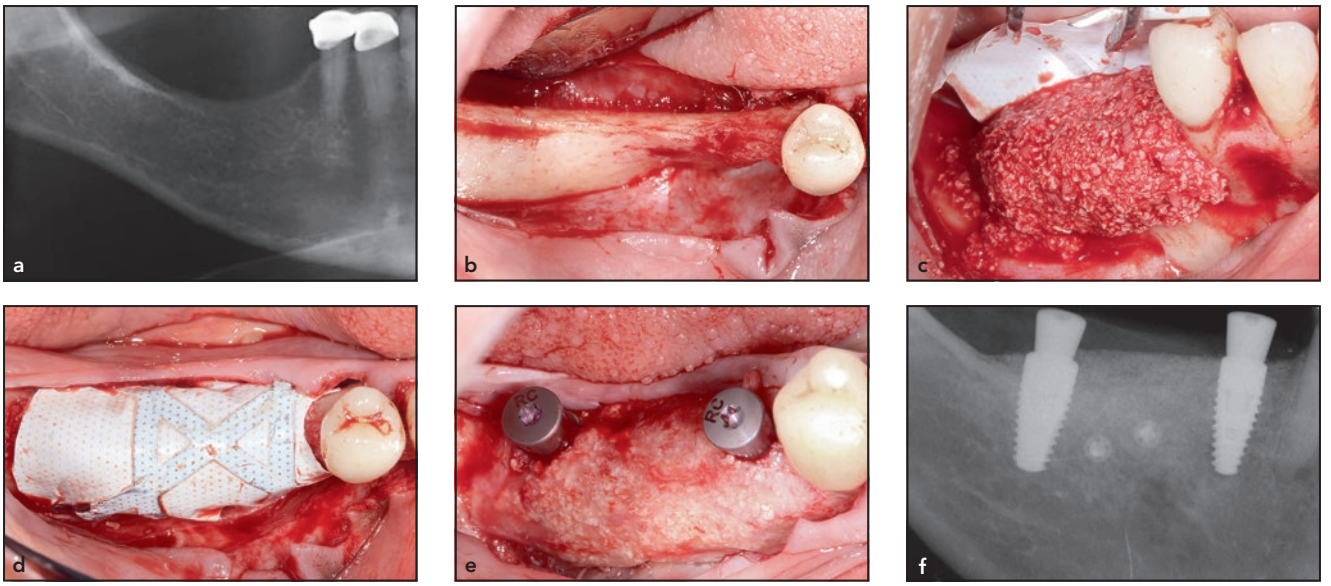

Fig 2 *Case 1. Low VBA case (< 5 mm).* (a) *Preoperative panoramic radiograph reveals a vertical ridge deficiency in the right posterior mandible.* (b) *Occlusal view of the atrophic posterior mandible.* (c) *GBR with particulate bone graft (1:1 autograft, bovine bone mineral) placed under a TR d-PTFE membrane.* (d) *The TR d-PTFE membrane is secured to the ridge with tacks.* (e) *Two dental implants are placed into the healed bone graft.* (f) *A periapical radiograph of the two dental implants and healed bone graft.*

TM can also be used with particulate bone graft to vertically direct bone ingrowth. The choice of graft material used for GBR and TM is important. Although bone substitutes may be used for small GBR gains (3.0 mm), they may not result in complete vertical bone fill using TM.[3,16] Clinical studies suggest that at least 50% particulate autograft is needed for greater vertical gains (> 3 mm) with GBR or TM.[12,13,15,17–19] Small amounts of autograft can be procured locally from the ridge or a secondary intraoral donor site (posterior mandible). The use of mineralized bone allograft mixed with recombinant human bone morphogenic protein-2 (rhBMP-2) may be considered as an alternative to autogenous bone for TM grafting, but the cost is high.[4]

For augmentation needs up to 5 mm, autogenous BG can be harvested from intraoral donor sites such as the mandibular ramus or symphysis.[14] Allogeneic BG have been used for minor VBA, but their varying amounts of resorption can make them less predictable.[6] BG made from xenograft or alloplasts lack strong evidence in this application.

IG is a reliable treatment option in cases of minimal vertical bone deficiency of the posterior mandible.[20] Ridge defects in the anterior maxilla and mandible are well accessible for performing segmental osteotomies and IG.[21,22]

Although OE of a hopeless tooth is well documented for gaining bone height, there is limited information on actual bone volume gains.[10]

Medium VBA (5 to 8 mm)

Modest gains in VBA may be accomplished using GBR, TM, BG, IG, or DO (Fig 3). For vertical gains over 5 mm using GBR, clinical studies have used TR d-PTFE membrane with at least 50% particulate autogenous bone mixed with bone substitutes.[12,13,15]

TM may be used with particulate autograft alone or combined with a bone substitute in a 1:1 ratio.[23–26] Particulate autograft may be harvested with burs or scraping devices from intraoral donor sites for limited areas of vertical augmentation. For larger spans and greater vertical deficiencies, TM may be used with cancellous bone harvested from the proximal tibia or iliac crest, or a combination of rhBMP-2 with mineralized allograft.[4,26]

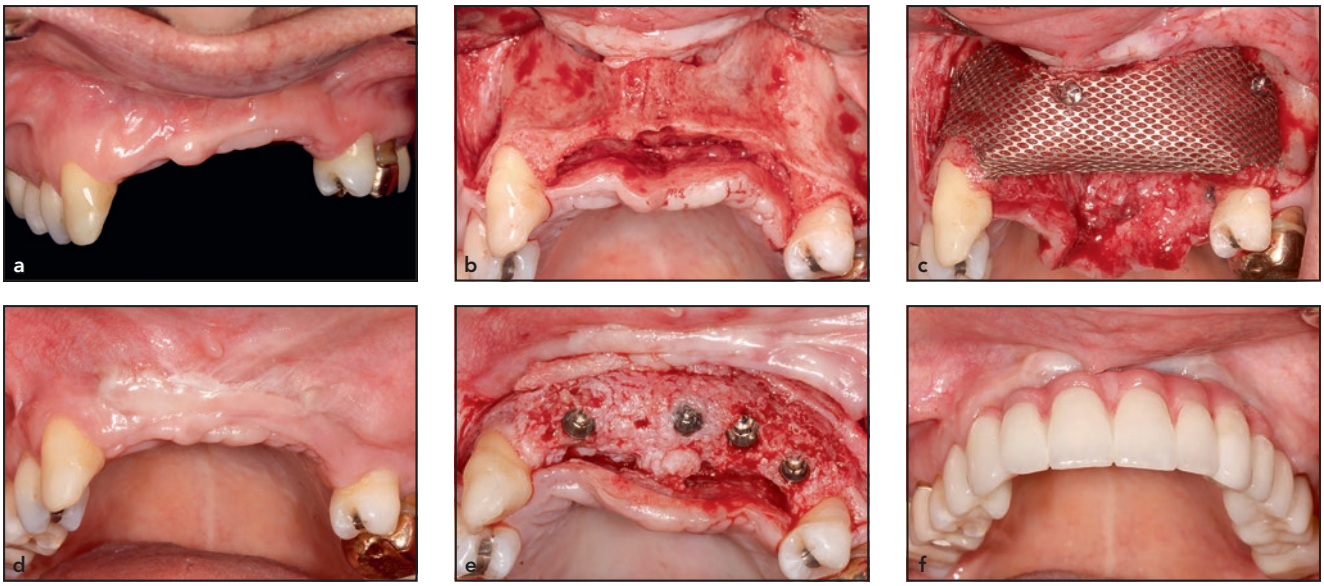

Fig 3 *Case 2. Medium VBA case (5 to 8 mm).* (a) *Preoperative view of moderate vertical deficiency in the anterior maxilla.* (b) *Surgical exposure of the maxillary anterior ridge.* (c) *The maxilla was augmented with rhBMP-2 with mineralized bone allograft in a titanium mesh.* (d) *The surgical site is well healed with no mesh exposure after 6 months.* (e) *Four dental implants are placed into the vertically regenerated bone.* (f) *The final fixed-implant partial denture.*

Intraoral BG (ramus, symphysis) may be used when gains of approximately 5 mm are planned.[27] Greater vertical bone reconstruction using BG may necessitate the use of extraoral donor sites such as the calvarium or iliac crest.[27–29]

IG can be used for moderate augmentation of the posterior mandible up to 8 mm.[30–36] Case studies have reported on the management of moderate alveolar deficiencies in the anterior maxilla and mandible with IG.[21,22] The atrophic edentulous maxilla can be effectively treated with a Le Fort 1 osteotomy and a corticocancellous IG from the iliac crest.[37–39]

In the treatment of moderate defects, DO can be utilized to correct vertical discrepancies.[14,27,40,41]

High VBA (> 8 mm)

Large amounts of VBA may be managed with the use of BG, GBR, TM, or DO (Fig 4). It may also be possible to consider IG, as larger gains are within the range of reported outcomes.[21,22] This category should be managed by well-trained, experienced specialists.

Corticocancellous BG may be harvested from the iliac crest for onlay augmentation.[42–44] It may also be an option to stack cortical BG from the calvarium for greater bone height.[44–47]

GBR using a TR d-PTFE membrane and particulate autograft mixed with bovine bone mineral (75:25 ratio) may be used for localized defects (< 4 teeth).[12]

For larger spans or significant vertical deficiencies, TM may be used with particulate bone from the iliac crest or tibia.[26] The use of rhBMP-2 with mineralized bone allograft offers an alternative to extraoral autograft harvest.[4] The severely atrophic edentulous maxilla can be treated with a Le Fort 1 osteotomy and IG.[38,48]

DO can be used to mobilize a bone segment for large vertical gains and may be preferred over an IG, as it overcomes the limitation of vertical movement from the soft tissue pedicle.[40,41,49] However, secondary horizontal bone augmentation is often required for 3D reconstruction.[50]

Discussion

Several systematic reviews on VBA have concluded that it is difficult to

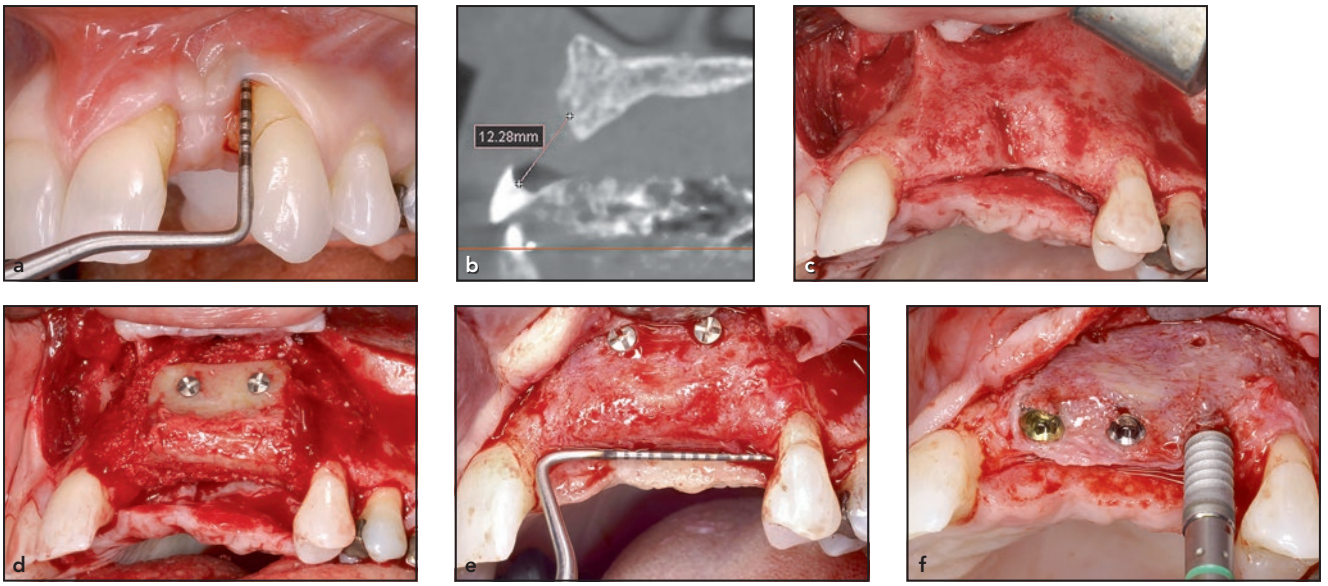

Fig 4 *Case 3. High VBA case (> 8 mm).* (a) *Preoperative view of a failed implant site with severe bone loss on the adjacent teeth.* (b) *A computed tomography scan reveals a severe vertical defect in the anterior maxilla.* (c) *Surgical exposure of the vertical bone defect in the anterior maxilla.* (d) *A corticocanellous block BG from the iliac crest is used to reconstruct the defect.* (e) *Exposure of the BG after 4 months of healing reveals favorable vertical bone gain.* (f) *Dental implants are inserted into the healed block BG.*

demonstrate one surgical procedure that offers superior outcomes compared to another.[14,20,51–53] This may be due to a lack of adequate high-quality studies, heterogeneity of the data, and the use of secondary outcomes (implant survival) to measure graft success.[2] However, clinical studies often identify that certain techniques may offer greater vertical bone gains.[2,14,20,52] Milinkovic and Cordaro[14] investigated evidence-based indications for the various bone augmentation procedures based on defect dimension and type. They concluded that in partially edentulous ridges, vertical defects can be treated with GBR, BG, and DO. In edentulous patients, bone BGs or a Le Fort I osteotomy can be used. The choice of a particular augmentation technique will depend on the degree of bone loss, the size and morphology of the osseous defect, the location in the mouth, the design of prosthesis, and clinician or patient preferences. Surgeons should consider the advantages and disadvantages of each alternative and select an approach with lower overall cost and morbidity and the highest likelihood of success.[54]

Dental implant placement may be performed simultaneous with VBA (GBR, TM, BG) or staged after graft healing. Simultaneous implant insertion will shorten the overall treatment time. However, there is a risk that postoperative incision dehiscence or graft resorption could compromise bone formation around the neck of the implant. Although studies have found favorable outcomes with simultaneous graft and implant insertion, when bone gains > 3 mm are required, delayed implant placement after site development may be preferred.[2]

An advantage of GBR is the ability to restore ridge contours and perform 3D augmentation using particulate bone.[12] Although autograft harvest may be needed for some GBR procedures, it can be performed with minimal morbidity using scrapers and burs. BGs have the advantage of a short healing time and denser bone quality upon incorporation.[55] For TM, the use of rhBMP-2 avoids the need for bone harvest but adds significant cost and postoperative edema.[4] Advantages of IG and DO include a lack of morbidity from bone harvest and a lower risk of wound dehiscence. In addition, dental implants are placed through native bone at the ridge crest. Although DO may offer

the potential for significant vertical bone gains, it has a high incidence of complications.[2,14,51] There can be issues with vector control and premature consolidation of the bony segment, device instability, mandibular fracture, and patient compliance. In addition, most cases require secondary horizontal augmentation for dental implant placement.[50]

VBA procedures are complex and more sensitive to technique and operator experience. Successful bone augmentation largely relies on primary wound closure for a closed healing environment.[56] The most frequent postoperative complication of VBA procedures (GBR, BG, TM) is wound dehiscence.[2] If this occurs early (prior to revascularization), it can expose the underlying graft material, making it susceptible to displacement, contamination, and infection.[56] The incidence of wound dehiscence in VBA can be high but may be related to the amount of augmentation, surgeon experience, smoking, and quality soft tissue. For GBR, membrane exposure can reduce the amount of bone regeneration.[57,58] The exposure rate of cross-linked membranes may be higher than that of non–cross-linked membranes.[3,58] The degradation of collagen membranes is accelerated by exposure to the oral cavity, and[59] the reported exposure rate of d-PTFE membranes ranges from about 0% to 50%.[2,60] Wound dehiscence over a BG will compromise incorporation of the expose area and can cause complete failure. Although early TM exposure is detrimental to graft success, late exposures may be better tolerated; however, less bone regeneration can be expected.[61] Studies on TM reveal a wide range of exposure rates, from approximately 5% to 50%.[15,18,26] Covering TM with a collagen membrane or platelet concentrate may reduce the risk of wound dehiscence.[62,63]

BG complications mostly originate from graft harvest morbidity and vary depending on the donor site. The mandibular ramus has a very low incidence of complications, and patients prefer this donor site over others.[64–66] The incidence of sensory nerve impairment is low and transient.[64,67,68] This area is also preferred as a secondary site for particulate bone harvest for GBR and TM. The mandibular symphysis provides more bone volume but is associated with greater postoperative pain and higher risk of complications, such as sensory nerve injury (teeth, chin).[64,67] Although the calvarium has a very low rate of complications, there is a risk of intercranial injury.[65] The iliac crest provides the greatest source of bone for arch reconstruction but also has the highest morbidity, including acute pain, transient sensory deficits, and temporary gait disturbance.[66] However, most patients tolerate the procedure well and are satisfied with treatment.[69] Extraoral donor sites also require treatment under general anesthesia in a hospital setting, which adds costs.

Although autogenous bone is considered the gold standard of graft materials, systematic reviews fail to prove its superiority over bone substitutes for ridge augmentation.[54,70,71] This is likely due to a lack of quality comparison studies and the use of dental implant survival as a measure of graft success. When evaluating VBA studies measuring extrabony gains, the trend toward using more autogenous bone for medium to high augmentation requirements (≥ 5 mm) becomes quite evident.[2,71] In these cases, the augmentation material requires a higher level of regenerative capacity, which can be achieved using autogenous bone alone or mixing it with a bone substitute to no more than a 50:50 ratio.[54] Bone substitutes alone or in higher ratios tend to show less bone formation occurring further from the ridge.[16,72] Autogenous bone can also accelerate bone formation and shorten healing times.[73] The use of cell-based therapies and growth factors to routinely replace autografts or shorten healing times needs further evaluation.[74]

Another factor that determines the choice of VBA technique is location in the oral cavity. In the partially edentulous anterior and posterior maxilla and mandible, the surgeon can consider GBR, TM, BG, and IG. Although DO is a useful modality in the anterior maxilla and mandible, it is associated with a high degree of complications in the posterior mandible, including jaw fracture.[75] The maxillary sinus may complicate DO in the posterior maxilla, and the thicker, inelastic palatal mucosa tends to direct the osseous segment medially. A technique for IG in the posterior maxilla combined with sinus grafting has been reported.[76] OE can be performed in any region but is traditionally applied to the anterior maxilla. The severely atrophic edentulous maxilla can be reconstructed using sinus grafting

and onlay augmentation with autogenous BG or TM and particulate autograft.[38] The other option is a Le Fort I downfracture and an IG using autogenous bone.

An alternative to VBA in the atrophic posterior maxilla and mandible is to place short dental implants (< 8 mm long). Studies on short implants vs VBA procedures for longer implants have concluded that short implants are often preferred and have fewer complications, lower costs, and shorter treatment length.[77–80] In the severely atrophic edentulous mandible, the placement of short dental implants is preferred over major arch reconstruction.[81] The use of tilted implants placed anterior to the sinus or mental foramen, as well as prosthetic restoration with cantilevered pontics, can also avoid the need for posterior VBA. The use of four zygomatic implants is an alternative to major maxillary reconstruction using Le Fort I and IG or iliac BG.[82]

Conclusions

The proposed decision tree for VBA was developed as a guide for selecting clinical procedures based on vertical bone gain requirements. The decision-making process for the preferred treatment should be made on site- and patient-related factors in combination with the clinician's surgical experience and skill. The clinician should also consider the advantages and disadvantages of each option, including associated complications and costs. The use of short and tilted implants may offer a more minimally invasive alternative to more-complex VBA.

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