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Review

Clinical Applications and Success Rates of Guided Bone Regeneration in Ridge Augmentation

Mohammed Abdullah Batwa[1*], Noura Mohammed Al Alshaikh[2], Nuha Mofareh Alkhayri[3], Juman Suliman Alhumayed[3], Abdulaziz Abdullah Alyahya[3], Saleh Abdullah Alqhtani[3]

[1] *Department of Periodontics, Al Thager Hospital, Jeddah, Saudi Arabia*
[2] *Department of General Dentistry, Dr. Hamza Medical Complex, Abha, Saudi Arabia*
[3]*College of Dentistry, King Khalid University, Abha, Saudi Arabia*

Correspondence should be addressed **Mohammed Abdullah Batwa**, Department of Periodontics, Al Thager Hospital, Jeddah, Saudi Arabia, Email: mbatwa@hotmail.com

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Abstract

Guided bone regeneration (GBR) is a surgical approach designed to promote new bone growth in deficient sites, such as alveolar defects. It is primarily employed to restore adequate bone volume and facilitate dental implant placement. Ridge augmentation is a procedure aiming to increase the shape and volume of the alveolar ridge. One of the most common applications of GBR is ridge augmentation. However, comprehensive clinical data on the effectiveness of GBR in ridge augmentation remain limited. This review aims to explore current evidence for clinical applications of GBR in ridge augmentation, highlighting its success rates. GBR has shown effectiveness in horizontal ridge augmentation and vertical ridge augmentation. It can provide and protect a secluded space over a bone defect, which is then populated by bone-forming cells. Membranes used in GBR can be classified into non-resorbable and resorbable membranes. Non-resorbable membranes can be combined with various grafts, including allografts, xenografts, autografts, alloplasts, or combinations. Resorbable collagen membranes are used either alone or with space-maintaining aids such as tenting screws, titanium mesh, osteosynthesis plates, and simultaneous implants. GBR procedures should be carefully planned, considering individual defect characteristics and materials used.

Keywords

Guided bone regeneration, GBR, Ridge augmentation, Horizontal ridge augmentation, Vertical ridge augmentation.

Introduction

Guided bone regeneration (GBR) is a surgical technique developed to induce new bone formation in deficient sites, including alveolar bone deficits. It is used mainly to restore functional bone volume and prepare for dental implant placement. GBR is based on the principle of selective cell repopulation, where a barrier membrane is utilized to prevent fast-growing soft tissue cells, such as connective tissue and epithelium, from migrating into the bone defect, thus allowing slow-growing osteogenic cells to regenerate bone. Therefore, GBR aims to provide and protect a secluded space over a bone defect, which is then populated by cells that form bone. The key components of GBR are barrier membrane, bone graft material, stable environment, and healing period (1).

The barrier membrane is used as a physical barrier and occasionally as a stabilizer for the bone graft material, which serves as a scaffold for bone regeneration. Barrier membrane is categorized as resorbable (e.g., collagen) or non-resorbable (e.g., PTFE). Furthermore, the types of bone graft material used in GBR include autograft, allograft, xenograft, or alloplast. A stable environment should also be provided by flap closure and fixation devices (e.g., tacks or screws). GBR should be followed by a healing period that typically ranges from 4 to 9 months, depending on defect size and site. The clinical applications for GBR include peri-implant bone defects, socket preservation after extraction, sinus floor elevation (as an adjunct), management of peri-implantitis, bone defects after cyst or tumor removal, and ridge augmentation (horizontal or vertical) (2).

Ridge augmentation is a surgical procedure designed to increase alveolar ridge volume that may be affected by trauma, tooth loss, or severe periodontal disease. This procedure is usually performed to facilitate dental implants, aiming to increase their success rates. Ridge augmentation can be classified based on the type of defect into horizontal ridge augmentation, vertical ridge augmentation, and combined augmentation. It can also be classified based on the surgical technique into hard tissue augmentation procedures, such as barrier membranes, alveolar distraction osteogenesis, onlay grafting, block onlay grafting, ridge split technique, and sinus lift procedures, and soft tissue augmentation such as roll flap procedures, modified roll technique, and pouch graft procedure (3).

GBR is one of the most frequent techniques used to perform ridge augmentation. However, evidence discussing clinical applications and success rates of various forms of GBR in ridge augmentation is lacking. Therefore, this review aims to explore current evidence focusing on clinical applications of guided bone regeneration in ridge augmentation, highlighting the success rates of this procedure.

Methods

A comprehensive literature search was conducted in Medline (via PubMed), Scopus, and Web of Science databases up to June 29, 2025. Medical Subject Headings (MeSH) and relevant free-text keywords were used to identify synonyms. Boolean operators (AND, OR) applied to combine search terms in alignment with guidance from the Cochrane Handbook for Systematic Reviews of Interventions. Key search terms included: “Guided bone regeneration” OR “GBR” AND “Ridge Augmentation” OR “Horizontal ridge augmentation” OR “Vertical ridge augmentation”. Summaries and duplicates of the found studies were exported and removed by EndNote X8. Any study that discusses the clinical applications and success rates of guided bone regeneration in ridge augmentation and is published in peer-reviewed journals was included. All languages are included. Full-text articles, case series, and abstracts with related topics are included. Case reports, comments, animal studies, and letters were excluded.

Discussion

Biomaterials of Guided Bone Regeneration

A recent systematic review evaluated the efficacy of different biomaterials used for GBR in ridge augmentation, such as membranes, bone substitutes, and bioactive factors (4). The study found no difference in peri-implant bone levels and

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dehiscence defect closure between various biomaterials and combinations. It reported that different combinations, such as polyethylene glycol (PEG) + deproteinized bovine bone mineral (DBBM) and non-cross-linked collagen membrane (NCL) + allograft, achieved comparable interproximal bone levels at 12 months (4). A study found that bone resorption was greater when using an NCL collagen membrane compared to a titanium-reinforced e-PTFE membrane (5). However, this hard tissue resorption did not affect the external buccal contour, as soft tissue thickening compensated for the underlying bone loss, a finding verified by intraoral scans.

The review also reported that NCL membrane + DBBM block had the highest probability of vertical dehiscence resolution, while cross-linked collagen (CL) membrane + DBBM particles ranked worst (4). However, no statistically significant differences were found due to heterogeneity in biomaterial use. Notably, CL membranes were linked to more complications than other membranes (6). Although NCL membranes are safer, their rapid resorption can reduce barrier function (7). Furthermore, resorbable collagen membranes are associated with simple treatment and reduced morbidity and are supported by literature for fenestration and dehiscence treatment (8). On the other hand, non-resorbable barriers (e.g., e-PTFE) provide better space maintenance and have succeeded even without grafts, offering an undisturbed healing space (9).

Conflicting data exists regarding complication rates between e-PTFE and resorbable membranes (5, 10). Long-term data suggests similar complication rates for NCL (13.6%) and e-PTFE (13.9%), but higher for CL membranes (44.4%) (8). PEG membranes have shown promise (11) but are linked to dehiscence and late exposure (5–7 weeks) (12). PEG barriers may rupture early if not carefully handled (13). Regarding bone grafts, most studies used DBBM, so no graft-specific meta-analysis could be conducted. Studies using bone morphogenic protein or acemannan showed no clear benefit (14, 15).

Clinical Applications of Guided Bone Regeneration

Horizontal Ridge Augmentation

Multiple studies evaluated the efficacy of horizontal ridge augmentation using GBR. A study examined horizontal ridge augmentation using autogenous block grafts with anorganic bovine bone mineral (ABBM) and collagen membranes performed by GBR (16). The study reported a mean crest width gain amounting to 4.6 mm. It confirmed the result of another study that reported a mean crest width gain of 3.53 mm, but used a non-resorbable barrier membrane (ePTFE) instead (17). The study also reported that collagen membranes are easier to use and have better tolerance than non-resorbable membranes; however, they have shorter barrier function duration (18).

Another study compared the effectiveness of horizontal ridge augmentation procedures using a combination of autogenous block grafts (ABG) with GBR versus GBR alone (19). The GBR technique included an anorganic (xenograft) bovine bone mineral (ABBM) particle and an absorbable collagen membrane (CM). The effectiveness was measured by evaluating the amount of bone gained using the analysis of cone-beam computed tomography (CBCT). The study reported that both procedures were effective for horizontal ridge augmentation in the maxilla and mandible (19).

The mean horizontal bone gain at 18 months was 4.8 mm for the ABG + GBR procedure, while it was 5.6 mm for GBR alone. No statistically significant difference was observed between the two procedures. Furthermore, CBCT scans showed no significant difference in horizontal bone width between procedures. A minor resorption (0.3 mm from 6 to 18 months) in the ABG group was observed (19). The study reported that barrier membranes may increase complication rates, including exposure and infection. The ABG + GBR group showed higher exposure (18%) than the GBR group (10%).

Additionally, most studies reported implant survival rates >90% (20). Simultaneous implant + graft,

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extraoral grafts, and machined implants were associated with higher failure rates, while staged procedures, intraoral ABG, and rough implants were associated with lower failure rates (20). There was a 0% regrafting rate in both groups.

Multiple studies evaluated the effectiveness of autogenous dentin grafts combined with GBR for horizontal ridge augmentation. Dentin grafts achieve better space maintenance than resorbable membranes and are similar to titanium mesh (21, 22), which helps decrease cost and complexity. The dentin grafts preserve dentin and part of the cementum, as these components are more similar to bone (23). They are placed after cortical perforation to improve integration with alveolar bone and marrow. A previous study reported a high success rate of autogenous tooth root grafts without shaping or coverage, establishing a basis for dentin graft use (24).

A recent prospective observational study evaluated the effectiveness of thinner autogenous dentin grafts combined with GBR for horizontal ridge augmentation (25). Significant bone mass gain was observed at 6 months post-grafting; however, it showed mild resorption (0.48 ± 0.52 mm). Despite this, residual buccal bone >1 mm and an implant stability quotient of 78.31 ± 6.64 supported implant stability (26, 27). Additionally, no soft tissue complications or infections were observed. Dentin grafts showed good biocompatibility, simple preparation, and a low incidence (26.3%) of severe postoperative pain. Linear regression suggested a significant correlation between immediate and 6-month bone gain, though larger studies are needed for precise quantification (25).

A case series assessed the utilization of GBR for horizontal maxillary alveolar ridge augmentation using a 1:1 autogenous and xenogenic bone graft mixture delivered into patient-specific, nonperforated occlusive titanium barriers (28). Titanium barriers can protect the graft effectively, provide space and contour, and facilitate device removal even in the presence of mucosal dehiscence (29), unlike perforated devices that allow fibrous tissue ingrowth (30). These barriers can also reduce soft tissue complications and inflammatory responses (31).

The study reported that the mean horizontal bone gain at 6 months was 3.89 mm, matching observations with other studies (32, 33). Furthermore, the histology of bone samples showed a mix of woven and lamellar bone, with minor residual biomaterial, aligning with other studies (34, 35). The study highlighted the significance of soft tissue exclusion and barrier seal at the titanium periphery to suppress fibrous ingrowth (28).

Success Rates and Predictors of Implant Survival After GBR

GBR in dental implant procedures generally has high success rates, with most studies reporting success rates exceeding 90% for both horizontal and vertical ridge augmentation (36). Several factors significantly influence the success of dental implants. These include the type of membrane used during bone grafting, the type of graft material employed, the specific characteristics of the bone defect (morphology), and the timing of implant placement in relation to tooth extraction (immediate, early, or delayed) (37). Simultaneous implant placement during GBR is associated with higher risk in complex or deep defects, particularly when non-resorbable membranes are used. Various patient-related factors can significantly increase the risk of complications and failure of Guided Bone Regeneration (GBR) dental implants. These factors include smoking, poor oral hygiene, systemic diseases like diabetes, and a thin soft tissue biotype (38). Adequate flap management, use of space-maintaining devices, and tension-free primary closure are critical for success. Rough-surfaced dental implants used with guided bone regeneration (GBR) and staged augmentation protocols generally show better results than machined implants and simultaneous procedures, especially in areas with bone deficiency. This approach is particularly helpful in challenging anatomical sites where bone volume is insufficient for stable implant placement (39).

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Vertical Ridge Augmentation

Multiple studies examined the use of GBR, which includes non-resorbable or resorbable membranes, in vertical ridge augmentation. These studies include non-resorbable membranes that were combined with various grafts, including allografts (40), xenografts (41), autografts (40), alloplasts (42), or combinations (40). They resulted in bone gain percentages ranging from 62% to 139%. Additionally, both simultaneous and staged approaches were effective (40, 42, 43). Nevertheless, a study reported that each additional millimeter of required regeneration using PTFE membranes increased the risk of incomplete bone regeneration by 2.5 times, making simultaneous implant placement have more risk in deep defects (44).

Resorbable collagen membranes are used either alone (45) or with space-maintaining aids such as tenting screws (46), titanium mesh (47), osteosynthesis plates (48), and simultaneous implants (47, 48). They also may be grafted with alloplasts (45), xenografts (45), allografts (46), autografts, or mixed grafts (46, 47). A systematic review found mean vertical bone gains of 4.42 mm with non-resorbable membranes, 4.19 mm with cross-linked collagen membranes, and 2.66 mm with native collagen membranes (49).

Simion et al. evaluated the effects of using GBR with a titanium-reinforced e-PTFE membrane in vertical ridge augmentation in dogs (50). The study showed that GBR with a titanium-reinforced e-PTFE membrane increased alveolar bone fill significantly (52.77%, 62.07%) compared to controls (13.78%, 9.51%), which is aligned with other dog studies using e-PTFE membranes (51, 52). However, the study recognized limited bone-to-implant contact (BIC), as a dense connective tissue zone was always observed between the implant surface and new bone (50). These findings highlight the importance of using osteoconductive grafts, including autogenous bone or demineralized freeze-dried bone allografts, to improve BIC. Studies that used such grafts showed better outcomes (53, 54). Still, a study observed no significant BIC differences between grafted and non-grafted sites under membranes (51). The limited BIC can be explained by the use of machined implant surfaces, which are known to integrate less effectively than rough surfaces (55), soft tissue invasion into the membrane space, blood clot instability, membrane micromovements, air entrapment, or an insufficient healing period (54).

A previous systematic review and meta-analysis evaluated the effectiveness of vertical ridge augmentation interventions, including guided-bone regeneration (49). The study reported that GBR is the most frequently used technique. This technique provides a secluded space for osteoblast migration. The study also found that form-stable devices, such as resorbable membranes with space maintainers or titanium-reinforced membranes, were associated with better outcomes than resorbable membranes alone that tend to collapse. Compared to block grafts, GBR was superior by a weighted mean difference of 1.4 mm in bone gain. Notably, GBR was associated with the lowest complication rate (12.1%) compared to distraction osteogenesis (47.3%) and block grafts (23.9%) (49). Furthermore, resorbable membranes were associated with more complications (23%) than non-resorbable membranes (7%) (56, 57). PTFE-d membranes had fewer complications (4%) than PTFE-e membranes (8%), potentially due to the larger pore size of the latter, allowing bacterial ingress (58). These findings align with other studies in confirming that GBR and block grafts are both effective for VRA, with fewer complications for GBR (56, 57).

Conclusion

Guided bone regeneration has proven to be an effective and versatile technique for both horizontal and vertical ridge augmentation. Clinical evidence supports substantial horizontal and vertical bone gains with high implant survival rates, though outcomes are influenced by the type of membrane, graft material, surgical technique, and defect morphology. While resorbable membranes offer advantages in handling and morbidity, non-resorbable membranes provide superior space maintenance. Despite promising outcomes, GBR

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procedures should be carefully planned, considering individual defect characteristics and materials used, and further high-quality comparative studies are needed to optimize protocols and long-term outcomes.

Disclosure

Conflict of interest

There is no conflict of interest.

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Ethical consideration

Non applicable.

Data availability

All data are available within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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