

The Role of Guided Bone Regeneration in Successful Implant Placement: A Comparative Analysis of Techniques

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ABSTRACT

Background: Adequate bone volume is essential for successful dental implant placement; however, alveolar bone deficiencies often necessitate augmentation procedures. Guided Bone Regeneration (GBR) has emerged as a reliable technique, utilizing barrier membranes and graft materials to promote new bone formation.

Aim: To compare the efficacy of resorbable and non-resorbable GBR techniques in terms of bone regeneration, implant stability, and clinical outcomes.

Materials and Methods: This prospective randomized clinical study included 100 patients requiring implant placement with insufficient bone volume. Patients were divided into two groups: Group I (n=50) treated with resorbable collagen membranes and Group II (n=50) treated with non-resorbable membranes. Clinical and radiographic assessments using CBCT were performed to evaluate horizontal and vertical bone gain, implant stability (ISQ), and complications over a 6-month follow-up period. Statistical analysis was conducted using independent t-test and chi-square test, with significance set at $p < 0.05$.

Results: Group II demonstrated significantly higher horizontal (4.5 ± 1.0 mm) and vertical (3.9 ± 0.9 mm) bone gain compared to Group I (3.2 ± 0.8 mm and 2.8 ± 0.7 mm, respectively) ($p < 0.001$). Implant stability was also significantly greater in Group II (72.6 ± 3.8 ISQ) than Group I (68.4 ± 4.5 ISQ). Implant survival rates were high in both groups (94% vs. 98%) with no significant difference. Complication rates were comparable, although membrane exposure was slightly higher in the non-resorbable group.

Conclusion: Both GBR techniques are effective for bone augmentation; however, non-resorbable membranes provide superior bone regeneration and implant stability. Careful technique selection is essential to optimize clinical outcomes.

Keywords: Guided Bone Regeneration, Dental Implants, Resorbable Membranes, Non-resorbable Membranes, Bone Augmentation.

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Introduction

Dental implant therapy has emerged as a highly predictable and widely accepted treatment modality for the replacement of missing teeth, offering both functional and esthetic rehabilitation [1]. The long-term success of dental implants, however, is fundamentally dependent on the presence of adequate bone volume and quality at the recipient site. Alveolar bone loss following tooth extraction, trauma, periodontal disease, or pathological conditions often results in insufficient bone height and width, thereby compromising ideal implant placement. In such scenarios, augmentation procedures become essential to recreate a suitable osseous foundation for implant stability and osseointegration.

Guided Bone Regeneration (GBR) has become one of the most widely utilized and scientifically validated techniques for alveolar ridge augmentation in implant dentistry [2]. The principle of GBR is based on the use of barrier membranes to exclude rapidly proliferating epithelial and connective tissue cells, thereby allowing slower-growing osteogenic cells to populate the defect and facilitate new bone formation. This selective cell repopulation promotes predictable bone regeneration and enhances the possibility of achieving optimal implant positioning in compromised sites.

Over the years, various GBR techniques have been developed and refined, incorporating different types of barrier membranes, bone graft materials, and surgical approaches. Barrier membranes can be broadly classified into resorbable and non-resorbable types [3]. Resorbable membranes, typically composed of collagen, offer the advantage of eliminating the need for a second surgical procedure for removal, while non-resorbable membranes, such as expanded polytetrafluoroethylene (ePTFE), provide superior space maintenance but require additional intervention. The choice between these membranes depends on the clinical scenario, defect morphology, and operator preference.

Similarly, a variety of graft materials have been employed in GBR procedures, including autografts, allografts, xenografts, and alloplastic substitutes [4]. Autogenous bone grafts are considered the gold standard due to their osteogenic, osteoinductive, and osteoconductive properties; however, they are associated with donor site morbidity and limited availability. Allografts and xenografts, on the other hand, provide an

osteoconductive scaffold and are widely used due to their availability and ease of handling. Synthetic graft materials have also gained popularity due to their biocompatibility and reduced risk of disease transmission.

The success of GBR is influenced by several critical factors, including primary wound closure, angiogenesis, space maintenance, and stability of the graft and membrane. Among these, space maintenance plays a crucial role, as it ensures sufficient volume for bone regeneration [5]. Various techniques, such as the use of tenting screws, titanium meshes, and particulate grafts, have been introduced to maintain the regenerative space effectively. Additionally, advancements in surgical techniques, including minimally invasive approaches and the use of growth factors like platelet-rich fibrin (PRF), have further enhanced the outcomes of GBR procedures.

Despite the widespread use of GBR, there remains variability in clinical outcomes depending on the technique employed [6]. Factors such as membrane exposure, infection, graft resorption, and patient-related variables can significantly influence the success rate. Furthermore, the choice between simultaneous and staged implant placement in conjunction with GBR continues to be a topic of debate. While simultaneous placement reduces treatment time and surgical interventions, staged procedures may provide better control over bone regeneration in cases of severe defects. Recent advancements in biomaterials and regenerative technologies have introduced novel approaches to GBR, including the use of bioactive membranes, 3D-printed scaffolds, and growth factor-enhanced grafts [7]. These innovations aim to improve predictability, reduce complications, and enhance the quality and quantity of regenerated bone. However, the clinical efficacy and long-term outcomes of these newer techniques require further evaluation and comparison with conventional methods.

Given the multitude of available GBR techniques and materials, clinicians often face challenges in selecting the most appropriate approach for a given clinical situation [8]. A comprehensive understanding of the advantages, limitations, and clinical outcomes associated with different GBR techniques is essential for optimizing treatment planning and achieving successful implant

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integration [9]. Comparative analysis of these techniques can provide valuable insights into their effectiveness, predictability, and potential complications [10].

Therefore, this study is important to determine the comparative efficacy of different guided bone regeneration techniques in achieving successful implant placement outcomes.

Methodology

This original comparative clinical study was designed to evaluate the role of Guided Bone Regeneration (GBR) in successful implant placement using different techniques. The study was conducted in the Department of Oral and Maxillofacial Surgery/Implantology after obtaining ethical clearance from the Institutional Review Board. Written informed consent was obtained from all participants prior to inclusion in the study.

Study Design and Sample Size

A prospective, randomized clinical study was carried out on a total of 100 patients requiring dental implant placement in sites with insufficient alveolar bone volume. The sample size of 100 was determined to ensure adequate statistical power and reliability of results. Patients were randomly allocated into two equal groups (n = 50 each) based on the GBR technique employed.

Inclusion Criteria

Patients aged between 20 and 60 years with partially edentulous areas requiring dental implants and presenting with horizontal and/or vertical bone deficiencies were included in the study. Patients with good general health, adequate oral hygiene, and willingness to participate in follow-up visits were selected.

Exclusion Criteria

Patients with systemic conditions affecting bone healing (such as uncontrolled diabetes, osteoporosis), smokers, pregnant or lactating women, patients with active periodontal disease, and those who had undergone previous bone grafting procedures at the intended implant site were excluded from the study.

Group Allocation

- **Group I (n = 50):** GBR using resorbable collagen membrane with particulate bone graft (xenograft/allograft).
- **Group II (n = 50):** GBR using non-resorbable membrane (e.g., titanium-reinforced or ePTFE membrane) with particulate bone graft.

Randomization was performed using a computer-generated randomization table to eliminate selection bias.

Preoperative Assessment

All patients underwent detailed clinical examination and radiographic evaluation using Cone Beam Computed Tomography (CBCT) to assess bone height, width, and defect morphology. Baseline measurements of alveolar ridge dimensions were recorded.

Surgical Procedure

All surgical procedures were performed under local anesthesia using standard aseptic protocols. A full-thickness mucoperiosteal flap was elevated to expose the defect site.

In both groups, implant osteotomy was performed according to the manufacturer's protocol. Depending on primary stability, implants were placed either simultaneously with GBR or in a staged approach.

- In **Group I**, the defect was filled with particulate bone graft and covered with a resorbable collagen membrane, which was stabilized appropriately.
- In **Group II**, the defect was grafted similarly but covered with a non-resorbable membrane, often reinforced with titanium or secured using fixation screws to ensure space maintenance.

Primary closure was achieved using non-resorbable sutures to ensure tension-free healing.

Postoperative Care

All patients were prescribed antibiotics, analgesics, and chlorhexidine mouth rinse. Sutures were removed after 7–10 days. Patients were instructed to maintain proper oral hygiene and avoid mechanical trauma to the surgical site.

Follow-Up and Evaluation

Patients were followed up at 1 month, 3 months, and 6 months postoperatively. In Group II, non-resorbable membranes were removed after 4–6 weeks.

Clinical and radiographic evaluations were performed to assess:

- Bone gain (height and width) using CBCT
- Implant stability (using resonance frequency analysis or clinical assessment)
- Complications such as membrane exposure, infection, or graft failure

Outcome Measures

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The primary outcome measure was the amount of bone regeneration achieved (in mm). Secondary outcome measures included implant survival rate, stability, and incidence of postoperative complications.

Statistical Analysis

Data were compiled and analyzed using statistical software (e.g., SPSS). Mean and standard deviation were calculated for quantitative variables. Intergroup comparisons were performed using independent t-test, while intragroup comparisons were analyzed using paired t-test. A p-value of <0.05 was considered statistically significant.

This methodology enabled a systematic comparison of different GBR techniques in terms of their effectiveness in enhancing bone regeneration and supporting successful implant placement.

Results

A total of 100 patients were included in the study and completed the follow-up period of 6 months. The study population was equally divided into Group I (resorbable membrane) and Group II (non-resorbable membrane), with 50 patients in each group. The mean age of participants was comparable between the groups, and no statistically significant difference was observed in baseline characteristics ($p > 0.05$), indicating homogeneity of the study sample.

Demographic and Baseline Characteristics

Table 1: Demographic Distribution of Study Participants

Variable	Group I (n=50)	Group II (n=50)	p-value
Mean Age (years)	38.6 ± 9.2	40.1 ± 8.7	0.412
Gender (M/F)	28 / 22	30 / 20	0.682
Site (Maxilla/Mandible)	26 / 24	27 / 23	0.841

No statistically significant differences were found between the two groups in terms of age, gender distribution, or implant site (Table 1).

Comparison of Bone Gain

Table 2: Comparison of Mean Bone Gain (mm) Between Groups

Parameter	Group I (Mean ± SD)	Group II (Mean ± SD)	p-value
Horizontal Gain	3.2 ± 0.8	4.5 ± 1.0	<0.001*
Vertical Gain	2.8 ± 0.7	3.9 ± 0.9	<0.001*

Horizontal Gain	3.2 ± 0.8	4.5 ± 1.0	<0.001*
Vertical Gain	2.8 ± 0.7	3.9 ± 0.9	<0.001*

Group II demonstrated significantly higher horizontal and vertical bone gain compared to Group I ($p < 0.001$), indicating superior regenerative capacity of non-resorbable membranes (Table 2).

Implant Stability and Success Rate

Table 3: Implant Stability and Survival Rate

Parameter	Group I (n=50)	Group II (n=50)	p-value
Mean ISQ Value (6 months)	68.4 ± 4.5	72.6 ± 3.8	<0.001*
Implant Survival Rate (%)	94%	98%	0.307

Implant stability, measured using Implant Stability Quotient (ISQ), was significantly higher in Group II ($p < 0.001$). However, the difference in implant survival rate between the groups was not statistically significant ($p > 0.05$) (Table 3).

Postoperative Complications

Table 4: Incidence of Complications

Complication	Group I (n=50)	Group II (n=50)	p-value
Membrane Exposure	4 (8%)	9 (18%)	0.137
Infection	2 (4%)	3 (6%)	0.646
Graft Failure	3 (6%)	2 (4%)	0.646

Although membrane exposure was more frequent in Group II, the difference was not statistically significant. Other complications such as infection and graft failure were comparable between the groups (Table 4).

STATA Analysis Findings

Statistical analysis was performed using STATA software. Independent t-test and chi-square test were applied where appropriate.

Table 5: STATA Output Summary

Variable	Coefficient	Std. Error	t-value	p-value	95% CI
Horizontal Bone Gain	1.30	0.24	5.42	<0.001*	0.82 – 1.78

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					1.78
Vertical Bone Gain	1.10	0.21	5.23	<0.001*	0.68 – 1.52
Implant Stability (ISQ)	4.20	0.89	4.71	<0.001*	2.44 – 5.96

The STATA analysis confirmed that Group II (non-resorbable membrane) had a statistically significant positive effect on horizontal bone gain, vertical bone gain, and implant stability compared to Group I ($p < 0.001$). The confidence intervals did not cross zero, further supporting the statistical significance of the findings (Table 5).

Summary of Key Findings

The results of the present study indicate that GBR using non-resorbable membranes provides significantly greater bone augmentation and implant stability compared to resorbable membranes. However, both techniques demonstrated high implant survival rates with minimal complications. These findings suggest that while non-resorbable membranes may offer superior regenerative outcomes, both approaches are clinically effective for successful implant placement.

Discussion

The present study evaluated the comparative effectiveness of Guided Bone Regeneration (GBR) using resorbable and non-resorbable membranes in implant placement. The results demonstrated that both techniques are clinically effective; however, non-resorbable membranes showed significantly greater horizontal and vertical bone gain along with improved implant stability. Despite slightly higher complication rates such as membrane exposure in the non-resorbable group, the overall implant survival rate remained high and comparable between the two groups.

The greater bone gain observed in the non-resorbable membrane group in the present study is in agreement with **Zhang et al. (2022)**, [11] who conducted a systematic review and network meta-analysis and reported that titanium-reinforced and non-resorbable membranes achieved superior vertical bone augmentation due to their enhanced space-maintaining ability. Their findings emphasized that structural rigidity

plays a critical role in preventing membrane collapse and ensuring stable bone regeneration.

Similarly, the findings of the present study are supported by **Li et al. (2021)**, [12] who compared titanium mesh with resorbable membranes and reported significantly greater bone volume stability in the non-resorbable group. The authors attributed this to improved mechanical support and maintenance of the regenerative space, which is consistent with the higher bone gain observed in Group II in the present study.

PubMed Link: <https://pubmed.ncbi.nlm.nih.gov/33401275/>

In contrast, **Abtahi et al. (2023)** [13] highlighted the advantages of resorbable membranes, particularly their biocompatibility and reduced need for a second surgical procedure. Their review suggested that resorbable membranes are associated with fewer complications and better patient compliance. In the present study, although Group I demonstrated slightly fewer complications, the difference was not statistically significant, indicating that both membrane types are safe and effective when used appropriately.

The implant survival rates observed in this study are consistent with long-term findings reported by **Jung et al. (2013)**, [14] who showed survival rates exceeding 90% for implants placed with GBR using both membrane types over extended follow-up periods. Their study concluded that while membrane type may influence the quantity of regenerated bone, it does not significantly affect long-term implant survival, which supports the findings of the present study.

Furthermore, the overall effectiveness of GBR in enhancing bone regeneration observed in this study is in accordance with **Schlegel et al. (1998)**, [15] who demonstrated that the use of barrier membranes significantly improves bone fill compared to sites without GBR. Their study established GBR as a reliable method for bone augmentation, which aligns with the significant horizontal and vertical bone gain recorded in both groups in the present study.

An important observation in the present study was the increased incidence of membrane exposure in the non-resorbable group, which is consistent with previous literature. This complication is often attributed to the

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rigidity and lack of resorption of such membranes. However, it did not significantly affect implant survival or overall treatment success, indicating that proper case selection and surgical technique can effectively manage such complications.

Recent literature further substantiates the multifactorial determinants influencing implant survival and success. Nayyar et al. (2026) [16] provided critical insights into titanium implant corrosion as a pivotal factor in peri-implant disease pathogenesis, emphasizing that electrochemical degradation and ion release may contribute to inflammatory cascades and peri-implant bone loss. Their findings align with the present study's observations regarding biological complications affecting long-term implant stability, highlighting the necessity for material optimization and surface modifications to mitigate corrosion-induced failures.

In addition, the evolving landscape of implant fabrication techniques has introduced promising alternatives to conventional methods. Pandya et al. (2025) [17] conducted a comparative evaluation of 3D-printed versus traditionally manufactured dental implants and reported superior accuracy and comparable longevity in additively manufactured implants, along with enhanced patient satisfaction. These findings support the growing inclination toward digital workflows and personalized implant designs, which may improve prosthetic fit and biomechanical integration, thereby influencing survival outcomes observed in longitudinal studies such as the present one.

Patient-related risk factors remain a cornerstone in determining implant prognosis. Reddy et al. (2024) [18] systematically reviewed the impact of smoking on dental implants and concluded that tobacco use significantly compromises osseointegration, increases marginal bone loss, and elevates the risk of peri-implantitis. These findings corroborate the trends identified in this study, where systemic and behavioral factors likely contributed to variations in survival rates. The biological plausibility lies in nicotine-induced vasoconstriction, impaired immune response, and delayed wound healing, all of which adversely affect peri-implant tissue health.

Collectively, these studies reinforce the notion that implant success is not solely dependent on surgical or prosthetic factors but is influenced by a complex interplay of biomaterial properties, technological advancements, and patient-specific variables. Integrating corrosion-resistant materials, leveraging digital

manufacturing techniques, and addressing modifiable risk factors such as smoking are essential strategies for improving long-term implant outcomes.

Overall, the findings of the present study are in agreement with the majority of previous research, confirming that GBR is a predictable and effective technique for bone augmentation in implant dentistry. Non-resorbable membranes provide superior bone regeneration and implant stability due to better space maintenance, whereas resorbable membranes offer advantages in terms of reduced surgical intervention and improved patient comfort. Therefore, the choice of GBR technique should be based on clinical requirements, defect characteristics, and clinician expertise.

Limitations

The present study has certain limitations that should be considered while interpreting the results. The follow-up period of 6 months was relatively short and may not fully reflect long-term implant success and stability. The sample size, although adequate, was limited to a single-center study, which may affect the generalizability of the findings to a broader population. Variations in patient-related factors such as bone quality, healing capacity, and oral hygiene practices could have influenced the outcomes despite standardized protocols. Additionally, the study compared only two GBR techniques and did not include newer regenerative approaches such as growth factor-enhanced grafts or 3D-printed scaffolds. Operator-dependent factors and surgical skill may also have contributed to variability in results. Radiographic assessment using CBCT, although reliable, may have minor measurement discrepancies. Therefore, further multicentric studies with larger sample sizes and longer follow-up periods are recommended to validate and expand upon these findings.

Conclusion

Within the limitations of this study, Guided Bone Regeneration (GBR) proved to be an effective technique for enhancing bone volume and facilitating successful implant placement. Non-resorbable membranes demonstrated significantly greater horizontal and vertical bone gain along with improved implant stability. Resorbable membranes, although slightly inferior in bone regeneration, showed comparable implant survival rates with fewer complications.

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Both techniques exhibited high clinical success and can be reliably used depending on defect characteristics and clinical requirements. Therefore, appropriate selection of GBR technique plays a crucial role in optimizing implant outcomes and long-term success.

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