Comparative Analysis of Guided Bone Regeneration and Allograft Materials in Periodontal Implant Treatment: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Guided Bone Regeneration (GBR) treatment with allograft materials finds regular use in periodontal implant procedures to rebuild the alveolar bone structure and boost implant success rates. This systematic review and meta-analysis aimed to evaluate the effectiveness of GBR with allografts versus other implant approaches to identify the most effective periodontal treatment.

Methods: This systematic review and meta-analysis were conducted according to the PRISMA 2020 guidelines. The literature retrieval was conducted using PubMed, Scopus, Web of Science, and Google Scholar up to May 2025. The relevant studies compared guided bone regeneration (GBR). The Cochrane tool and Newcastle-Ottawa Scale (NOS) were used to determine risk of bias for observational studies and RCTs, respectively. The RevMan 5.4.1 was deployed to conduct meta-analyses, and pooled estimates were obtained using a random-effect model. Heterogeneity was determined by the I2 statistic. GRADE framework was used for the certainty of evidence.

Results: 9 studies (5 RCTs, 3 observational, and 1 retrospective study) were included. Vertical/horizontal bone gain and peri-implant probing depth were the primary outcomes. Meta-analysis revealed significant bone gain results on GBR (SMD: 0.83, 95% CI: 0.31-1.34) and no significant difference on probing depth (SMD: 1.23, 95% CI: -0.75-3.22). Most studies had a low risk of bias. The probing depth had significant heterogeneity (I2 = 86%), whereas bone gain heterogeneity was not present (I2 = 0%).

Conclusion: Periodontal implant stability improves through GBR treatment beyond the use of allograft procedures, which still show effective results in clinical practice.

Keywords: Guided Tissue Regeneration, Periodontal, Bone Transplantation, Dental Implants, Alveolar Bone Loss, Treatment Outcome.

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INTRODUCTION

Successful periodontal implant therapy depends on effective bone regeneration procedures because Guided Bone Regeneration (GBR), in combination with allografts, serves as the core solution for rebuilding the alveolar bone structure and creating conditions for osseointegration [1]. This regenerative approach not only restores lost bone volume but also supports soft tissue integration and long-term implant stability, especially in compromised ridges where native bone is insufficient [2].

Guided Bone Regeneration achieves bone healing through membrane barriers that separate the defect from the rest of the tissue space, followed by cell repopulation selection mechanisms, and allografts function as scaffolding structures for newly developing bones and their integration with host tissues [3]. The techniques aim to create enduring implant foundations and maintain long-term operational abilities. This biologically driven process is critical in both horizontal and vertical ridge augmentation, particularly in areas with severe atrophy [4]. Membranes help prevent epithelial downgrowth, while graft materials stimulate osteogenesis and space maintenance. Long-term data suggest that GBR combined with allografts leads to improved implant success rates and more predictable esthetic outcomes [5]. Clinicians report various outcomes between GBR techniques and allograft procedures, specifically regarding bone volume expansion and treatment duration, and implant success [6].

The treatment benefits of GBR methods exceed those of allografts through their ability to control tissue regeneration, although allografts offer advantages regarding material availability and osteoconductive properties [7]. Peri-implant bone conditions alter following implant procedures and create an impact on the general success of periodontal implants. Studies have shown that GBR procedures result in significantly greater bone volume gain and reduced probing depth compared to graft-only approaches [8]. However, clinical outcomes may vary depending on defect morphology, membrane type, and patient-specific healing capacity. As such, personalized treatment planning remains essential for optimizing regenerative outcomes [9].

Research success faces implementation barriers because surgeons use different methods in combination with individual patient needs and varying characteristics of reconstructive materials during treatment [10]. The differing situations introduce obstacles in the development of standardized therapeutic guidelines while making it difficult to correctly anticipate clinical results. There is now an increasing necessity for detailed assessment methods that enable clinicians to receive better guidance [11].

This systematic review and meta-analysis aimed to assess the clinical effectiveness of Guided Bone Regeneration with allograft materials and other periodontal implant treatment approaches to establish the most effective treatment option for periodontal implantation in patients.

METHODS

Study Design

This meta-analysis and systematic review were performed following the guidelines of PRISMA 2020 [12].

Literature Search Strategy

A search was conducted on the four main databases, including PubMed, Scopus, Web of Science, and Google Scholar, to obtain all the literature on the subject matter published till May 2025. Only the articles written in English were taken into account. The search strategy mixed acceptable keywords and MeSH terms that were: "guided bone regeneration", "GBR", "allograft", "freeze-dried bone allograft", "FDDBA", "horizontal bone gain", "vertical bone gain", "peri-implant probing depth", and "PRF". Refinement of the results through Boolean operators and filters was done.

The search criteria encompassed the randomized controlled trials (RCTs), prospective cohort studies, and observational studies on the comparison of guided bone regeneration (GBR). Studies were excluded where they were not clinical studies, animal studies, review studies, case reports, in vitro, or had no reporting of clinical outcome within the scope of objectives.

Outcomes Studied

The primary outcomes assessed were horizontal or vertical bone gain (mm) or peri-implant probing

depth (mm). Secondary ones have been taken into account, PROMs, soft tissue thickness, rate of implant success, and complications.

There were three stages of study selection, i.e., title, screening, abstract, and full-text screening. All records were screened by two reviewers who excluded any differences with the help of discussion or by inviting a third reviewer to help make an agreement. No automated systems were applied in this process.

Data Screening

Two independent reviewers used a form that contains a standardized data extraction form. The elements to be retrieved were the author, year, study design, sample size, intervention and control arms, outcome measures, follow-up period, and the estimate of effects like standardized mean difference (SMD) of continuous outcomes. In case of the absence of numerical data, researchers would derive estimates based on graphs or contact the authors. No automated systems were applied in this process.

Quality Assessment

Risk of bias within randomized trials was assessed using the Cochrane Risk of Bias tool, whereas the observational studies were analyzed using the Newcastle-Ottawa Scale (NOS). The certainty of evidence regarding the outcomes was determined with the help of GRADE. Nine studies overall were selected to undergo a final analysis, which include four randomized controlled trials, four observational studies and one retrospective observational study [13,14,15,16,17,18,19,20,21].

Data Synthesis

Review Manager (RevMan) was used to conduct meta-analyses, version 5.4.1. Pooled effects for continuous outcomes, which include: vertical/ horizontal bone gain and probing depth, were estimated based on the inverse variance approach in a random effects model. Standardized Mean Difference (SMD) was used for outcomes measured on different scales, such as probing depth and bone gain, across heterogeneous measurement methods. The I2 statistic was utilized to measure heterogeneity, and a value greater than 50% indicated the presence of moderate to high heterogeneity. The narrative synthesis was presented where meta-analysis was inappropriate because of the inconsistency of data or the few numbers of studies.

Outcome type (e.g., horizontal versus vertical bone gain) was used as a subgrouping variable in the analysis. Sensitivity analyses were performed by omitting studies with small sample sizes or moderate risk of bias to assess their impact on the overall estimates. Where necessary, standard deviations were imputed using established statistical methods to allow for inclusion in the meta-analysis.

The pooling effect estimate was captured on the forest plots, and the summary tables were formulated to outline the major study characteristics and outcomes.

RESULTS

A total of 9 studies out of 114 initial reports were included after full-text analysis as fulfilling the inclusion criteria. Studies were retained if they compared guided bone regeneration (GBR) with allografts or other graft materials in clinical periodontal implant procedures and reported at least one primary outcome; horizontal/vertical bone gain or peri-implant probing depth. Studies were excluded if they were animal or in vitro studies, reviews, case reports, lacked a comparator group, or did not report relevant clinical outcomes. Only RCTs, prospective cohort, or observational designs were considered eligible.

The selection of the studies based on the PRISMA diagram is presented in **Figure 1.**

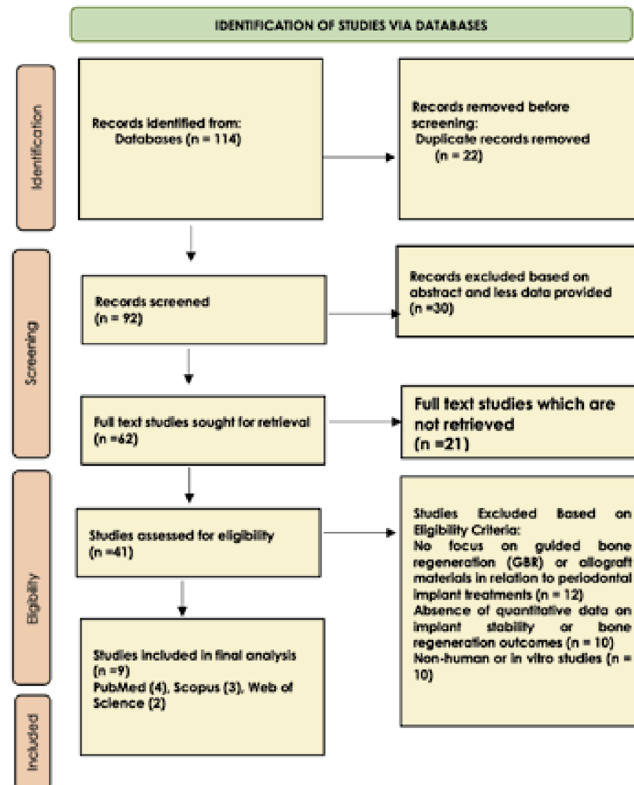

Figure 1: PRISMA flow diagram for Study Selection. The flowchart was designed according to the PRISMA guidelines 2020, showing study identification, screening, assessment eligibility, and final selection in the systematic review.

Characteristics of Studies

9 studies containing about 258 patients were reviewed, and their results were used to evaluate the clinical outcome of guided bone regeneration (GBR) using membranes, allografts, or a combination of two or more. There were randomized controlled studies (n=4), observational studies (n=3), and retrospective studies (n=1). Experimental and control groups were well defined in four studies and others by comparative observation methods.

Vertical or horizontal bone gain; peri-implant probing depth (PD) was the main outcome. Other secondary outcomes encompassed soft tissue recession, crestal resorption, opening of the wound, and patient-reported outcome measures (PROMs) with regard to pain, swelling, and OHIP-14. Although the majority of works found positive results of GBR, the greatness and stability of impact were diverse in the different works.

Outcomes Studied

The studies have provided two main clinical outcomes, which include horizontal and/or vertical bone gain (in mm) and peri-implant probing depth (PD). The radiographic or direct intra-operative bone gain that was measured was found to be better at the sites that had undergone GBR as compared to those that were treated using allografts alone. One study found that the statistical comparison between the GBR group and the open flap debridement control group showed a 3.0 mm vertical bone gain with the former and underscored more significant generic vertical bone gain in the former (3.0 mm) vis-a-vis the latter (0.4 mm) ($p < 0.001$), whereas the other study found that there was consistence in the horizontal ridge augmentation between the two groups but the difference has no statistical significance ($p = 0.05$).

Another important finding was probing depth reduction, and according to two RCTs, the changes occurred during follow-up stages that ranged between 6 and 12 months. Another study showed a decrease in the mean probing depths of 1.7 mm and 0.9 mm in the experimental and control groups, respectively. One other trial reported comparable decreases in both sets, indicating that both modes of treatment may be used to improve the peri-implant soft tissue health, but the combined modality (e.g., GBR-allograft) could produce more favorable outcomes.

Soft tissue recession, pain, swelling, and patients' reported oral health quality of life were among secondary outcomes. PROMs were somewhat different, but they did not differ significantly among groups. All in all, the data accentuates the regenerative capacity of GBR-based methods to increase bone volume and maintain peri-implant tissue health, and stresses the necessity to conduct long-term studies in order to prove the advantages under a wide range of clinical applications.

Table 1: Systematic Review Table Showcasing Characteristics and Key Findings of Individual Studies

Sr No.	Author & Year	Sample Size	Experimental Groups	Control groups	Study Design	Outcomes Measured	Secondary Outcomes	Key Findings
1.	**Kofina et al., 2023**	27	*NR*	*NR*	Observational Study	Pain, swelling, difficulty in opening, and wound opening	None explicitly mentioned	PROMs varied slightly between the GBR and allograft groups
2.	**Wang et al., 2022**	19 patients	*NR*	*NR*	Observational Study	Horizontal bone mass at different levels	Soft tissue complications and adverse effects	Guided bone regeneration showed superior horizontal gain and implant stability, with fewer complications compared to allografts.
3.	**Lee et al., 2022**	14 patients	*NR*	*NR*	Observational Study	Profilometric changes	Volumetric changes	GBR with CTG improved peri-implant stability.
4.	**Dawar et al., 2025**	27	*NR*	*NR*	Observational Study	Pain, swelling, difficulty in opening, oral health quality of life (OHIP-14)	None explicitly mentioned	Short-term outcomes after GBR or allograft correlated with better quality of life.
5.	**Yun-Ho Park et al., 2017**	21 patients	9	12	Retrospective observational study	Vertical bone gain	Peri-implant marginal bone loss, Vertical bone gain,	Greater vertical bone gain with autografts.
6.	**C.R. Anderegg et al., 1991**	30	15	15	Randomized Controlled Trial (RCT)	Probing Depth	Soft tissue recession, bone repair	Combined GBR with DFDBA showed superior bone regeneration
7.	**D.G. Metzler et al., 1991**	34	17	17	RCT	Probing pocket depths	Soft tissue recession, attachment levels, crestal resorption, and bone repair	Both groups showed clinical improvement; combined approaches enhanced HOPA and VOPA outcomes.
8.	**Meadows et al., 1993**	20 patients	10	10	RCT	Vertical bone gain	Soft tissue recession, probing pocket depths	Significant bone regeneration was observed
9.	**Mau et al., 2019**	48 patients	*NR*	*NR*	RCT	mPI, mSBI, PD, KM, at 12 months	None explicitly mentioned	No significant differences were observed

Meta-Analysis

Review Manager (RevMan) version 5.4.1 was used to perform the meta-analysis due to the inverse variance method, based on a random-effect model. Standardized Mean Difference (SMD) and 95% Confidence Intervals (CIs) were used to determine the effectiveness of guided bone regeneration (GBR) techniques in reducing peri-implant probing depth (PD) through the comparison with controls. The effect sizes were created as forest plots.

There were two studies, each with 19 and 22 subjects in the experimental and the control group, respectively, reporting the PD outcomes. The pooled outcome gave an SMD of 1.23 [95% CI: -0.75 to 3.22] that is not significantly different among groups. Overall effect test was insignificant (p> 0.05. Ample heterogeneity (I^2 = 86%, p = 0.01) indicates that the studies were inconsistent, most likely because of the clinical or methodological differences in their effect size or direction. **Figure 2** presents a forest plot showing the standardized mean difference (SMD) in probing depth between GBR and control interventions. Each study is represented by a point and confidence interval on the plot. Values to the right of the center line indicate a greater reduction in probing depth with GBR. Values to the left suggest better outcomes with the control treatment.

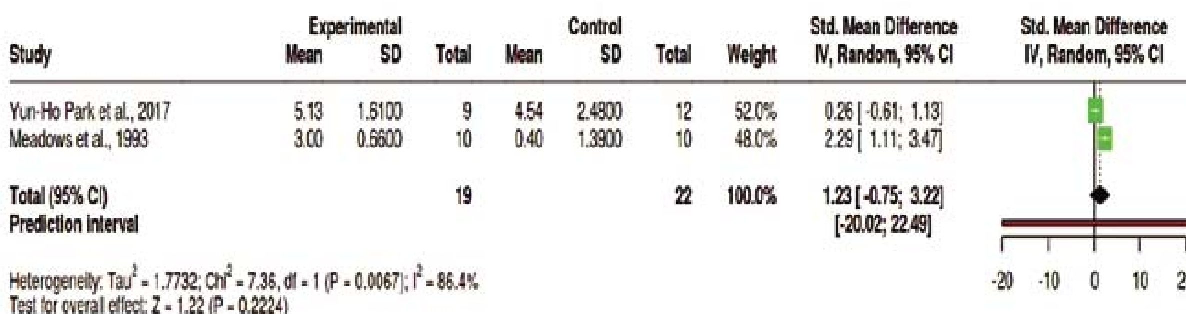

Figure 2: The Forest plot representation of standardized mean difference (SMD) of probing depth against GBR versus control interventions. The value to the right of the center line is evidence of the fact that there is a higher value of probing depth reduction linked to GBR, and vice versa.

The comparison of the vertical bone gain results between the guided bone regeneration (GBR) and the control was conducted with the help of the forest plot that is displayed in **Figure 3**. The first study considered vertical bone gain in GBR with autogenous block grafts and compared them with other substitutes, and the second study considered bone fill in GBR with decalcified freeze-dried bone allograft (DFDBA) in comparison with flap debridement. The pooled estimate represents a mean standardized mean difference of 0.83[95% CI: 0.31, 1.34], which means that the effect of GBR on the bone gain is statistically significant ($p < 0.05$).

There was really no significant indication of heterogeneity (I^2 = 0%), which suggests that studies were comparable in terms of the size of results and direction.

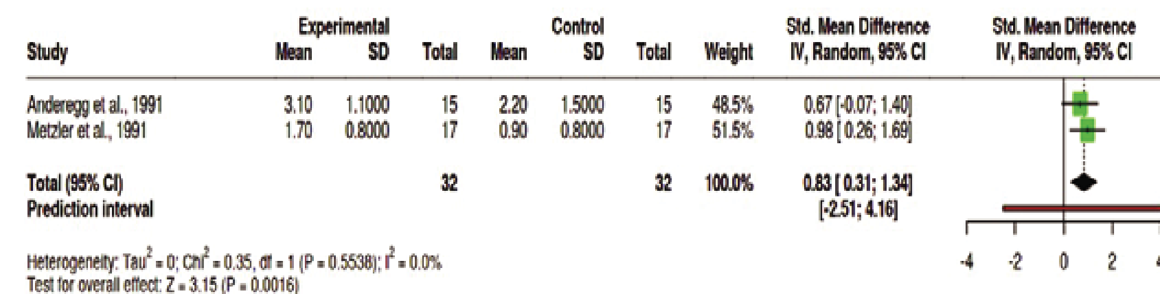

Figure 3: Forest plot of standardized mean differences (SMD) vertical bone gain regarding GBR versus control interventions. The numbers on the positive side of the center line signify increased levels of bone gain because of GBR, whereas the figures on the negative side signify increased levels in the control group.

Subgroup Analyses

Within the bone gain subgroup, two randomized controlled trials evaluated the comparative merits of GBR-based interventions, compared to control periodontal interventions, on the ability to induce vertical or horizontal bone regeneration. One study indicated that the average vertical gain in the bone treated with guided tissue regeneration (GTR) and decalcified freeze-dried bone allograft (DFDBA) showed a mean gain of 3.0 mm in the bone as compared to 0.4 mm average gain in the control group who were given flap debridement treatment. The amount of crestal bone loss also decreased in the GTR group, where (0.6mm) was less compared to the control (1.3mm), which suggests reversal of bone resorption. Similarly, the sites where DFDBA was used obtained a percentage filling of 65 bondless fill (mean gain: 3.0 mm), the only-debridement sites only 11.2 percent (0.4 mm), and the polylactic acid (PLA) 2.2 percent (0.1 mm). All of these studies showed that GBR with bone grafts, such as DFDBA, showed far more vertical or horizontal bone gain than the non-grafted control.

In the subgroup reduction of probing depth, 2 trials examined the effects on improvements to the parameters of peri-implant soft tissues. One trial noted that the probing depth decreased 3.1 +/- 1.1 mm in the GBR + DFDBA group, as opposed to 2.2 +/- 1.5 mm at the membrane-only control. Similarly, probing depth decreased by 1.7 +/- 0.8 mm in the GBR group as compared to the reduction by 0.9 +/- 0.8 mm in the control group. The results of the two related articles were similar and indicated that there was a definite pattern of improvement in the amount of reduction in probing depth when the GBR and allograft materials were used in the healing and soft tissue closure of pockets.

Sensitivity Analyses

The subgroup of probing depth outcome outcomes (2 studies) was found to be rather heterogeneous (I^2 = 86%). The exclusion of one or the other study in the sensitivity test portrayed significant changes in the pooled effect size, and reduced heterogeneity to 55% and 0%, respectively, thus indicating an unstable outcome. This inconsistency can be explained by variations in the study design, operating procedure, or the initial probing levels amongst the groups.

The subgroup of bone gain produced more consistent results in both of the reviewed studies, with comparatively small heterogeneity. When each study is removed, the overall effect does not change meaningfully, which adds credibility to the outcome of the bone gain concerning the effectiveness of guided bone regeneration using allografts.

Although the sensitivity analysis demonstrates the robustness of the results of vertical and horizontal bone gain, more methodologically homogeneous researches are required to investigate the depth reduction procedure in the search for firmer conclusions.

Risk of Bias

Based on the design of the study, the risk of bias was assessed with relevant tools. The Newcastle-Ottawa Scale (NOS) was used to evaluate observational studies, and the Cochrane Risk of Bias Tool was used to evaluate randomized controlled trials (RCTs).

NOS scores were between 7 and 8 out of 9 in all five observational studies, which meant a low risk of bias. These studies exhibited a high quality of methodology, involved in the selection of participants, comparability, and measurement of outcomes, also high.

In the selected RCTs, studies proved to have a low to moderate risk of bias across all domains, with adequate sequence generation, allocation concealment, and blinding. Nonetheless, the risk of all the RCTs was low in major methodological categories such as blinding of the outcomes and data completeness.

The evidence from both observational and experimental studies did not raise many issues of systematic bias; overall, it was acceptable. Such evaluations assist in the internal validity of the data incorporated in the study, yet the future inclusion of RCTs that are thoroughly designed will be necessary to clarify the findings with greater definitiveness. The GRADE assessment rated the overall study as moderate.

Table 2: Risk of Bias Assessment of Observational Studies

Study	Selection (max 4)	Comparability (max 2)	Outcome (max 3)	Total Score (max 9)	Interpretation
Kofina et al., 2023	★★★	★★	★★★	8	Low
Wang et al., 2022	★★★	★★	★★★	7	Low
Lee et al., 2022	★★★	★★	★★★	8	Low
Dawar et al., 2025	★★★	★★	★★★	8	Low
Yun-Ho Park et al., 2017	★★★	★★	★★★	8	Low

Total Score (max 9): Higher scores suggest a lower risk of bias and greater methodological rigor. 7–9 stars: Low risk of bias, 4–6: Moderate risk of bias, <4: High risk of bias

Table 3: Risk of Bias Assessment of Individual RCTs

Study	Sequence Generation	Selection Bias	Allocation Sequence Concealment	Blinding of Participants and Personnel (Performance Bias)	Blinding of Outcome Assessment (Detection Bias)	Incomplete Outcome Data	Selective Outcome Reporting	Other Bias
C.R. Anderegg et al., 1991	+	+	+	±	+	+	+	+
D.G. Metzler et al., 1991	+	+	+	±	+	+	+	+
Meadows et al., 1993	+	+	+	+	+	+	+	±
Mau et al., 2019	+	+	+	+	+	+	+	±

"+" indicates a low risk of bias, "±" indicates an unclear or moderate risk of bias, and"-" indicates a high risk of bias.

DISCUSSION

Periodontal implant therapies continue to evolve with advancements in biomaterials and regenerative techniques that aim to restore function and aesthetics. Among these, regenerative approaches are preferred when bone defects compromise implant placement or long-term stability [22]. The combination of membranes and grafting materials has gained clinical significance due to their synergistic roles in promoting predictable bone fill and integration. The medical practice of periodontal implant treatment supports GBR with allograft materials as established procedures to boost results for patients whose alveolar bone requires enhancement [23]. The medical practice of periodontal implant treatment supports GBR with allograft materials as established procedures to boost results for patients whose alveolar bone requires enhancement [24].

GBR establishes an isolated space that prioritizes new bone growth by using membranes that dissolve or remain intact in the periodontium. The treatment

method allows for precise bone regeneration that results in positive results regarding marginal bone preservation and implant stability [25,26]. Experimental evidence from reviewed studies proved that the use of GBR treatment led to successful implant survival results, particularly during vertical and horizontal bone defect situations [27].

The use of allograft materials from human donors represents a practical approach that connects effectively due to their osteoconductive properties and biological features, and decreased requirement for extra surgical procedures [28,29]. Tests of allografts showed both moderate and high implant success rates, together with improved bone filling; however, the research data showed some variability in outcomes [30].

The observed differences stem from how allografts are processed, while patients generate different immune system responses, and their defects present various complexities. The use of allografts alone in extensive defects leads to increased vulnerability of graft resorption as well as decreased effectiveness in maintaining open spaces [31]. Variability in clinical outcomes may also arise from differences in anatomical site morphology, vascular supply, and graft-host integration rates. Additionally, the mechanical stability and volume maintenance offered by allografts can be insufficient in larger or poorly contained defects without the support of barrier membranes [32]. Patient-related factors such as age, systemic health, and oral hygiene further influence regenerative success [33].

The clinical outcomes of GBR and allograft procedures improved significantly, yet GBR produced marginally better results regarding defect reconstruction and long-term implant connection. The maintenance of proper regenerative space, along with bone cell differentiation toward bone formation, accounts for the improved outcomes of this treatment approach [34]. Furthermore, the barrier membrane used in GBR prevents soft tissue invasion, allowing osteogenic cells to populate the defect site efficiently [35]. This controlled healing environment enhances the quality and quantity of regenerated bone, which is essential for stable implant placement. Over time, this leads to improved structural integrity and load-bearing capacity of the peri-implant bone [36].

Members of the dental community are now using both techniques together to boost healing capabilities in practice. Research investigations highlighted that treatment effects can be influenced by patient healthcare conditions, alongside oral hygiene practices and smoking behaviors [37].

The integration of guided bone regeneration (GBR) with allograft materials continues to demonstrate superior clinical effectiveness in managing peri-implant defects [38]. While both techniques support bone healing, GBR enhances space maintenance and selective cellular repopulation, leading to improved outcomes in bone volume and implant stability [39]. As periodontal regenerative procedures evolve, combining GBR with suitable grafting materials remains a pivotal strategy for optimizing patient care and ensuring long-term success of dental implants [40].

The included studies displayed inconsistencies relating to their surgical procedures, as well as membrane products and graft types, and durations of patient follow-up. The consistent positive results derived from the wide array of GBR protocols strengthen the reliability of concluding findings, although direct comparisons remain complicated by publication bias and the restriction to English-language articles, which could have influenced the breadth of included evidence. But this work also depicted the necessity for extensive randomized trials to set standard procedures based on individual patient conditions in the future.

CONCLUSION

The systematic evaluation and analysis demonstrate that periodontal implant treatments achieve better results through the combination of guided bone regeneration (GBR) with allograft materials. The application of GBR technology strengthens bone generation and space preservation processes, which leads to better implant stability. The clinical results become better when allografts are combined with GBR procedures compared to a single use of either technique separately.

Due to diverse research approaches, the clinical applications of both treatment methods remain effective. Standardized clinical trials must be conducted to validate these results so implant dentistry can adopt the best regenerative protocols.

LIST OF ABBREVIATIONS

GBR - Guided Bone Regeneration
PRF - Platelet-Rich Fibrin
PROMs - Patient-Reported Outcome Measures
CTG - Connective Tissue Graft
OHIP-14 - Oral Health Impact Profile-14
DFDBA - Demineralized Freeze-Dried Bone Allograft

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None

CONFLICT OF INTEREST

None

AUTHORS' CONTRIBUTION

All Authors participated equally as per ICMJE.

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