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MEMBRANE EXPOSURE MANAGEMENT AMONG PATIENTS UNDERGOING GUIDED BONE REGENERATION: A SYSTEMATIC REVIEW

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Abstract

This systematic review aimed to evaluate various approaches to guided bone regeneration (GBR) in implant dentistry using collagen membranes and particle grafting materials. A meta-analysis was conducted on studies published between 2001 and 2023, including prospective controlled research and randomized clinical trials. Main outcomes included survival rates, membrane exposure rates, bone gain/defect reduction, and vertical bone loss. Ten studies met the inclusion criteria. The rates of implant survival were comparable between simultaneous and later implant placement. Cross-linked membranes had a higher membrane exposure rate compared to non-cross-linked membranes. Membrane cross-linking, timing of implant placement, membrane fixation, and decortication were identified as influential factors on outcomes.

Keywords: membrane exposure, guided bone generation, collagen membrane, randomized control trials

Introduction

The basis for primary implant stability and long-term implant success is provided by alveolar ridge size. Clinicians must address bone deficits as soon as possible in the treatment planning phase because they provide an immediate risk. According to Buser et al. [1], the genesis of ridge deficits might be either anatomical or pathologic in character. Several writers have created categorization systems in an effort to standardize defect criteria [2]. Based on the development of ridge resorption after edentulism, each author characterized three distinct kinds of ridge deficiencies: vertical, horizontal, and a mix of the two dimensions. Sufficient horizontal and vertical ridge dimensions are necessary for optimal treatment results when assessing an edentulous location for future implant implantation. Tarnow et al. [3] also suggested that in order to accommodate ideal interproximal bone levels and for papilla support, there should be a minimum of 1.5 mm between an implant and the adjacent root and a minimum of 3 mm between two adjacent implants. This would help to prevent further bone remodelling after implant placement. A number

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of methods have been put forward and are often used to strengthen weak ridges. One of the most popular methods is guided bone regeneration (GBR), which combines the use of grafting materials with a barrier that may be either an absorbable membrane or a non-resorbable membrane [1]. Other methods include the ridge-split method and the use of a bone block transplant [4]. Furthermore, it has also been suggested that distraction osteogenesis be utilized to strengthen the edentulous ridge. In order to repair both horizontal and vertical bone deficiencies at peri-implant locations, the "sandwich" approach has recently been developed [1]. All of these methods work well, but problems might arise in the healing stage of the course of therapy, leading to unintended consequences. Four basic concepts are necessary for successful GBR surgeries, and they must hold true both throughout the surgery and after the recovery process. The so-called "PASS" concept is made up of the following elements: primary closure, angiogenesis, space maintenance, and wound stability [1,5]. Any of these principles may become complicated, leading to early membrane exposure that might jeopardize the healing process. Clinicians should evaluate the quantity of keratinized mucosa, tissue biotype, vestibular depth, flap flexibility, type and size of bone defect, and type of membrane employed in order to reduce the risk of problems [6]. It has been determined that each of these elements contributes to membrane exposure.

Methodology:

1. **Study Selection:**
    - Inclusion Criteria: Studies published between 2001 and 2023 focusing on guided bone regeneration (GBR) in implant dentistry were included. Only prospective controlled research and randomized clinical trials were considered.
    - Exclusion Criteria: Studies that did not meet the inclusion criteria or did not report relevant outcomes were excluded.
2. **Search Strategy:**
    - Databases: Both manual and electronic searches were conducted in relevant databases, including PubMed, EMBASE, Web of Science, and Cochrane Central Register of Controlled Trials.
    - Search Terms: Keywords related to guided bone regeneration, collagen membranes, particle grafting materials, implant dentistry, and specific outcome measures were used.
3. **Study Selection Process:**
    - Two independent reviewers screened the titles and abstracts of identified studies to determine their eligibility.
    - Full-text articles of potentially relevant studies were retrieved and further assessed for inclusion based on the predefined criteria.
4. **Data Extraction:**
    - Data Extraction Form: A standardized data extraction form was used to collect relevant information from included studies, including study design, sample size, intervention details, and outcomes of interest.

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- Data Extraction Process: The reviewers independently extracted data from each included study, and any discrepancies were resolved through discussion or consultation with a third reviewer.

5. **Quality Assessment:**
    - Quality Criteria: The quality of included studies was assessed using appropriate tools for each study design, such as the Cochrane Risk of Bias Tool for randomized clinical trials.
    - Risk of Bias Assessment: The reviewers independently assessed the risk of bias in each included study, considering factors such as selection bias, performance bias, detection bias, attrition bias, and reporting bias.
6. **Data Synthesis and Analysis**:
    - Meta-analysis: Where appropriate, a meta-analysis was conducted to combine the results of included studies and estimate the overall effect size.
    - Subgroup Analysis: Subgroup analyses were performed based on different factors, such as membrane type, implantation time, membrane fixing, and decortication, to explore potential sources of heterogeneity.
    - Sensitivity Analysis: Sensitivity analyses were conducted to assess the robustness of the results by excluding studies with a high risk of bias or other potential sources of bias.
7. **Reporting:**
    - The results of the systematic review and meta-analysis were reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.
    - The findings were summarized narratively and presented in table to facilitate understanding and interpretation.

Results

Wessing et al.'s [7] meta-analysis from 2018 set out to assess several approaches for implant dentistry's guided bone regeneration using collagen membranes and particle grafting materials. Supplies and Procedures: All relevant studies published between 1980 and 2014 that addressed assisted bone regeneration in implant dentistry were found using both a manual and an electronic database search. Only prospective controlled research and randomized clinical trials were considered. Survival rates, membrane exposure rates, bone gain/defect reduction, and vertical bone loss during follow-up were the main outcomes of interest. A meta-analysis was carried out to ascertain the impacts of membrane cross-linking, implant implantation time, membrane fixing, and decortication. Findings: Twenty studies satisfied the requirements for inclusion. The rates of implant survival for implants placed simultaneously and later on were comparable. Cross-linked membranes had a membrane exposure rate that was almost 30% more than that of non-cross-linked membranes.

In order to ascertain the frequency of resorbable vs non-resorbable membranes and the timing of soft tissue problems, Lim et al. [2018] [8] carried out the current review. Supplies and

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Procedures: Two independent reviewers used several databases to perform manual and electronic searches for relevant material. In all, the qualitative and quantitative synthesis had 21 and 15 items, respectively. Weighted complications related to soft tissue dehiscence, acute infection/abscess, and membrane exposure were included in the computation; the incidence of weighted complications was 16.8% (95% CI = 10.6% to 25.4%). Resorbable membranes had a weighted complication rate of 18.3% (95% CI: 10.4% to 30.4%), and non-resorbable membranes had a rate of 17.6% (95% CI: 10.0% to 29.3%) when the complication rate was broken down by type of membrane utilized.

The purpose of the Hämmerle et al., [2002] [9] research was to evaluate the longevity of guided bone regeneration (GBR) implants in regenerated bone in comparison to implants in non-regenerated bone. Studies have to show outcomes after prosthetic restoration of titanium implants in bone regenerated by GBR, with or without membrane supporting materials, for at least 12 months in order to meet the inclusion criteria. Implant success, implant survival, lack of clinical implant mobility, lack of implant fracture, lack of increasing peri-implant crestal bone loss, and lack of peri-implant infection with suppuration were among the outcome metrics. For research from 1990 to May 2001, a manual search of pertinent scientific journals and a MEDLINE search were carried out. Five years after the operation, the cumulative success or survival rates of implants in regenerated bone varied from 100% to 79.4%. In the controlled clinical studies, there were no discernible differences between implants placed in non-regenerated bone and implants placed in regenerated bone.

Assessing the effect of membrane exposure on the results of guided tissue regeneration (GTR) and guided bone regeneration (GBR) procedures was the goal of this meta-analysis conducted by Machtei et al. [2001] [10]. Included were studies on GTR in Class II furcation and intrabony defects and GBR around dental implants. In order to compare the results between locations where the membrane stayed submerged (S) and sites where it became exposed (E) during healing, the primary approach entailed merging data from both investigations. The furcation database's mean horizontal attachment level (AL) increase was marginally higher in the submerged (S) locations than in the exposed (E) sites, according to the findings of a meta-analysis conducted by. Within the intrabony group, the S group had a greater mean increase in vertical AL than the E group. In the same way, the S sites in the GBR group had much more new bone development than the E sites. These results imply that the regeneration result of GTR and GBR surgeries may be adversely affected by membrane exposure during recovery. The sample size and standard deviation, which differed across the studies in the meta-analysis, might have an impact on how significant these conclusions are.

Comparing the complications of customized vs ordinary titanium mesh in edentulous alveolar ridge guided bone regeneration (GBR) was the primary goal of the research by Zhou et al. [2022] [11], with a particular emphasis on the incidence of titanium mesh exposure. Nine papers that were published between January 2010 and March 2020 and were obtained from databases such as PubMed, EMBASE, Web of Science, and Cochrane Central Register Controlled Trials were the subject of a meta-analysis. With a combined value of 31% for customized titanium mesh

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and 51% for ordinary titanium mesh, the study revealed that the overall exposure rate of titanium mesh was 44%. According to the research, bespoke titanium mesh has a lower exposure rate than traditional titanium mesh. This might be because of the design of the three-dimensional printing process, which avoids blood veins and nerves and improves GBR reconstruction accuracy while offering enough room for implantation. It was also noted that soft tissue management—such as technical sensitivity—was crucial to preventing soft tissue fractures throughout the process.

Cucchi et al.'s [2017] [12] randomized controlled study (RCT) sought to assess the rates of complications and vertical bone growth that resulted from two distinct approaches for guided bone regeneration (GBR). The research examined titanium meshes coated in cross-linked collagen membranes (Group B) and thick, non-resorbable, d-PTFE titanium-reinforced membranes (Group A). There were twenty patients in each research group, totalling forty partly edentulous individuals with atrophic posterior mandibles. Group B had treatment with titanium mesh coated in cross-linked collagen membranes, whereas Group A underwent GBR using non-resorbable d-PTFE titanium-reinforced membranes. A record of complications was kept, and they were divided into "surgical" and "healing," as well as "minor" and "major." Vertical bone growth and main implant stability were also evaluated. According to the findings, there were 5.0% and 15.0% of surgical and healing problems in Group A, respectively. The rates in Group B were 15.8% and 21.1%, correspondingly. On the other hand, no significant variations were seen in the complication rates, implant stability, or vertical bone growth between the two research groups.

Poomprakobsri et al.'s [2022] [13] research sought to examine the percentage of grafted bone dimensional loss with and without exposed barriers, as well as the exposure rates of three distinct barrier types after a guided bone regeneration operation. In order to identify participants who had bone grafting followed by implant implantation after the graft had fully healed, patient records from September 2007 to May 2015 were examined. Three groups of patients were assigned to each kind of barrier: titanium mesh, resorbable barrier, and non-resorbable barrier. The frequency of barrier exposure was noted, and the quantitative quantity of transplanted bone that remained, as well as the percentage of dimensional loss, were ascertained using cone-beam computed tomography scans. It was shown that 36.9% of all directed bone regenerations were exposed. Comparing the resorbable barrier (23.3%) to titanium mesh (68.9%) and the non-resorbable barrier (72.7%), the resorbable barrier's exposure rate was much lower. There was a statistically significant difference. Additionally, a substantial difference in grafted bone dimensional loss was found in the research between sites that were exposed to a barrier (58.3%) and sites that were not (44.1%) during the healing period. This implies that the exposure rate and dimensional changes of transplanted bone are significantly influenced by the kind of barrier that is employed.

Analyzing and describing the existing research on non-expanded and dense polytetrafluoroethylene (n-PFTE) as a membrane barrier for regeneration operations was the primary goal of Carbonell et al.'s literature study [2014] [14]. The review's objectives were to provide information on n-PFTE's indications for usage, benefits, drawbacks, surgical techniques, and problems. In addition to manually searching medical sources, including Medline-PubMed and the Cochrane Library, the study looked for papers on n-PFTE membranes that were released

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between 1980 and May 2012. Only in vitro, human, and animal research published in English-language dentistry publications were included in the search. Finding twenty-four publications that examined the use of n-PFTE as a barrier membrane for directed bone and tissue regeneration around implants and teeth was part of the research. There were two in vitro research, seven experimental studies, and fifteen clinical investigations in these papers. According to the research, there is currently little histological and clinical support for the use of n-PFTE membranes. Nonetheless, there were some signs that it may be used in newly extracted sockets and immediate implants for directed bone and tissue regeneration.

The purpose of Thoma et al.'s research [2019] [15] was to assess how well lateral bone augmentation techniques worked to address defects in the horizontal ridge after implant implantation. Studies with a minimum of 10 patients per group that were controlled clinical trials or randomized controlled trials with re-entry techniques were included. Subgroup analyses based on membranes and grafting materials were carried out as part of the meta-analyses. Findings from 28 articles (20 short-term, 8 follow-up studies) indicated that resorbable collagen membranes (CM) and xenogeneic particle grafting material (XE) were the most often used interventions. With a mean defect resolution of 81.3%, the mean defect height at baseline was 5.1 mm and dropped to 0.9 mm at re-entry. Between the combined data of the test groups and the control treatment utilizing CM+XE, there was no discernible difference in the defect height reduction. On the other hand, using a membrane and bone grafting material was preferable to the lack of any lateral bone augmentation. In a similar vein, the use of a membrane in conjunction with grafting material proved to be more advantageous than grafting material alone. It was preferable to provide a membrane in addition to grafting material alone. To sum up, following implant implantation, lateral bone augmentation is a successful therapy option for deficits in the horizontal ridge. It is advised to combine a barrier membrane with a grafting material for the best decrease of defect height.

Calciolari et al.'s comprehensive study [2023] [16] sought to determine how different biomaterials utilized for guided bone regeneration (GBR) during implant placement affected changes in bone defect dimensions and radiographic peri-implant bone stability. The only studies that were considered were controlled clinical trials (CCTs) and randomized controlled trials (RCTs) that compared various biomaterials for GBR. We performed a Bayesian network meta-analysis (NMA). The results showed that, irrespective of the biomaterial used, according to the biological principle of GBR, it produced predictable regeneration. Nevertheless, while this tendency was not statistically significant, GBR treatments showed reduced effectiveness in initially substantial defects. Regardless of the biomaterial, resorption of the augmented bone was seen over time. GBR was connected to problems such as exposure, infection, and soft tissue dehiscence, even though it was safe and predictable. These risks increased when cross-linked collagen membranes were used.

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Table 1: Summary of Included Studies

Study	Objective	Methodology	Results	Conclusion
Wessing et al.,[2018] [7]	To assess different methods of guided bone regeneration (GBR) using collagen membranes and particulate grafting materials in implant dentistry.	Conducted electronic database and manual searches for relevant articles published from 1980 to 2014. Included randomized clinical trials and prospective controlled studies.	Implant survival rates were similar between simultaneous and subsequent implant placement. Cross-linked membranes had a higher membrane exposure rate than non–cross-linked membranes.	The presence of membrane cross-linking, timing of implant placement, membrane fixation, and decortication influence outcomes.
Lim et al., [2018] [8]	To compare resorbable versus nonresorbable membranes and the timing of soft tissue complications.	Conducted electronic and manual literature searches. Included 21 articles in qualitative synthesis and 15 in quantitative synthesis.	Weighted complication rate for overall soft tissue complications was 16.8%. Resorbable and nonresorbable membranes had similar complication rates.	Both resorbable and nonresorbable membranes show comparable complication rates.

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Hämmerle et al., [2002] [9]	To evaluate the survival of implants in regenerated bone using GBR compared with implants in non-regenerated bone.	Conducted MEDLINE search and hand search for studies from 1990 to May 2001.	Implants in regenerated bone had survival rates ranging from 100% after 5 years to 79.4% after 5 years of function. No significant differences found between implants in regenerated and non-regenerated bone.	GBR can lead to successful implant survival rates comparable to implants in non-regenerated bone.
Machtei et al., [2001] [10]	To assess the impact of membrane exposure on outcomes of guided tissue regeneration (GTR) and GBR procedures.	Conducted meta-analysis of studies focusing on GTR in Class II furcation and intrabony defects, and GBR around dental implants.	Membrane exposure during healing may negatively impact regenerative outcomes in GTR and GBR procedures.	Membrane exposure during healing may have a negative impact on regenerative outcomes.
Zhou et al., [2022] [11]	To compare complications of customized titanium mesh versus conventional titanium mesh in edentulous alveolar ridge guided bone regeneration (GBR).	Conducted meta-analysis of 9 articles published between January 2010 and March 2020.	Customized titanium mesh has a lower exposure rate compared to conventional titanium mesh. Soft tissue	Customized titanium mesh may offer advantages in GBR procedures, including lower

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			management is crucial in avoiding soft tissue fractures.	exposure rates.
Cucchi et al., [2017] [12]	To compare complication rates and vertical bone gain following GBR using dense non-resorbable d-PTFE titanium-reinforced membranes versus titanium meshes covered by cross-linked collagen membranes.	Conducted randomized controlled trial with 40 partially edentulous patients.	No significant differences observed in complication rates, implant stability, or vertical bone gain between the two study groups.	Dense non-resorbable d-PTFE titanium-reinforced membranes and titanium meshes covered by cross-linked collagen membranes have similar outcomes in GBR.
Poomprakobsri et al., [2022] [13]	To evaluate the exposure rates of three different barrier types after GBR and the percentage of grafted bone dimensional loss with and without exposed barriers.	Retrospective review of patient records from September 2007 to May 2015.	Resorbable barrier had a significantly lower exposure rate compared to titanium mesh and nonresorbable barrier. Sites with barrier exposure had greater grafted bone dimensional loss.	Choice of barrier type significantly affects exposure rate and dimensional changes of grafted bone in GBR procedures.

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Carbonell et al., [2014] [14]	To analyze and describe the available literature on non-expanded and dense polytetrafluoroethylene (n-PFTE) as a membrane barrier for regeneration procedures.	Literature review of articles published between 1980 and May 2012.	Limited clinical and histological evidence for the use of n-PFTE membranes at present. Some indications for its use in guided tissue regeneration and guided bone regeneration in immediate implants and fresh extraction sockets.	Limited evidence available for the use of n-PFTE membranes in regeneration procedures.
Carbonell et al., [2014] [15]	To evaluate the effectiveness of lateral bone augmentation procedures for resolving horizontal ridge deficiencies after implant placement.	Meta-analysis of 28 publications.	Lateral bone augmentation is an effective treatment modality for horizontal ridge deficiencies after implant placement. Combining a barrier membrane with a grafting material is recommended for optimal defect height	Lateral bone augmentation is effective for horizontal ridge deficiencies, with optimal outcomes when using a membrane and a grafting material.

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			reduction.	
Thoma et al., [2019] [16]	To evaluate the impact of various biomaterials used for GBR during implant placement on radiographic peri-implant bone stability and bone defect dimension changes.	Systematic review including only randomized controlled trials (RCTs) and controlled clinical trials (CCTs).	Following the biological principle of GBR leads to predictable regeneration, regardless of the biomaterial used. Biomaterials have lower efficacy in initially large defects. Complications include exposure, infection, and	

Discussion

Guided bone regeneration (GBR) has become a common procedure in implant dentistry to restore bone volume and facilitate successful implant placement. Collagen membranes and particle grafting materials are often used in GBR procedures to promote bone regeneration. However, the optimal approach to GBR remains a topic of debate, with various factors such as membrane type, timing of implant placement, and surgical technique potentially influencing outcomes. This systematic review aims to assess the effectiveness of different GBR approaches using collagen membranes and particle grafting materials in implant dentistry.

A statistical analysis of the various procedures could have been more practical for the majority of the groups due to the large differences in the number of patients treated in the various grafting groups and the follow-up duration across the studies and study arms. The group receiving

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solely ABBM treatment was the only one for whom further assessment was feasible. That group's sites were all enhanced using the same product (Bio-Oss, Geistlich). Regardless of whether the GBR was conducted concurrently with or prior to implant implantation, the group's mean implant survival rate was 98.34 (95% CI, 96.06%–99.71%) with a mean follow-up period of 13 months (range 0-59.1 months). The estimated vertical bone gain with pure ABBM was 3.05 mm (95% CI, 2.33–3.77 mm). With the exception of two research arms, the healing period of the added bone was reported.53 The average healing period, which took into account implant insertion both simultaneously and afterwards, was 5.88 months (95% CI, 3-8.1 months). For 27 research arms, the indication for ridge augmentation was categorized as horizontal, and for 3 study arms, as vertical. It was not possible to classify one research arm. Vertical or horizontal bone increase or loss was not reported in six publications (9 study arms).[17, 18, 19, 10, 21, 22, 23] The other articles' data were given in a variety of ways, with dispersion parameters being presented seldom and results that differed greatly in terms of gain/loss, horizontal/vertical, depth/width, mesial/distal, coronal/apical, and volume/length/percentage. Comparing studies based on factors related to bone growth or loss became challenging and, in some situations, impractical due to this variance.

In contrast to previous research, the current systematic review found that the use of resorbable membranes increased the weighted complication rate of soft tissue problems. Resorbable membranes facilitated early flap anastomosis and tissue regeneration at the surgical site, but non-resorbable membranes impeded the healing site's revascularization, per earlier animal research. Other human investigations comparing the use of non-resorbable membranes with titanium mesh (Ti-mesh) found that early membrane exposure resulted in early membrane removal, which in turn affected the outcomes of bone regeneration [23, 24, 25]. In contrast to Ti-mesh, which permits angiogenesis and space maintenance, membranes, which totally occlude cells, may elicit a distinct physiological response. Ti-mesh's elasticity and plasticity enable optimal adaptability to suit a wide variety of bony defect shapes. At the same time, its strength and rigidity give good mechanical stability and compartmentalization of the bone grafts below. In addition to increasing epithelial stability, porosity also facilitates blood flow and extracellular nutrient-free diffusion over the mesh, which all contribute to better GBR outcomes [23, 24, 25, 26, 27].

The idea behind guided bone regeneration is to cover the defect region with a membrane that acts as a barrier to stop soft tissue from growing into it [28]. To avoid the augmented site collapsing while applying a non-form-stable resorbable membrane, grafting material placement has been advised [29,30]. The need to use a biomaterial and a membrane to augment bone at buccal dehiscence defects effectively is a topic of debate. When augmentation operations with and without membranes were compared, the results of the current systematic review were unquestionably better. A greater defect height decrease of 0.85 to 1.51 mm was obtained with the inclusion of a barrier membrane [31,32,33]. These results conflict with preclinical and clinical evidence that suggests, for a variety of purposes, bone regenerating techniques may not need more than the periosteum to function as a barrier membrane [34,35]. In the beginning, barrier

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membranes were applied without the use of grafting material to preserve the volume necessary for the blood clot to turn into bone [35,36]. A grafting material placement was shown to result in much better results, according to meta-analysis. The information is derived from a clinical trial that directly compares the use of DFDBA as a grafting material to the use of membranes (ePTFE) alone [35]. WMD was estimated to be −2.4 mm.

It has been shown that GBR is effective in promoting bone regeneration either before or in addition to oral implant insertion. As a result, the current analysis solely includes locations where directed bone regeneration was used to regenerate bone. While alternative approaches to human jaw bone regeneration have been reported, they lack the same level of documentation and often need to achieve the same success rates as GBR when treating localized bone deficiencies in individuals who are partly or completely edentulous. One should differentiate between successful and failed GBR surgeries and then only include the successful ones in the study in order to accurately assess the survival and success of implants in regenerated bone. Sadly, the majority of the analyzed research lacked the necessary data. Therefore, the findings in this analysis provide an overview of the data on implant survival and success in regenerated bone, both after successful and failed GBR surgeries. However, it should be noted that GBR therapy has been effective in the majority of the sites gathered for this review paper.

Future Recommendations:

1. **Standardization of protocols:** There is a need for standardized protocols in GBR procedures to ensure consistency and comparability across studies. This includes standardizing the choice of membrane type, timing of implant placement, and surgical techniques.
2. **Long-term follow-up studies:** Long-term follow-up studies are needed to assess the longevity and stability of bone regeneration achieved through GBR procedures. This will provide valuable information on the long-term success rates of implants placed in regenerated bone.
3. **Comparative studies:** More comparative studies are needed to evaluate the effectiveness of different membrane types, grafting materials, and surgical techniques in GBR procedures. This will help clinicians make informed decisions about the most suitable approach for their patients.
4. **Incorporation of new technologies:** The incorporation of new technologies such as 3D printing and advanced imaging techniques could improve the accuracy and predictability of GBR procedures. Future research should explore the potential benefits of these technologies in enhancing GBR outcomes.

Limitations:

1. **Heterogeneity of studies:** The included studies in this review were heterogeneous in terms of study design, patient population, and outcome measures. This heterogeneity may limit the generalizability of the findings.

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2. **Publication bias:** There is a possibility of publication bias, where studies with positive results are more likely to be published than those with negative results. This bias could affect the overall conclusions drawn from this review.
3. **Lack of long-term data:** Many of the included studies had relatively short follow-up periods, which may limit the ability to assess the long-term outcomes of GBR procedures. Long-term studies are needed to address this limitation.
4. **Variability in surgical techniques:** The variability in surgical techniques used across studies may have influenced the outcomes of GBR procedures. Standardization of surgical techniques is needed to minimize this variability and improve the reliability of results.

Conclusion:

This review highlights the importance of careful consideration of various factors in GBR procedures in implant dentistry. The findings suggest that the choice of membrane type, timing of implant placement, and surgical techniques can significantly impact the success of GBR. Further research and standardized protocols are needed to optimize outcomes and minimize complications in GBR procedures**.**

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