Journal of Pioneering Medical Sciences
Received: January 29, 2025 | Accepted: March 05, 2025 | Published: April 27, 2025
Volume 14, Issue S01, Pages S85-S88

DOI https://doi.org/10.47310/jpms202514S0111

Novel Bioactive Glass-Infused Periodontal Membranes: Antibacterial and Cytotoxic Evaluation for Guided Tissue Regeneration

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Abstract **Objectives:** No other treatment works as effectively as guided tissue regeneration (GTR) membranes in periodontal therapy because they facilitate selective cell growth. The addition of bioactive glass (BG) to periodontal membranes enhances their antibacterial features along with the ability to be compatible with biological tissues. The current study examines both antibacterial effectiveness and cytotoxic characteristics of new bioactive glass-treated periodontal membrane constructions. **Methods:** New periodontal membranes were created by adding bioactive glass particles into a polymer substance that breaks down naturally over time. The antibacterial activity measurement for Streptococcus mutans and Porphyromonas gingivalis involved agar diffusion with zone of inhibition determination. The tests were carried out for cytotoxicity using MTT assays and human gingival fibroblasts (HGF) during 24 and 48 hours of incubation time. Statistical evaluation used one-way ANOVA as the analysis method. **Results:** The biological activity of bioactive glass-containing membranes effectively inhibited bacterial growth producing zones of inhibition that measured 15.2±1.3 mm for S. mutans and 14.8±1.5 mm for P. gingivalis. The MTT assay results showed that cell viability exceeded 85% at 24 hours and reached 80% at 48 hours which proved the low level of cytotoxicity in the samples. **Conclusion:** The periodontal membranes with incorporated bioactive glass displayed strong antimicrobial effects together with favorable biocompatible behavior. Bioactive glass shows indications to become an effective material for guided tissue regeneration applications in periodontal treatment. **Limitations:** The current research only examines laboratory results testing two bacterial strains while conducting brief tests for toxicity. **Clinical Implications:** Additional testing with live human subjects must validate the membranes for their intended use in guided tissue regeneration.

Key Words Bioactive glass, Guided tissue regeneration, Periodontal membrane, Antibacterial activity, Cytotoxicity, Tissue engineering

INTRODUCTION

Periodontal disease affects numerous patients because this condition causes steady deterioration of periodontal tissues that can result in permanent tooth loss if no treatment is provided [1]. The well-recognized therapy for periodontal healing called Guided tissue regeneration (GTR) makes use of barrier membranes to direct cell repopulation and support periodontal regeneration [2]. The optimal GTR membrane needs to be biocompatible and maintain mechanical strength and antibacterial quality as these elements aid successful periodontal healing by preventing microbial contact [3].

Researchers extensively study bioactive glass (BG) because of its demonstrated osteoconductive properties and antimicrobial actions which qualify it as an appealing material for periodontal uses [4]. The release of calcium and phosphate ions from BG enables double action which serves to support mineral reconstruction and fights bacterial growth [5]. Multiple research projects have shown that mixing

bioactive glass into membranes effectively promotes bone repair and has aDestructor effect on bacterial populations [6,7]. Test protocols should evaluate material toxicity because these concerns stop the evaluation of their periodontal tissue compatibility.

The research evaluates the antibacterial properties alongside cytotoxic effects of bioactive glass-infused periodontal membranes that were developed recently. This study evaluates the material's bacterial inhibition abilities and its capacity to support fibroblast cell health in order to establish its appropriateness for GTR applications. The results would contribute important understanding for developing next-generation periodontal membranes that show improved tissue healing characteristics. We hypothesized that bioactive glass-infused periodontal membranes exhibit superior antibacterial activity with minimal cytotoxic effects, making them suitable for guided tissue regeneration applications.

METHODS

Bioactive glass (BG) involved synthesis by sol-gel processing of calcium, phosphorus and silica precursors. The BG synthesis process led to thin flexible membranes through electrospinning between PCL and chitosan that were appropriate for tissue-regenerating purposes. More testing proceeded after membrane sterilization was performed by ethylene oxide gas exposure. The chosen sample size and number of replicates (n = 3) were based on prior studies and preliminary tests demonstrating sufficient statistical power for comparative analysis.

The membranes underwent antibacterial testing against Streptococcus mutans and Porphyromonas gingivalis by means of the agar diffusion technique. The fabricated membranes were cut into 10-mm diameter sterile discs before they were applied onto bacterial culture plates containing 0.5 McFarland turbidity standardized bacterial suspensions. The bacterial culture plates stayed in the 37°C environment while operating under anaerobic conditions for 24 hours. The antibacterial property of each membrane disc was determined through the measurement of the inhibition zone size surrounding the disc.

Human gingival fibroblasts (HGF) underwent the MTT assay to determine the toxicity effect of these membranes. Dulbecco's Modified Eagle Medium (DMEM) containing 10% fetal bovine serum together with antibiotics supported the cell growth. HGF cells received seeding at 5 × 10 cells per well on the membranes placed within 96-well culture plates. The analysis of MTT reagent (5 mg/mL) absorption at wavelength 570nm occurred using a microplate reader after the samples incubated for 24 and 48 hours. The researchers measured cell viability against the control group that contained cells without membranes expressed as a percentage.

The researchers used one-way ANOVA together with Tukey's post-hoc test to analyze their results. The data showed outcomes as mean values with standard deviation measurements (SD) and statistical significance levels occurred below 0.05. The experiments were conducted three times to guarantee reliable results.

RESULTS

Antibacterial Activity

The test revealed that S. mutans and P. gingivalis developed inhibition zones of 15.2±1.3 mm and 14.8±1.5 mm respectively yet the plain polymer membrane control showed limited antibacterial response (Table 1). Bioactive glass additives increase the antibacterial effects of the results.

Cytotoxicity Assessment

Data from the MTT assay showed that membranes containing bioactive glass solution maintained excellent cellular survival levels. HGF cells maintained a viability rate of 85.7±2.5% when in contact with the bioactive glass-infused membranes at 24 hours but showed a decrease to 80.3±2.8% at 48 hours duration. Cells maintained higher viability rates on the plain polymer membrane where they reached 92.4±1.9% at 24 hours before declining to 89.6±2.2% at 48 hours but the toxic reference caused substantial cell viability reduction (Table 2).

These findings indicate that the bioactive glass-infused membranes exhibit antibacterial properties while maintaining acceptable biocompatibility, making them suitable candidates for guided tissue regeneration applications.

DISCUSSION

This research shows that bioactive glass-infused periodontal membranes display powerful antibacterial properties alongside excellent compatibility with human body tissues.

Table 1: Antibacterial Activity of Bioactive Glass-Infused Periodontal Membranes

Sample Type	*S. mutans* (mm)	*P. gingivalis* (mm)
Bioactive Glass-Infused Membrane	15.2±1.3	14.8±1.5
Plain Polymer Membrane	3.4±0.8	2.9±0.7
Positive Control (Chlorhexidine disc)	18.5±1.2	17.9±1.1

$p<0.05$ for bioactive glass-infused membrane compared to the plain polymer membrane

Table 2: Cytotoxicity Assessment (MTT Assay) of Periodontal Membranes

Sample Type	Cell Viability (%) at 24 h	Cell Viability (%) at 48 h
Bioactive Glass-Infused Membrane	85.7±2.5	80.3±2.8
Plain Polymer Membrane	92.4±1.9	89.6±2.2
Positive Control (Toxic Reference)	45.8±3.1	38.2±3.5

$p<0.05$ for bioactive glass-infused membrane compared to toxic reference

Bioactive glass shows potential for GTR therapy use in periodontal treatment because of its useful features.

The antibacterial assessment demonstrated that the bioactive glass-infused membranes strongly blocked the development of Streptococcus mutans and Porphyromonas gingivalis bacteria. Bacterial inhibition and biofilm suppression result from the ion release behavior of bioactive glass that alters bacterial metabolic functions [1,2]. The release of calcium and phosphate ions by bioactive glass increases the local tissue pH while producing an unfavorable growth environment for bacteria as scientific studies show [3,4]. The antibacterial properties of this mechanism become crucial in periodontal regeneration since bacterial settlement has the potential to damage treatment results [5].

Bioactive glass-additive membrane yielded better antibacterial performance with larger infected zone compared to the plain polymer membrane that exhibited inferior antibacterial effects. Earlier studies have confirmed the antimicrobial effectiveness of bioactive glass in dental therapies as reported in literature [6,7]. Bioactive glass proves to prevent bacterial adhesion in regenerative procedures by acting as an antibacterial agent [8].

A periodontal membrane must achieve compatibility with biological tissues to succeed in clinical settings. Bioactive glass-infused membrane specimens demonstrated more than 85% cell survival in the MTT assay at the 24-hour time point and this value fell to 80% after 48 hours of incubation. Bioactive glass-containing materials have been found to enhance fibroblast attachment and cell growth according to previous research they also show low cytotoxicity [9,10]. These membranes maintain good cellular viability rates which indicates their capacity to promote periodontal tissue restoration without harmful biological effects [11].

Excessive ion releases from bioactive glass tend to be cytotoxic despite their influence on cellular behavior [12]. The bioactive glass concentration utilized to make membranes exhibited levels of biocompatibility as indicated by the continuous cell survival rates in this study. Research studies indicate that maintaining controlled ion discharge from bioactive glass leads to enhanced cellular responses which do not result in apoptotic or necrotic effects [13,14].

Bioactive glass integrated into periodontal membranes offers two major benefits which include antimicrobial properties and compatibility with tissues making it a promising method for advancing GTR success rates. Bioactive glass acts as an antibacterial agent which reduces postoperative infections along with being biologically compatible for effective tooth-regeneration processes. Additional scientific research needs to examine the in vivo long-term membrane stability and determine their clinical degradation patterns and mechanical performance [15].

CONCLUSIONS

Future research needs to study bioactive glass compositions together with membrane thickness and degradation rates to improve the substance's regenerative potential. Research in the future should investigate how bioactive glass interacts with other bioactive compounds including antimicrobial peptides and growth factors to improve its functions in treating periodontal conditions.

Bioactive glass-infused membranes may serve as a clinically viable material for guided tissue regeneration, offering antibacterial protection and tissue compatibility. However, practical challenges such as fabrication scalability, regulatory approval, and cost-effectiveness must be addressed.

Future research should include in vivo studies to evaluate long-term tissue integration, membrane degradation, and synergistic performance with antimicrobial peptides or growth factors. Optimizing bioactive glass content and membrane thickness will be crucial for clinical translation.

Acknowledgment

This study received no external funding and was supported by institutional resources at Batterjee Medical College

Limitations

This study was limited to in vitro conditions, focusing only on two bacterial strains and short-term cytotoxicity. The membrane's long-term antibacterial performance and degradation behavior in vivo were not assessed. Additionally, ion release kinetics and their potential variability in different BG compositions require further investigation.

Conflicts of Interest

The authors declare no conflicts of interest

Ethical Statement

This study involved only in vitro experiments and did not require ethical approval as no human or animal subjects were involved

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