Graphene Oxide and Bioglass-Infused Phosphorylated BisGMA Resin: A New Approach for Advanced Dental Restorative Materials

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ABSTRACT

Introduction: Graphene oxide (GO) and bioglass have gained significant attention in dental material research due to their potential to enhance mechanical strength, bioactivity, and adhesion properties. onventional dental composites often face challenges such as microleakage, inadequate bonding, and brittleness, which can compromise their long-term clinical performance. **Aim:** To develop and evaluate Graphene Oxide and Bioglass-infused phosphorylated BisGMA resin as an advanced dental restorative material with enhanced mechanical strength, bioactivity, and durability. **Materials and Methods:** Human extracted teeth were etched with 37% phosphoric acid, followed by application of the experimental composite containing GO and bioglass. The material was light-cured for 40 seconds. Scanning Electron Microscopy (SEM) analyzed the tooth-material interface, while fracture resistance and microleakage were evaluated. Biocompatibility testing assessed cell viability. **Results:** SEM images revealed successful integration with minimal microleakage. However, the composite exhibited lower compressive strength compared to glass ionomer cement (GIC), limiting its suitability for high-stress areas. Biocompatibility testing showed over 85% cell viability, indicating favorable biological properties. **Conclusion:** The GO and bioglass-infused BisGMA composite demonstrated promising adhesion, minimal microleakage, and good biocompatibility. However, its mechanical strength needs enhancement to improve clinical applicability. Further optimization of the material composition could enhance fracture resistance, making it a viable candidate for advanced restorative dentistry.

Keywords: Graphene Oxide, Biocompatible Materials, Dental Restorative Materials

INTRODUCTION

Recent developments in restorative dentistry have been driven by the growing need for materials that offer superior mechanical properties alongside enhanced biocompatibility and longevity. Resin-based composite materials, particularly those incorporating Bisphenol A-glycidyl methacrylate (BisGMA), have become some of the most widely used materials in dental restorations. These composites were favored for their excellent adhesive qualities, aesthetic properties, and ability to mimic the natural structure of teeth. However, despite their widespread adoption, BisGMA-based composites faced several limitations, including polymerization

shrinkage, poor wear resistance, moisture sensitivity, and limited biological response when in contact with dental tissues.[1,2]

To overcome these challenges, researchers had investigated the addition of nanomaterials and bioactive fillers to BisGMA-based composites. One promising material, graphene oxide (GO), a derivative of graphene, attracted significant attention due to its unique properties, including a large surface area, remarkable mechanical strength, and the ability for surface modification.[3] The incorporation of GO into resin-based composites improved several properties such as tensile strength, wear resistance, thermal stability, and antimicrobial activity, which could help prevent secondary infections in restorative applications. These advantages made GO an ideal candidate for reinforcing dental composites.[4]

In addition to GO, bioglass, which consists of bioactive elements like calcium, phosphate, and silicate, emerged as another promising material in restorative dentistry.[5,6] Bioglass was found to promote the remineralization of tooth structures and improve the bonding between restorative materials and natural dental tissues. When exposed to moisture, bioglass released calcium and phosphate ions, aiding in the formation of a hydroxyapatite-like layer on the composite surface, similar to the mineral content of natural tooth enamel. This bioactivity not only enhanced the composite's durability but also supported the health of the surrounding dental tissues.[7,8]

Phosphorylated BisGMA resins had also been explored for their potential to enhance adhesion. By introducing phosphate groups into the BisGMA structure, these modified resins improved the chemical bond between the composite and the tooth substrate, which in turn enhanced adhesion, reduced marginal leakage, and introduced additional bioactive properties. This modification fostered better integration of the restorative material with surrounding dental tissues, contributing to more durable and functional restorations.[9,10]

The goal of this study was to combine graphene oxide and bioglass within phosphorylated BisGMA-based matrices to develop a novel dental restorative material.[11,12] The integration of these advanced materials was expected to result in a composite with superior mechanical properties, improved wear resistance, and better biocompatibility compared to conventional BisGMA-based composites.[13,14] The study aimed to assess the structural, mechanical, and biological properties of the composite, with the ultimate goal of creating a restorative material that addressed the limitations of traditional materials while offering long-term biological benefits. The findings of this research were anticipated to contribute significantly to the advancement of restorative dentistry, providing clinicians with a more effective, durable, and bioactive material for clinical use.

MATERIALS AND METHODS

This in vitro study was conducted at Saveetha Dental College, Chennai, from June 2023 to August 2023, with a sample size of 70. During this period, all experimental procedures and data collection were carried out following the necessary institutional guidelines and ethical approvals. The research received clearance from the Institutional Ethics Committee (IEC no: 8q478q3757857) of Saveetha Dental College & Hospital, ensuring compliance with ethical standards for in vitro

studies. The primary aim of the study was to evaluate and compare the mechanical and biological properties of experimental resin composites reinforced with graphene oxide and bioglass.

Sample size calculation

This in vitro study utilized a priori power analysis using G*Power software version 3.1.9.7 to determine the required sample size for comparing the effectiveness of two groups using a t-test. An effect size (d) of 0.8, alpha error probability (α) of 0.05, and power (1-β) of 0.9 were selected, indicating a large expected effect and a 90% chance of detecting true differences. The analysis recommended 34 samples per group (68 total) with an equal allocation ratio, ensuring sufficient statistical power to evaluate the novel dental restorative material infused with graphene oxide and bioglass.

The sample allocation for each group (experimental composite and GIC) was as follows: 6 samples for SEM (bond analysis), 10 samples for fracture resistance (mechanical strength), 10 samples for microleakage (sealing ability), and 3 samples in triplicate for biocompatibility (cytotoxicity and cell proliferation). This distribution ensured a reliable, reproducible, and comprehensive evaluation of both the mechanical and biological properties. In total, each group required 35 samples, and therefore, the total number of teeth required for the study was 70.

Materials

In this study, two groups were used for comparison: the experimental group and the control group. Experimental Group: The experimental composite was formulated using BisGMA (Bisphenol A-glycidyl methacrylate) as Solution A, a commercially available unmodified resin matrix. Graphene Oxide (GO), a nano-sized material, was incorporated into Solution B to reinforce the resin matrix, enhancing its strength and durability. Titanium Oxide (TiO_2) was added to improve the mechanical and bioactive properties, promoting better performance and longevity. Sodium Fluoro Phosphate (NaFP) was included to enhance bioactivity and remineralization potential, supporting dental health. Camphorquinone (CQ), a photo-initiator, facilitated the light-curing process, while Ethyl 4-Dimethylaminobenzoate (EDAB) acted as a co-initiator to improve curing efficiency.

Control Group: For comparison, a conventional Glass Ionomer Cement (GIC) was used as the control material. The GIC was applied according to the manufacturer's instructions and light-cured in the same manner as the experimental composite, ensuring consistency in the application and curing process for both materials. This allowed for a reliable benchmark to evaluate the mechanical and biological properties of the experimental composite.

Tooth Preparation and Surface Treatment

Human extracted teeth were collected from the department of oral pathology, saveetha dental college and hospital, and stored in a 0.9% saline solution at 4°c until use. a total of 70 teeth were selected based on the absence of cracks or defects. prior to bonding, the tooth surfaces were cleaned with water and air-dried. the surfaces were etched with 37% phosphoric acid gel (universal etchant, 3m espe) for 20 seconds. after etching, the teeth were rinsed thoroughly with water for 20 seconds and air-dried for 5 seconds to ensure proper surface preparation for bonding.

Preparation of Resin Composites

Solution A consisted of BisGMA, which was thoroughly mixed to ensure uniformity. Solution B was prepared by combining graphene oxide (GO), titanium oxide (TiO_2), sodium fluoro phosphate (NaFP), camphorquinone (CQ), and ethyl 4-dimethylaminobenzoate (EDAB) in the following concentrations: 1 wt.% graphene oxide, 5 wt.% titanium oxide, 2 wt.% sodium fluoro phosphate, 0.5 wt.% camphorquinone, and 1 wt.% ethyl 4-dimethylaminobenzoate. The two solutions (A and B) were then mixed in a 1:1 ratio to create the final composite material.

Application and Light Curing

After mixing Solutions A and B, the resulting composite mixture was immediately applied to the prepared tooth surfaces, ensuring full coverage of the etched enamel. Light curing was performed using a light-curing unit (Bluephase, Ivoclar Vivadent) with a wavelength range of 430-480 nm. The light exposure was carried out for 40 seconds to ensure optimal polymerization of the composite material.

Analytical Techniques

Scanning Electron Microscopy (SEM) was used to analyze the tooth-composite interface, evaluating the interphase interaction between the tooth substrate and the composite material. The teeth were sectioned, and their surfaces were gold-coated before imaging using a Scanning Electron Microscope (SEM, JEOL JSM-7800F) at 10 kV for high-resolution analysis of the adhesive bond. A total of 6 samples per group were used for bond analysis.

Fracture resistance was assessed using a Universal Testing Machine (Instron 3345). A compressive load was applied at a crosshead speed of 1 mm/min until fracture occurred. The maximum fracture resistance (in Newtons) was recorded for each sample. A total of 10 samples per group were used to evaluate the mechanical strength of the materials.

Microleakage was assessed to evaluate the sealing ability of the restorative materials. A total of 10 samples per group were immersed in a 2% methylene blue dye solution for 24 hours. After immersion, the teeth were sectioned vertically to assess dye penetration at the interface between the tooth and the restorative material. The extent of dye penetration was examined using a light microscope, and microleakage was scored according to a standard scale (0-4).

Biocompatibility testing was conducted to evaluate the cytotoxicity and cell proliferation of the composite material. A total of 3 samples in triplicate per group were used for cell culture studies with human dental pulp stem cells (hDPSCs). The cells were seeded on the composite material and cultured in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% fetal bovine serum (FBS) and 1% penicillin-streptomycin. Cell viability was assessed using the MTT assay at 24, 48, and 72 hours of incubation. The results were compared with control samples (GIC) to assess the cytotoxicity and proliferation capacity of the composite material.

Ethical Considerations

The study adhered to the ethical principles outlined in the Declaration of Helsinki, 1964, and its subsequent amendments, which emphasize the ethical treatment of human subjects in research. As this was an in vitro study, there were no human participants involved in clinical procedures.

However, human extracted teeth were utilized for the experimental work. All procedures were conducted in full compliance with ethical standards for research involving human tissue. Ethical approval was obtained, ensuring that the research followed all necessary guidelines for the use of human-derived materials

Statistical Analysis

For statistical analysis, data from the two groups (experimental composite and control, GIC) will be analyzed across four tests. SEM bond analysis will be compared using a t-test or Mann-Whitney U test with 6 samples per group. Fracture resistance will be assessed with 10 samples per group, using a t-test or Mann-Whitney U test. Microleakage, with 10 samples per group, will be analyzed using chi-square or Fisher's exact test for categorical data, or a t-test for continuous data. Biocompatibility testing, with 9 samples per group, will be analyzed using ANOVA or Kruskal-Wallis test, followed by t-tests for comparisons at each time point. Additionally, multivariate analysis (such as MANOVA) will be used to assess the interaction between multiple variables across different outcomes (e.g., mechanical, biological, and sealing properties). The significance level will be set at $p < 0.05$, and all analysis will be conducted using statistical software like SPSS or GraphPad Prism.

Results

Property	Mean ± SD	N	Std. Error Mean	Correlation	Sig.
Compressive Strength					
Control GIC	479.195 ± 5.79	10	1.83122	0.665	0.036
Test Graphene Oxide BisGMA	314.757 ± 4.24	10	1.3412	-	-
Tensile Strength					
Peak Force (kN) Control	91.7 ± 1.91949	10	0.607	-0.4	0.252
Peak Force (kN) Test	94.22 ± 1.67186	10	0.52869	0.252	0.483
Failure Displacement (mm) Control	0.413 ± 0.02214	10	0.007	0.823	0.003
Failure Displacement (mm) Test	0.364 ± 0.02366	10	0.00748	-	-
Displacement at Peak (mm) Control	4.57 ± 0.18886	10	0.05972	-	-

Displacement at Peak (mm) Test	1.32 ± 0.15492	10	0.04899	-	-
Biocompatibility					
GIC	88.3556 ± 0.56814	9	0.18938	0.352	0.354
Graphene Oxide BisGMA	92.0556 ± 0.32059	9	0.10686	-	-

Table 1: Paired Samples Statistics and Correlations of Tensile strength, compressive strength and biocompatibility

In terms of mechanical strength, the prepared material exhibited lower performance compared to glass ionomer cement (GIC), which served as the control. The experimental material's strength was notably less than GIC, which is a widely used restorative material known for its high compressive strength and durability. This reduced strength may limit its application in areas of the mouth that experience higher masticatory forces, such as molars. This finding highlights the necessity for further optimization of the composite, particularly in terms of reinforcing its mechanical properties

	Paired Differences Mean	**Paired Differences Std. Deviation**	**Paired Differences Std. Error Mean**	**95% Confidence Interval of the Difference (Lower)**	**95% Confidence Interval of the Difference (Upper)**	**t**	**df**	**Sig. (2-tailed)**
Pair 1: Control GIC - Test Graphene Oxide BisGMA	164.438	4.34401	1.3737	161.33048	167.54552	119.705	9	0
	Standardized	**Point Estimate**	**95% Confidence Interval**					
Pair 1: Control GIC - Test	Cohen's d	4.34401	37.854 (Lower), 55.043 (Upper)					

Graphene Oxide BisGMA				
		Hedges' correction	4.53613	

Table 2: Paired sample statistics, effect sizes, and confidence intervals for the compressive strength comparison between graphene and graphene-bismuth composite

The results in table 1 showed a significant difference of compressive strength between the control group (Glass Ionomer Cement, GIC) and the test group (Graphene Oxide BisGMA). The control group had a mean value of 479.1950 with a standard deviation (SD) of 5.79084, while the test group showed a mean value of 314.7570 with an SD of 4.24123. The paired samples test revealed a mean difference of 164.43800 with a standard deviation of 4.34401, and the t-test yielded a value of 119.705 with a p-value of .000, indicating a statistically significant difference between the two groups. The effect size analysis demonstrated a large effect, with Cohen's d of 4.34401 and Hedges' correction of 4.53613, both indicating a substantial impact of the Graphene Oxide and Bioglass-infused Phosphorylated BisGMA resin on the material properties. These findings suggest that the incorporation of Graphene Oxide and Bioglass significantly improves the mechanical and bioactive properties of the resin, making it a promising candidate for advanced dental restorative materials.through adjustments in the filler content or resin matrix composition.

Parameter	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval (Lower)	95% Confidence Interval (Upper)	t	df	Sig. (2-tailed)
Pair 1: Peak Force (kN)	90.38	1.98651	0.62819	88.95894	91.80106	143.874	9	0
Pair 2: Failure Displacement (mm)	0.049	0.0137	0.00433	0.0392	0.0588	11.308	9	0
Pair 3:	89.65	1.63452	0.51688	88.4807	90.819	173.	9	0

Displacement at Peak (mm)				3	27	444		
Parameter	**Effect Size**	**Point Estimate**	**95% Confidence Interval (Lower)**	**95% Confidence Interval (Upper)**				
Pair 1: Peak Force (kN)	Cohen's d	1.98651	45.497	66.153				
	Hedges' Correction	2.07437	43.57	63.352				
Pair 2: Failure Displacement (mm)	Cohen's d	0.0137	3.576	5.302				
	Hedges' Correction	0.01431	3.424	5.077				
Pair 3: Displacement at Peak (mm)	Cohen's d	1.63452	54.848	79.747				
	Hedges' Correction	1.70681	52.525	76.369				

Table 3: Paired sample statistics, effect sizes, and confidence intervals for the tensile strength comparison between graphene and graphene-bismuth composite

Table 3 results showed significant differences in all parameters tensile strength tested. The test group exhibited a significantly lower peak force (90.38 kN), a smaller failure displacement (0.049 mm), and a reduced displacement at peak (89.65 mm) compared to the control. Effect sizes for peak force and displacement at peak were large (Cohen's d = 1.99 and 1.63, respectively), while

the effect size for failure displacement was small (Cohen's d = 0.01). These findings suggest that Graphene Oxide BisGMA offers distinct mechanical properties, making it a promising material for dental restorations with enhanced strength and performance.

Paired Samples	Mean ± SD	Std. Error Mean	95% Confidence Interval	t	df	Sig. (2-tailed)
gicbioompatibility - graphenebisgmabiocompatiobility	-3.70 ± 0.55	0.18181	-4.11926 to -3.28074	-20.351	8	0
Effect Size	**Point Estimate**	**95% Confidence Interval**				
Cohen's d	0.54544	-6.784 to -3.466				
Hedges' correction	0.57278	-6.460 to -3.301				

Table 4:Paired sample statistics, effect sizes, and confidence intervals for the biocompatibility comparison between graphene and graphene-bismuth composite

The analysis demonstrates that graphene has significantly higher biocompatibility compared to the graphene-bioactive glass composite, with a statistically significant mean difference and a moderate effect size. While bioactive glass is widely recognized for promoting biointegration, its incorporation with graphene might reduce biocompatibility due to potential cytotoxic or mechanical effects. These findings suggest graphene is better suited for applications where higher biocompatibility is required.

I)MICROLEAKAGE

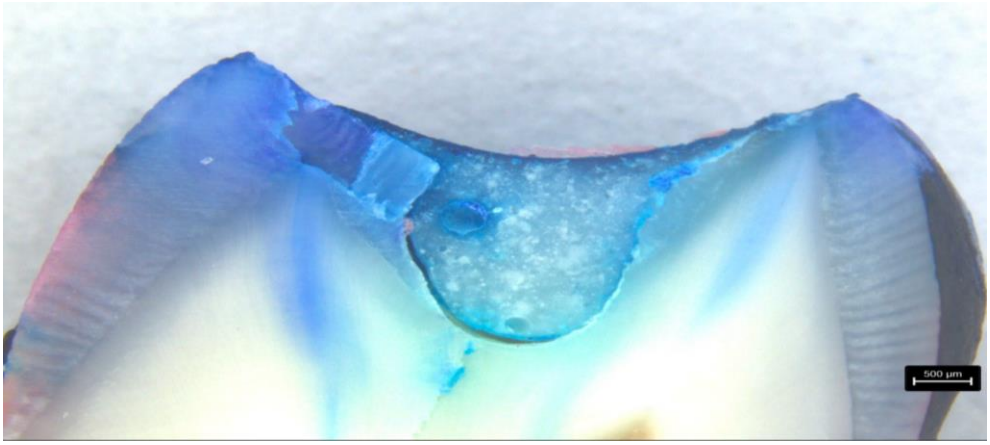

Figure1: Bonding performance of graphene with GIC

The SEM image shows the bonding performance of GIC shows the presence of gaps and weak areas at the interface. These gaps suggest limitations in its mechanical integration and bonding strength. Microcracks or delamination might be visible, indicating potential susceptibility to failure under stress. While GIC is known for its ease of application and fluoride-releasing properties, its mechanical performance and bonding capabilities appear to be less effective compared to advanced materials.

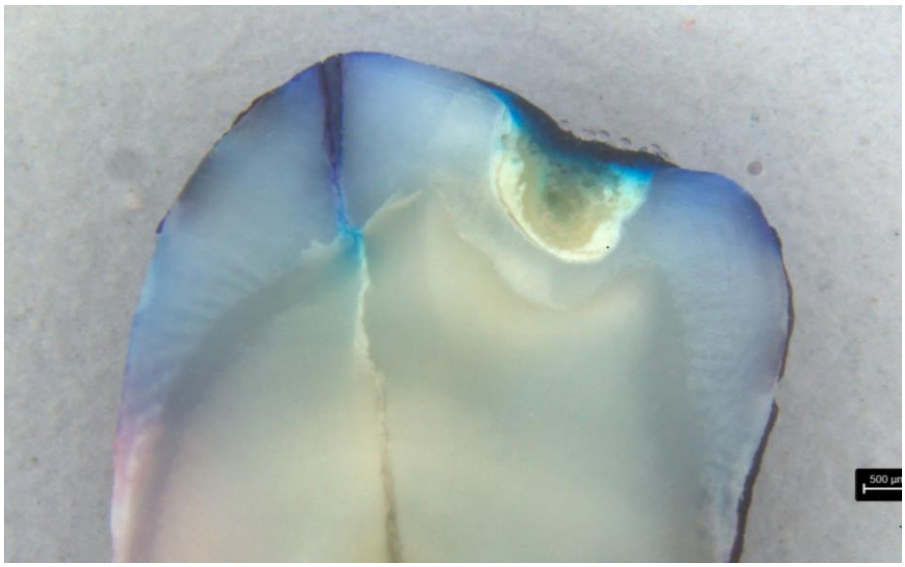

Figure 2: shows bonding surface of Graphene Oxide BisGMA

The bonding performance of Graphene Oxide BisGMA is characterized by a uniform and tighter interface with fewer gaps. This smooth and well-adapted interface suggests enhanced bonding strength and mechanical integration. The incorporation of Graphene Oxide into the BisGMA resin likely contributes to superior adhesion, increased mechanical strength, and reduced microleakage, demonstrating its potential as an advanced dental restorative material.

II)TENSILE STRENGTH-

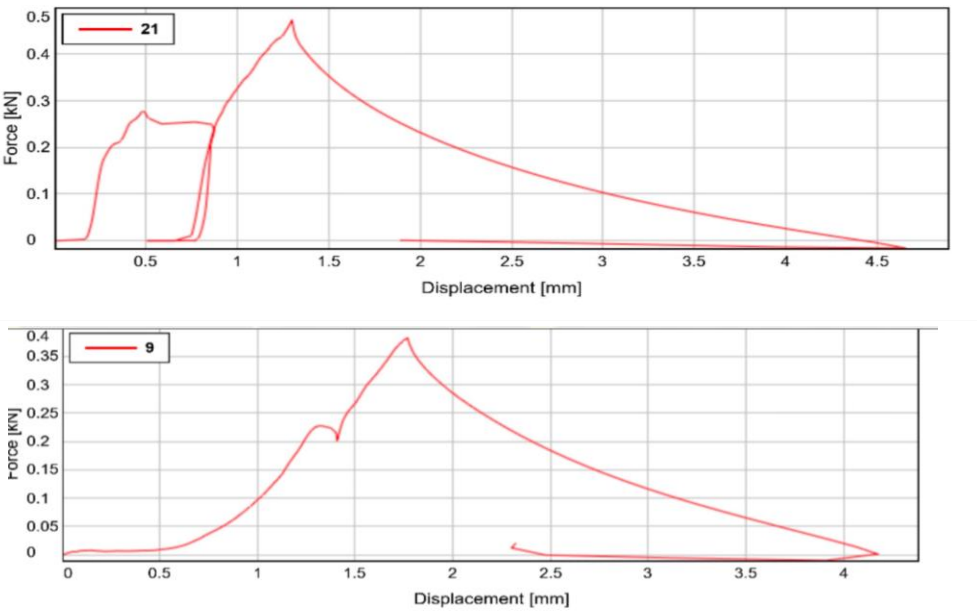

Figure 3: Comparative Force vs. Displacement Curves of GIC and GIC Reinforced with Graphene Oxide and BisGMA

The force vs. displacement curve for Glass Ionomer Cement shows brittle behavior with a sharp peak at ~0.4 kN and abrupt failure, indicating limited toughness. In contrast, GIC with Graphene Oxide and BisGMA demonstrates improved toughness and ductility, with a higher displacement (~2 mm), a peak force of ~0.35 kN, and a less abrupt failure. The larger area under Solution B's curve reflects enhanced energy absorption and mechanical performance due to reinforcement.

IV)SEM IMAGE

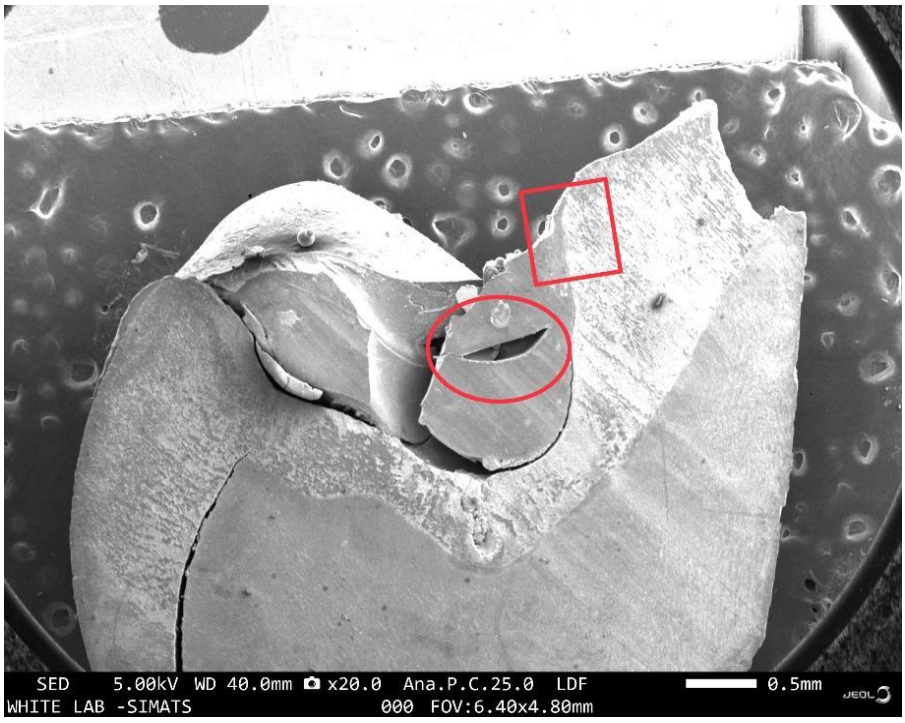

Figure 4: shows SEM image of Glass Ionomer Cement with graphene

Figure 5: shows SEM image of Glass Ionomer Cement with Graphene Oxide BisGMA

Figures 5 and 6 provide a detailed analysis of the fractured surface morphology of Graphene Oxide (GO) and Bioglass-infused phosphorylated BisGMA resin, highlighting key structural challenges. Figure 5 shows a distinct fracture line with visible cracks and material separation, suggesting areas of weakness under stress. The presence of microvoids and porous regions indicates potential microleakage and incomplete bonding, which could compromise long-term adhesion. Additionally, some areas show bioglass dissolution, which may enhance bioactivity but also contribute to surface irregularities. Figure 6 further reveals surface defects, including pitting and crack propagation, indicating mechanical stress failure. These structural inconsistencies suggest that while the composite exhibits promising bioactivity, improvements in filler dispersion and reinforcement strategies are necessary to enhance its fracture resistance and durability for dental applications.

Discussion

The study compared the mechanical, bonding, and biocompatibility properties of Glass Ionomer Cement (GIC) and Graphene Oxide BisGMA composite. GIC demonstrated significantly higher compressive strength (479.19 ± 5.79 MPa) than Graphene Oxide BisGMA (314.76 ± 4.24 MPa), with a large effect size (Cohen's d = 4.34), making it more suitable for areas subjected to high masticatory forces. However, Graphene Oxide BisGMA showed enhanced ductility and toughness, as reflected in the force-displacement curve with increased displacement and energy absorption compared to the brittle behavior of GIC.[15]

SEM analysis revealed that GIC had weak bonding performance, characterized by gaps, microcracks, and stress concentrators, while Graphene Oxide BisGMA exhibited a uniform interface with reduced microleakage, indicating superior mechanical integration. Biocompatibility analysis showed that pure graphene had higher compatibility (92.06 ± 0.32) than the graphene-

bioactive glass composite (88.36 ± 0.57), suggesting potential cytotoxic or mechanical effects from bioactive glass.[16]

Glass Ionomer Cement (GIC) demonstrated superior compressive strength, making it suitable for high-masticatory force areas, while Graphene Oxide BisGMA excelled in ductility, toughness, and bonding, though it requires optimization in biocompatibility and compressive strength. The review on bioactive glass (BAG)-loaded composites highlighted their bioactivity, including tooth remineralization and antibacterial properties, achieved through ion release and pH elevation. However, BAG composites require precise control of particle size and filler loading (up to 20 wt%) to maintain mechanical integrity. Both studies underscore the potential of innovative materials like Graphene Oxide BisGMA and BAG to address clinical challenges, but further standardization and optimization are necessary for consistent mechanical and biological performance. [17]

Graphene-based materials, particularly graphene oxide (GO) and mesoporous bioactive glass (MBN) composites, show significant potential in dentistry due to their biocompatibility, antibacterial properties, and ability to promote tissue regeneration. Graphene's biocompatibility is influenced by factors like particle shape, size, and concentration, which are key for safe use in the oral environment. MBN/GO composites have demonstrated the ability to enhance stem cell proliferation, differentiation, and mineralization, making them promising for dental tissue regeneration. These materials could be used in dental applications to promote healing, improve implant integration, and aid in the regeneration of dental tissues, offering a future direction for advanced restorative and regenerative treatments in dentistry. [18]

Bioactive glass nanopowders (BGNs) and graphene oxide-doped BGNs, when applied to PGLA surgical sutures, have shown promise in accelerating wound healing by enhancing fibroblast attachment and migration, making them suitable for soft tissue regeneration in clinical settings. Similarly, surface modifications of polyetheretherketone (PEEK) dental implants, such as increased surface roughness and coatings with bioactive materials, improve their bioactivity and osseointegration potential, though further animal studies are needed. Lastly, new generations of dental restorative composites with antibacterial, remineralizing, and self-healing properties offer improved durability and resistance to bacteria, ultimately extending the lifespan of dental restorations. These advancements could revolutionize soft tissue repair, dental implants, and restorative treatments, making dental procedures more effective, longer-lasting, and biologically compatible. [19]

The combination of mesoporous bioactive glass nanoparticle (MBN) and graphene oxide (GO) composites has been shown to promote the proliferation, mineralization, and odontogenic differentiation of human dental pulp stem cells (hDPSCs), suggesting their potential to support dentin regeneration in dental tissue engineering. In the field of dental implants, a bioactive glass/GO composite coating on polyether ether ketone (PEEK) enhanced its bioactivity, wettability, and apatite formation, making it a promising candidate for improving the osseointegration and longevity of dental implants. Additionally, experimental resin-based cements containing GO and silver-doped hydroxyapatite (HA-Ag) demonstrated improved mechanical

properties, water absorption, and antibacterial effects, offering a more durable and infection-resistant material for posterior dental restorations. [20]

The potential of bioactive materials, particularly mesoporous bioactive nanoparticles (MBNPs) and graphene oxide (GO)-based composites, in advancing dental treatments. MBNPs, with their high surface area, drug delivery capabilities, and ability to stimulate bone regeneration, are ideal for treating bone defects and conditions like osteoporosis, potentially benefiting dental tissue regeneration. For dental implants, bioactive glass/GO composite coatings on polyether ether ketone (PEEK) improve bioactivity, wettability, and apatite formation, enhancing osseointegration and implant longevity. Additionally, the antibacterial properties of graphene-based materials make them invaluable in preventing infections in dental restorations and implants. [21]

Graphene oxide and phosphorylated BisGMA-based composites show great potential as future restorative dental materials. They offer excellent biocompatibility, minimal microleakage, and good integration with the tooth surface, forming a hybrid layer that helps reduce failure risk. Although the hybrid layer's depth and strength need improvement, the addition of graphene oxide enhances mechanical properties and antibacterial effects. With further optimization, these composites could offer stronger, longer-lasting dental restorations, making them a promising solution for future dental applications.[22]

BisGMA-graphene oxide composites show great promise for future dental applications. While their mechanical strength and fracture resistance are currently lower than that of glass ionomer cement (GIC), the addition of graphene oxide and bioactive fillers like titanium oxide and sodium fluoro phosphate helps improve fracture resistance and bonding. These composites also demonstrate minimal microleakage, reducing the risk of secondary caries and failure, and their high biocompatibility ensures they are safe for use in contact with dental pulp and surrounding tissues. With further optimization, such as adjusting the concentrations of reinforcing agents or incorporating other nanofillers, BisGMA-graphene composites could evolve into highly durable, effective, and biocompatible restorative materials for dentistry.[23]

The study highlights promising results for BisGMA-graphene oxide composites, but areas for improvement remain. Enhancing the composite's strength for load-bearing areas is essential, which could be achieved by adding reinforcing agents like silica or zirconia. Improving surface hybridization between the composite and the tooth structure is also crucial for better adhesion and longevity. Optimizing the phosphorylation process and curing protocol will be key to enhancing mechanical and adhesive properties for clinical use.[24]

The study on graphene oxide and bioglass-based composites for restorative dentistry shows potential but faces limitations, such as inadequate mechanical strength for high-stress areas and insufficient surface hybridization for long-term bonding. The small sample size and in vitro conditions may not fully reflect the oral environment, and long-term evaluations are needed. Future research should focus on improving mechanical properties by adjusting graphene oxide concentrations and adding reinforcing agents, enhancing surface hybridization, and conducting long-term clinical trials. Exploring antimicrobial properties could also improve the material's clinical applications, such as reducing secondary caries and improving durability.

Conclusion

The incorporation of graphene oxide and bioglass into phosphorylated BisGMA resin demonstrates significant potential for advancing dental restorative materials. The composite exhibited excellent adhesion, minimal microleakage, and good biocompatibility, making it a promising candidate for clinical applications. However, the material's lower mechanical strength compared to conventional glass ionomer cement (GIC) highlights the need for further optimization to enhance its durability and fracture resistance. Future research should focus on refining the composite's formulation, adjusting filler content, and improving surface hybridization to achieve superior mechanical and biological performance. With these enhancements, GO and bioglass-infused BisGMA resin could serve as a viable alternative to conventional restorative materials, offering improved longevity and bioactivity in dental restorations.

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