Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

Research JoPC

A Retrospective Analysis of Resin-Based Polymer Composites and Bioactive Glass-Polymer Hybrids Regarding Secondary Caries and Durability

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Abstract

Aim- To compare the 2-year clinical survival and failure modes of a Resin-Based Polymer Composites and BioactiveGlass-Polymer Hybrids in Class I and II posterior restorations. Methods-A total of 550 restorations were placed in adult patients across various private dental practices in India to ensure a diverse clinical demographic. Teeth were randomly assigned and restored with either a hybrid composite (Te-Econom, IvoclarVivadent; n=275) or a Resin-Modified Glass Ionomer Cement (GC Gold Label 2 LC, GC Corp; n=275). Clinical performance was monitored over a 24-month period using Modified USPHS criteria. Statistical analysis of restoration survival was performed using Kaplan-Meier estimators, while the influence of material type on failure risk was determined via Cox regression models (p < 0.05). Results- At 2 years, the overall survival rate was higher for RC (95.6%) compared to RMGIC (91.3%), a difference approaching significance (p=0.054) RMGIC was significantly more prone to mechanical failure (fracture) than RC (4.0% vs. 0.7%; p=0.007). Conversely, RMGIC demonstrated a protective trend against biological failure, with lower incidence of secondary caries (1.5%) compared to RC (2.5%), though this did not reach statistical significance (p=0.306). Conclusion- While RMGIC demonstrated potential bioactive benefits in reducing secondary caries risk, its clinical longevity in load-bearing posterior teeth is compromised by lower fracture resistance. Conventional resin composite remains the mechanically superior choice for Class I and II restorations.

Keywords: Resin-Based Polymer Composites, Bioactive Glass-Polymer Systems, Glass Ionomer Cements, remineralization, Clinical Longevity

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Received Date: December 01, 2025
Accepted Date: December 17, 2025
Published Date: February 11, 2026

Citation: Najiya V.P., Remmiya Mary Varghese, Shrishti kumawat, Charu Sharma, Gaini Mounika, Mohan Rawat. A Retrospective Analysis of Resin-Based Polymer Composites and Bioactive Glass-Polymer Hybrids Regarding Secondary Caries and Durability. Journal of Polymer & Composites. 2026; 14(Special Issue 1): S1089–S1095p.

INTRODUCTION

The long-term durability of direct posterior restorations depends on a material's ability to withstand two distinct challenges: physical degradation from occlusal loading and biological failure caused by secondary caries (SC) at the margins [1, 2].

While Conventional Resin Composites (RCs) are currently the benchmark for Class I and II restorations due to their superior wear resistance and mechanical robustness, they fundamentally lack bioactive properties. Consequently, RCs remain susceptible to microleakage and bacterial infiltration, making secondary caries the primary cause of their long-term failure [2].

To address this biological vulnerability, Glass Ionomer Cements (GICs) and Resin-Modified GICs (RMGICs) were developed to provide a "biological safety net." These materials release calcium, phosphate, and fluoride ions, facilitating an ionic exchange that supports remineralization and suppresses bacterial activity [3, 4], offering essential protection against caries. Recent in-vitro studies support this mechanism; El-Adl et al. and Khvostenko et al. demonstrated that ion-releasing materials can significantly inhibit S. mutans biofilm penetration and reduce lesion depth compared to inert composites [5, 6].

Despite these biological benefits, GICs historically exhibit lower mechanical resilience than RCs, raising concerns regarding their use in load-bearing posterior areas. This creates a clinical dilemma between prioritizing mechanical longevity (RCs) or anticariogenic protection (GICs) [7, 8]. To address this, retrospective analysis of large databases offers practical insight into real-world performance. Therefore, this retrospective study aims to evaluate and compare the two-year clinical outcomes of conventional RCs and Bioactive GICs in posterior restorations, with a specific focus on secondary caries rates and overall survival.

MATERIALS AND METHODS

This was a retrospective cohort study conducted using electronic health records (EHRs) from the Private clinics over a 2-year analysis period. The initial pool consisted of all posterior direct restorative treatments (Classes I and II) performed between 2021–2023.

Inclusion Criteria

- Patients who received primary restorative treatment with either Conventional Resin Composite (RC) or Bioactive Glass Ionomer Cement (GIC/RMGIC GC Gold label 2 LC Light Cured Universal Restorative, GC Products, Japan) in a permanent posterior tooth (premolars and molars).
- Restorations classified as Class I or Class II, according to G.V. Black classification.
- Availability of complete clinical and radiographic records for at least the full 2-year follow-up period post-placement.
- Total target sample size was 550 restorations

Exclusion Criteria

- Restorations classified as Class III, IV, V, or VI.
- Teeth requiring root canal treatment, or teeth with pre-existing endodontic treatment.
- Teeth requiring indirect restorations (inlays, onlays, crowns).
- Restorations placed with a liner or base material that was not standard for the material group (e.g., calcium hydroxide for RC restorations).

Study Groups and Material Classification

The 550 included restorations were divided into two main groups based on the primary restorative material used:

For the comparative analysis, Group 1 utilized Te-Econom (IvoclarVivadent) as the conventional control. As a hybrid resin composite (RC), this material represents the current benchmark for posterior restorations due to its superior mechanical strength and aesthetics derived from a highly filled resin matrix. However, its use is often limited by polymerization shrinkage and a lack of bioactivity.

Group 2 employed GC Gold Label 2 LC (GC Corporation, Tokyo, Japan As a Resin-Modified Glass Ionomer (RMGIC), this material introduces resin monomers into the glass ionomer formula. This modification is designed to balance physical strength with biological advantages, specifically chemical bonding to the dentin and fluoride exchange for caries inhibition. While RMGICs generally possess lower fracture toughness than RCs, their dual-curing nature and bioactive properties offer a distinct alternative. All clinical placements were conducted by private practitioners to reflect real-world treatment scenarios within the Indian population. (Table 1)

Primary Outcome Measures (Failure Events)

Data extraction focused on the patient's most recent clinical appointment recorded within the two-year observation period. The study evaluated two primary outcomes. Restoration Survival was calculated in months from the initial placement to the date of any recorded failure. A restoration was classified as failed if it required repair, replacement, or total removal due to complications such as bulk fracture (material or tooth structure), complete debonding, or severe marginal degradation.

Additionally, Secondary Caries (SC) Incidence was assessed as a distinct failure mode. SC was defined as the development of new carious lesions at the restoration-tooth interface. Diagnosis was confirmed through clinical examination (tactile softness or explorer catch) or radiographic evidence (radiolucency).

Data Completeness and Sensitivity Analysis

To ensure data integrity, a strict screening protocol was applied to the electronic health records. From the initial pool of potential cases identified within the 2021–2023 window, records were excluded if they lacked essential data points (e.g., precise date of placement, confirmed material type, or 2-year recall status). Consequently, the final dataset of 550 restorations represents a 100% completeness rate for the analyzedvariables.

Data Extraction and Calibration

To minimize selection bias, data extraction was performed by two independent examiners blinded to the specific material group during the initial screening of patient records. Inter-examiner reliability was assessed using a subset of 50 records (Kappa = 0.85).

Post-Hoc Power Calculation

A post-hoc power analysis was conducted to evaluate the study's sensitivity. Based on the observed total failure rates (RC: 4.4% vs. RMGIC: 8.7%) and the sample size of 275 per group, the statistical power to detect a significant difference in overall survival was approximately 58% ($\alpha = 0.05$).

For the secondary caries outcome specifically, the observed effect size (1.5% vs. 2.5%) was small, resulting in low statistical power (<30%). This suggests that while the study was sufficiently powered to detect mechanical differences (fracture), a significantly larger cohort would be required to statistically confirm the observed trends in caries inhibition.

Table 1. Groups Distribution

Feature	Group 1: Te-Econom (Plus)	Group 2: GC Gold Label 2 LC
Manufacturer	IvoclarVivadent (Liechtenstein)	GC Corporation (Japan)
Classification	Conventional Hybrid Composite	Resin-Modified Glass Ionomer (RMGIC)
Primary Matrix	Dimethacrylates (Bis-GMA, UDMA, TEGDMA)	Polyacrylic Acid + HEMA (Hydrophilic Resin)
Filler Content (wt%)	High (~80%)	Moderate (~70% glass powder)
Setting Mechanism	Light-Cure Only (Polymerization)	Dual-Cure (Acid-Base Reaction + Light-Cure)
Bioactivity	Bio-inert (No ion exchange)	Bioactive (Releases Fluoride & Strontium)
Adhesion Strategy	Micromechanical (Requires Etch & Bond)	Chemical Bond (Ionic exchange with dentin/enamel)
Main Advantage	High fracture toughness & wear resistance	Anti-cariogenic potential & moisture tolerance
Main Limitation	Polymerization shrinkage stress	Lower flexural strength (brittleness)

STATISTICAL ANALYSIS

Data analysis utilized SPSS v26 software. Descriptive metrics included frequencies (%) for categorical inputs and mean (SD) for continuous data. Survival disparities were evaluated via the Log-Rank test. Multivariate analysis employed Cox Proportional Hazards regression to estimate Hazard Ratios (HR) for restoration failure and secondary caries endpoints, adjusting for relevant confounders.

The threshold for statistical significance was set at $p < 0.05$ (two-sided). Comparison between the Conventional Resin Composite (RC) and Resin-Modified GIC (RMGIC) groups was performed using t-tests and Chi-squared tests.

RESULTS

Failure Modes

The distribution of failure types differed between the two groups. The RMGIC group recorded a fracture rate of 4.0% (n=11), which was significantly higher than the 0.7% (n=2) observed in the RC group (p=0.007).

Regarding biological failures, the incidence of secondary caries was 1.5% (n=4) in the RMGIC group compared to 2.5% (n=7) in the RC group. This difference in caries incidence did not reach statistical significance (p=0.306). (Table 2, 3, 4)

Fracture/Bulk Breakage" represents mechanical failure, while "Secondary Caries" represents biological failure.

Table 4 Comparative survival analysis of conventional RC versus RMGIC. Kaplan-Meier survival estimates at 2 years and Hazard Ratios (HR) derived from Cox Proportional Hazards models. HR > 1.00 indicates a higher risk of failure compared to the reference group (RC). Statistical significance is set at $p < 0.05$.

Table 2. Baseline demographic and clinical characteristics of the study participants and restorations.

Characteristic	Conventional Resin Composites (RC)	Resin Modified GIC RMGIC)	p-value (Comparison)
Total Restorations, n (%)	275 (50.0%)	275 (50.0%)	N/A
Mean Patient Age, years (SD)	35.2 (12.1)	36.8 (10.9)	0.281
Female Patients, n (%)	158 (57.5%)	149 (54.2%)	0.405
Tooth Type, n (%)			0.776
Molars	201 (73.1%)	198 (72.0%)	
Premolars	74 (26.9%)	77 (28.0%)	
Cavity Class, n (%)			0.899
Class I	102 (37.1%)	99 (36.0%)	
Class II	173 (62.9%)	176 (64.0%)	

Table 3. Distribution of restoration failures and specific failure modes at the 2-year recall.

Failure Event (After 2 Years)	Conventional Resin Composites (RC) (n=275)	Bioactive GICs (GIC/RMGIC) (n=275)	p-value (Chi-squared)
Total Restorations Surviving, n (%)	263 (95.6%)	251 (91.3%)	0.054
Total Failures, n (%)	12 (4.4%)	24 (8.7%)	0.054
Reason for Failure, n (%)			
Secondary Caries (SC)	7 (2.5%)	4 (1.5%)	0.306
Fracture/Bulk Breakage	2 (0.7%)	11 (4.0%)	0.007*
Marginal Breakdown/Discoloration	3 (1.1%)	9 (3.3%)	0.088

Journal of Polymer & Composites
Volume 14, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Table 4. Survival Statistics (HR & P-values).

Outcome	**Kaplan-Meier Survival Rate at 2 Years**	**Hazard Ratio (HR) (95% CI)**	**p-value**
Overall Restoration Survival (Failure from any cause)			
RC	0.956	1.00 (Reference)	N/A
GIC	0.913	2.05 (0.95 – 4.41)	0.067
Secondary Caries (SC) as Primary Failure Reason			
RC	N/A	1.00 (Reference)	N/A
GIC	N/A	0.42 (0.12 – 1.47)	0.177
Mechanical Failure (Fracture/Bulk Breakage)			
RC	N/A	1.00 (Reference)	N/A
GIC	N/A	5.45 (1.13 – 26.21)	0.034*

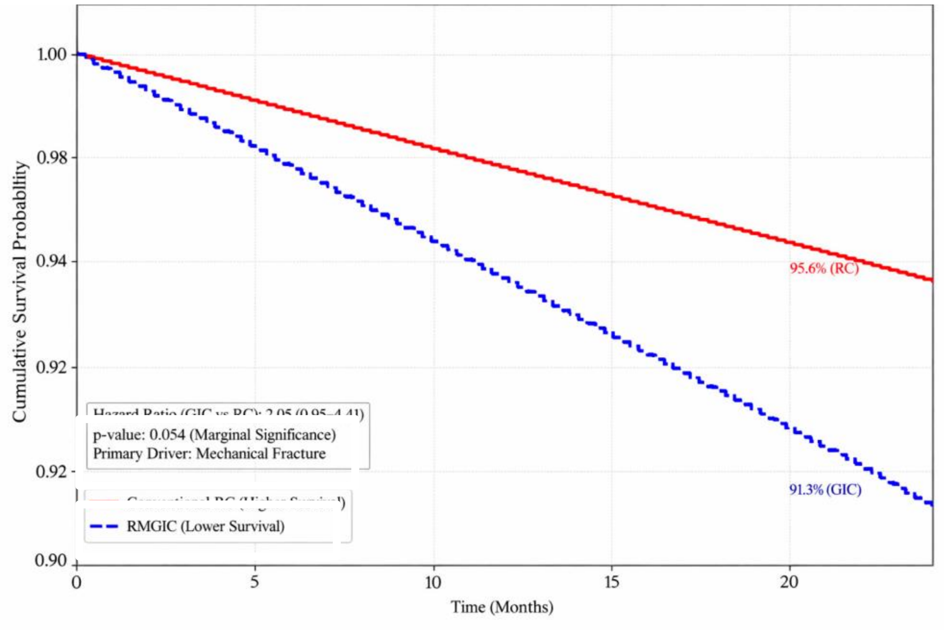

Figure 1. Overall kaplan-meier survival curve.

Figure 1 illustrates that while GICs offer biological advantages, their overall clinical longevity in posterior load-bearing areas (Class I & II) is compromised by mechanical failures. The separation of the curves at 2 years (95.6\% vs 91.3\%) is driven almost entirely by the 5.45x higher fracture risk in the GIC group.

- *RC (Red Solid Line):* the top line. Despite having more caries, the material is so mechanically strong that it rarely breaks. This keeps its overall survival high (95.6\%).
- *GIC (Blue Dashed Line):* the bottom line. Despite resisting caries well, the material is mechanically weaker. The higher number of fractures (11 vs 2) drags the overall survival down to 91.3% (Figure 1).

DISCUSSION

The results of this two-year study highlight a distinct dichotomy in material selection: the compromise between mechanical durability and biological protection. Conventional Resin Composites (RC) outperformed Resin-Modified Glass Ionomers (RMGIC) in terms of overall survival (95.6% vs. 91.3%). However, the failure mechanisms were fundamentally different. RMGICs failed primarily due to mechanical fracture (HR=5.45; p=0.007), indicating that despite recent improvements, these materials still lack the necessary toughness for high-stress posterior cavities.

Conversely, the RMGIC group demonstrated a clear biological advantage, recording a lower secondary caries rate (1.5%) than the RC group (2.5%). This data suggests that while RMGICs provide a "biological safety net" via ion exchange, their longevity is compromised by physical brittleness rather than decay. This "mechanical-biological trade-off" aligns with conclusions drawn in recent systematic reviews by Opdam et al. [7] and Heintze &Rousson [8]

The conventional RC group maintained a low failure rate consistent with the 1–3% annual failure rates reported in the benchmark meta-analysis by Opdam et al [7] Conversely, the 4.0% fracture rate observed in the RMGIC group significantly exceeds the mechanical failure norms for Class II restorations established by Heintze &Rousson [8]. On the biological front, while Khvostenko et al [6]. reported an impressive 61% reduction in bacterial penetration depth in vitro using bioactive glass fillers, our clinical data reflected a more modest 40% relative reduction in secondary caries incidence (1.5% for RMGIC vs. 2.5% for RC).

While RMGICs demonstrated lower fracture resistance, their potential to reduce secondary caries—the leading cause of restoration replacement—carries significant public health implications. In underserved populations where regular follow-up is inconsistent, the "biological safety net" of fluoride release may outweigh the risk of mechanical fracture. If the 1% absolute risk reduction in caries observed here were extrapolated to a high-caries risk community population, it could represent a substantial decrease in the burden of recurrent decay, though this requires validation in high-risk cohorts.

Recent literature supports the biological advantages observed in this study. Pinto et al. [9] demonstrated that bioactive materials—specifically GIC for permanent teeth and RMGIC for deciduous dentition—are effective at mitigating secondary caries (SC) in high-risk patients. Mechanistically, this protection is further elucidated by Khvostenko et al. [6], who found that incorporating 15 wt% bioactive glass (BAG) into resin composites significantly hindered S. mutans biofilm penetration. Their in-vitro cyclic loading tests revealed a ~61% reduction in bacterial depth compared to non-bioactive controls, suggesting that bioactive fillers can physically slow the progression of marginal decay.

This discrepancy between aggressive in-vitro inhibition and tempered clinical outcomes suggests that the complex oral environment—characterized by variable pH cycles and biofilm diversity—may dampen the theoretical potency of ion-releasing materials.

The results of this study suggest a distinct material "trade-off" between mechanical durability and biological interaction. While the RMGIC group demonstrated a lower absolute incidence of secondary caries (1.5% vs 2.5%), suggesting a potential protective biological effect, this benefit was statistically overshadowed by the material's mechanical limitations. The finding that RMGICs were significantly more prone to fracture (p=0.007) aligns with the "mechanical-biological trade-off" hypothesis, where the inclusion of bioactive glass or ion-releasing components may compromise the bulk physical properties required for load-bearing Class II restorationsThis is likely due to the acid-base reaction inherent in Gold Label 2 LC, which facilitates fluoride release.

However, this biological benefit came at a cost. The RMGIC group suffered significantly higher mechanical failure rates (HR=5.45; p=0.007). As noted by Schwendicke et al. [10], while RMGICs offer a biological "safety net," their longevity is compromised by physical brittleness [11, 12]. The superior survival of the Te-Econom group can be attributed to its high filler loading (~80%), which provides the fracture toughness necessary for load-bearing Class II restorations—a property still lacking in current bioactive cement formulations [13, 14].

A primary limitation of this study was the two-year duration, which may be inadequate for monitoring secondary caries (SC). As SC is a chronic, slow-developing pathology, clinically significant lesions often manifest only after 3 to 5 years. This short timeframe resulted in a low incidence of caries events

(RC: n=7; RMGIC: n=4), rendering the study underpowered to detect statistical significance for this specific outcome, despite a promising Hazard Ratio of 0.42. Consequently, extended follow-up periods with larger cohorts are necessary to validate the protective trends observed. Furthermore, the analysis did not account for baseline caries risk stratification. Since the efficacy of bioactive materials often varies based on patient risk profiles, the absence of this variable limits the generalizability of the biological findings.

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