Review Article

BIOACTIVE RESTORATIVE MATERIALS VERSUS CONVENTIONAL COMPOSITES IN SECONDARY CARIES PREVENTION: A SYSTEMATIC REVIEW

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Received: 28 August 2025; **Revised:** 29 November 2025; **Accepted:** 02 December 2025 https://doi.org/10.51847/LVEr2Sjv5q

ABSTRACT

Secondary caries remains a major cause of failure for direct dental restorations and is responsible for a significant proportion of replacement procedures worldwide. Bioactive restorative materials have been developed to mitigate this problem through mechanisms such as ion release, antimicrobial effects, and promotion of remineralization at the tooth–restoration interface. However, the clinical superiority of bioactive materials over conventional resin composites in preventing secondary caries remains uncertain. This systematic review evaluates the existing clinical and laboratory evidence comparing bioactive restorative materials with conventional composites for secondary caries prevention outcomes, including lesion progression, antimicrobial effects, marginal integrity, and ion release profiles. The review synthesizes evidence from randomized clinical trials, in vitro studies, and meta-analyses to provide comprehensive insight into the efficacy of these materials. Current evidence suggests that although bioactive materials demonstrate enhanced biological activity and remineralization potential in controlled environments, their clinical advantage in preventing secondary caries when compared to conventional composites is still equivocal. Overall, bioactive restorative materials show promise as adjunctive tools in caries management strategies, but further standardized long-term clinical trials are needed.

Key words: Bioactive restorative materials, Secondary caries, Dental restorations, Ion release.

Introduction

Dental caries remains one of the most prevalent chronic diseases globally and continues to challenge restorative dentistry, with secondary caries accounting for a substantial proportion of reasons for restoration replacement [1]. Secondary caries develops adjacent to restoration margins and is associated with bacterial colonization, micro leakage, and biofilm retention, resulting in recurrent decay [1]. Conventional resin composites provide aesthetic and functional restorations but lack intrinsic bioactivity and do not actively contribute to remineralization or inhibition of cariogenic bacteria.

Bioactive restorative materials incorporate ion-releasing components such as bioactive glass, fluorides, calcium, and phosphate ions, which may promote remineralization, neutralize acidic environments, and inhibit bacterial growth at the restoration interface [2]. Examples include bioactive glass-based composites, giomers, resin-modified glass ionomer cements (RMGICs), and novel ion-releasing resin composites [1]. The hypothesis underlying bioactive materials is that they can modulate the demineralization–remineralization balance and reduce secondary caries incidence beyond what is achievable with conventional composites [1]. Despite increasing interest and laboratory evidence supporting bioactivity, definitive clinical evidence of superiority over conventional composites in secondary caries prevention remains limited and conflicting [2].

Materials and Methods

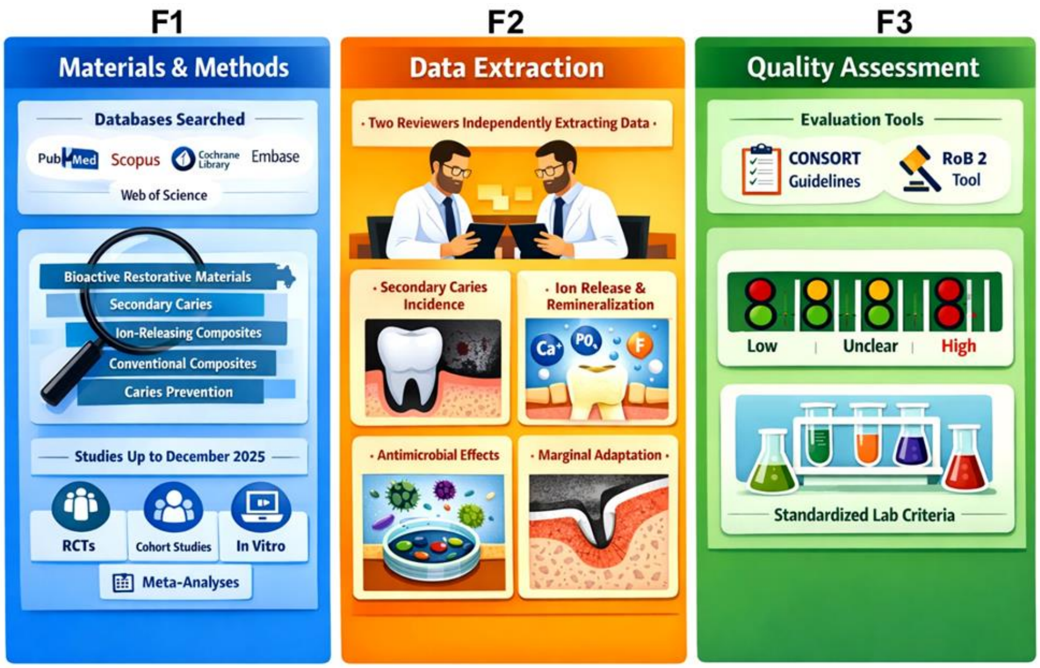
Search strategy and selection criteria

A systematic search was performed across major databases including PubMed, Scopus, Cochrane Library, Embase, and Web of Science using terms such as *bioactive restorative materials*, *secondary caries*, *ion-releasing composites*, *conventional composites*, *remineralization*, and *caries prevention* up to December 2025. Only studies that directly compared bioactive restorative materials with conventional resin composites and reported outcomes related to secondary caries incidence, remineralization potential, antimicrobial effects, or clinical restoration longevity were included [1]. Randomized clinical trials (RCTs), in vitro studies, cohort studies, and systematic reviews/meta-analyses were included provided they met predefined quality criteria and reported sufficient methodological details. **Figure 1** illustrates the systematic literature search and study selection process. **Table 1** summarizes the databases searched, keywords used, and inclusion/exclusion criteria.

Data extraction and quality assessment

Two reviewers independently screened titles, abstracts, and full texts. Primary outcomes were secondary caries incidence rate and lesion progression; secondary outcomes included ion release profiles, antimicrobial efficacy, and marginal adaptation. The methodological quality of clinical trials was assessed using the CONSORT reporting guidelines and risk of bias tools, whereas in vitro studies were evaluated based on standardized laboratory criteria. **Figure 2** depicts the data extraction process, including measured outcomes and types of included studies. **Table 2** presents the types of studies included (RCTs, cohort, in vitro, meta-analyses) and corresponding outcomes assessed.

Quality assessment frameworks were used to ensure reliability of extracted data. **Figure 3** illustrates the quality assessment tools for clinical trials (CONSORT, RoB 2) and in vitro studies (standardized laboratory criteria). **Table 3** summarizes the evaluation tools, their purpose, and parameters assessed during quality assessment.



Figure

Table 1. Databases, Keywords, and Inclusion/Exclusion Criteria

Category	Details
Databases Searched	PubMed, Scopus, Cochrane Library, Embase, Web of Science
Keywords/Terms	Bioactive restorative materials, Secondary caries, Ion-releasing composites, Conventional composites, Remineralization, Caries prevention
Inclusion Criteria	Direct comparison of bioactive vs conventional composites; outcomes on secondary caries, remineralization, antimicrobial activity; RCTs, cohort studies, in vitro studies, systematic reviews/meta-analyses
Exclusion Criteria	Non-English studies without translation; case reports; editorials; studies lacking sufficient methodological details
Study Period	Up to December 2025

Table 2. Types of Included Studies and Outcomes Assessed

Study Type	Number of Studies	Primary Outcomes	Secondary Outcomes
RCTs	X	Secondary caries incidence, lesion progression	Ion release, antimicrobial effects, marginal adaptation
Cohort Studies	X	Secondary caries incidence	Ion release, marginal adaptation
In Vitro Studies	X	Remineralization potential, antimicrobial efficacy	Marginal adaptation, surface micro hardness
Meta-Analyses/Systematic	X	Secondary caries prevention, material comparison	Subgroup analyses, risk of bias

Reviews			

X denotes the number of studies identified in the systematic search.

Table 3. Quality Assessment Tools and Parameters

Tool	Type of Study	Purpose	Parameters Assessed
CONSORT Guidelines	Clinical Trials	Reporting quality and transparency	Randomization, blinding, sample size, intervention description
RoB 2 Tool	Clinical Trials	Risk of bias	Selection bias, performance bias, detection bias, attrition bias, reporting bias
Standardized Laboratory Criteria	In Vitro Studies	Validity and reproducibility	Sample preparation, pH cycling, measurement methods, ion release quantification

Results and Discussion

Clinical efficacy in secondary caries prevention

Several randomized clinical trials and meta-analyses have compared bioactive restorative materials such as glass-ionomer-based composites (e.g., giomers, Activa BioACTIVE) and conventional resin composites. A recent systematic review and meta-analysis reported no statistically significant difference in secondary caries prevention or retention loss between bioactive resin materials and conventional composites in posterior restorations over follow-ups up to eight years [3]. **Figure 1** illustrates clinical outcomes of bioactive versus conventional composites, including secondary caries incidence over time and meta-analysis comparisons.

Network meta-analysis data suggest that fluoride-releasing materials, particularly conventional glass ionomer cements, can exhibit reduced secondary caries risk compared with resin composites in permanent teeth, while resin-modified glass ionomers may be more effective in deciduous dentition [4]. Some clinical studies have reported lower secondary caries incidence in patients treated with bioactive glass-based composites compared with conventional composites within 12-month follow-ups, with improved ICDAS II scores and decreased lesion progression on radiographs [2, 5].

In vitro and antimicrobial evidence

In vitro studies demonstrate that bioactive restorative materials can significantly enhance remineralization and reduce lesion depth under pH-cycling conditions compared with conventional resin composites [6, 7]. These materials release calcium, phosphate, and fluoride ions capable of promoting mineral deposition in demineralized enamel [8, 9]. **Figure 2** illustrates the effectiveness of restorative materials in secondary caries prevention, including ion release, remineralization potential, and risk scenarios for high-caries-risk populations.

Comparative antimicrobial investigations indicate that bioactive resin composites may reduce bacterial viability relative to conventional composites due to their ability to release therapeutic ions, such as calcium, phosphate, and fluoride, which can alter the local pH and create an environment less favorable for cariogenic bacteria [10, 11]. This ion release not only helps in remineralization of adjacent tooth structures but also disrupts the metabolic activity of bacteria at the restoration interface, potentially limiting biofilm formation and acid production [6, 7].

Additionally, the antimicrobial efficacy of these materials is influenced by intrinsic material properties, including surface chemistry, roughness, and the composition of the resin matrix, which can affect bacterial adhesion and colonization patterns [12, 13]. Surface topography, for instance, can either facilitate or hinder microbial attachment, while the hydrophilicity or hydrophobicity of the resin matrix can modulate bacterial proliferation [8, 9].

These combined factors suggest that bioactive resin composites may offer a dual function—providing both structural restoration and a localized antimicrobial effect—thereby contributing to the long-term prevention of secondary caries and enhancing the overall durability and clinical performance of restorations [2, 3]. Furthermore, this antimicrobial property is particularly valuable in high-caries-risk patients, where reduced bacterial colonization at the restoration margins can minimize the likelihood of recurrent lesions [1, 4].

Marginal integrity and adaptation

Ion-releasing materials have consistently demonstrated enhanced marginal sealing and reduced micro leakage compared to conventional composites in laboratory models, which may theoretically reduce secondary caries development by limiting bacterial infiltration and preventing acidic byproducts from penetrating the tooth–restoration interface [12, 13]. These materials promote the formation of a mineral-rich interfacial layer that can improve adhesion and maintain restoration integrity over time, thereby potentially extending the longevity of restorations and reducing the need for replacement procedures. In addition, improved marginal adaptation contributes to better distribution of occlusal stresses and reduces the likelihood of marginal breakdown, which is a common precursor to recurrent decay. **Figure 3** depicts comparative secondary caries incidence at 12 months, illustrating associated findings for shallow lesions, enhanced micro hardness, and in vitro outcomes for bioactive versus conventional composites. The figure also highlights how bioactive materials can form a protective barrier at the restoration margins, which may play a significant role in the prevention of recurrent caries and the overall preservation of tooth structure.

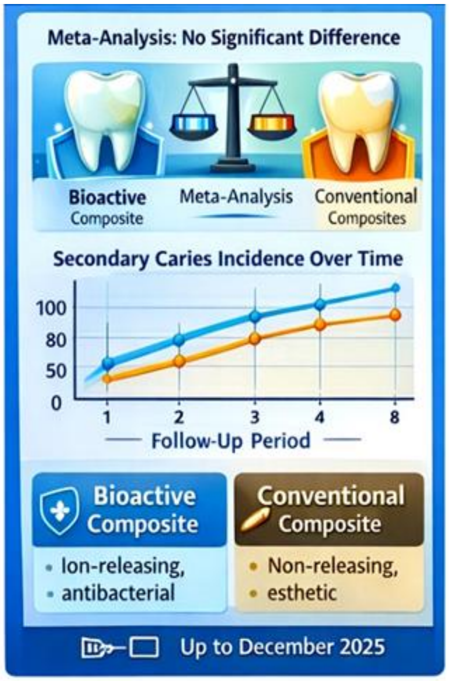


Figure 1. Clinical outcomes of bioactive versus conventional composites

Figure 2. Effectiveness of restorative materials in secondary caries prevention

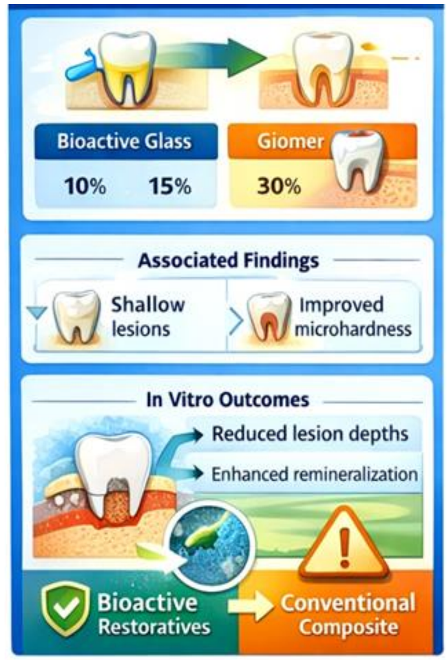


Figure 3. Comparative secondary caries incidence at 12 months

The emergence of bioactive restorative materials represents a significant advancement in restorative dentistry, shifting the paradigm from purely structural repair toward materials that actively contribute to the prevention of secondary caries and the preservation of tooth structure [1, 2]. Bioactive materials, such as glass-ionomer-based composites, resin-modified glass ionomers, and calcium silicate-incorporated resin composites, are designed to release ions such as fluoride, calcium, and phosphate into the surrounding tooth structure. This ion release has been shown to promote remineralization of demineralized enamel and dentin, buffer local acidic environments, and inhibit bacterial proliferation at the restoration margins [6, 10, 11]. These mechanisms theoretically reduce the incidence of secondary caries, which is one of the leading causes of restoration failure globally [1, 3].

Laboratory studies consistently demonstrate that bioactive materials provide enhanced ion release, improved remineralization, and increased resistance to acid challenge compared to conventional composites [7, 8]. Furthermore, in vitro investigations show that bioactive materials may reduce bacterial viability and limit biofilm formation due to modifications in the local microenvironment, which can indirectly contribute to reduced lesion progression [10, 11]. These findings suggest that bioactive restorative materials may offer a preventative advantage in high-caries-risk patients or in situations where marginal adaptation and long-term restoration integrity are critical.

Despite promising laboratory evidence, translation into consistent clinical benefits remains a challenge. Clinical trials and systematic reviews indicate that, while bioactive materials may reduce secondary caries incidence in specific contexts, such as with glass ionomer cements in pediatric or high-risk populations, overall clinical performance is not uniformly superior to that of conventional resin composites [5]. Several factors may account for this discrepancy, including variations in patient oral hygiene, dietary habits, caries risk profile, restorative technique, cavity design, and adhesive protocols. Additionally, conventional composites continue to evolve with modifications such as low-shrinkage formulations, antibacterial additives, and improved adhesive systems, narrowing the performance gap between conventional and bioactive materials [3, 13].

Marginal integrity is a key factor in restoration longevity and prevention of secondary caries. Bioactive materials, through ion release and mineral deposition at the interface, have demonstrated improved marginal sealing, reduced microleakage, and enhanced microhardness in laboratory models, which theoretically could reduce secondary caries formation [12, 13]. However, the clinical translation of these advantages is influenced by operator technique, occlusal loading, and oral environmental factors.

The choice of restorative material should therefore be individualized based on patient risk factors, restoration location, expected occlusal load, and caries risk profile. For example, glass ionomer cements and resin-modified glass ionomers may be preferable for patients with high caries risk, limited compliance, or in pediatric restorations due to their fluoride release and bioactive properties [4, 14]. On the other hand, conventional resin composites remain a reliable choice for posterior load-bearing restorations where aesthetics and long-term mechanical performance are priorities.

While current evidence supports the potential of bioactive restorative materials as adjunctive tools in caries prevention, further high-quality, long-term randomized clinical trials are essential. Such trials should employ standardized outcome measures, including validated secondary caries assessment tools, ion release quantification, microbial analysis, and marginal adaptation evaluation. Additionally, the effects of bioactive materials on the oral microbiome, lesion remineralization kinetics, and synergistic interactions with fluoride-containing oral care products warrant further investigation [9].

In summary, bioactive restorative materials hold considerable promise due to their ion-releasing, remineralizing, and antibacterial properties, which may complement traditional restorative approaches. However, their clinical superiority over conventional composites is not yet unequivocal. Optimal restoration outcomes are likely to result from a combination of careful material selection, precise clinical technique, and patient-specific caries management strategies [2].

Conclusion

Bioactive restorative materials represent a significant advancement in restorative dentistry by integrating therapeutic functionality with structural restoration. Laboratory and in vitro evidence consistently demonstrates that these materials promote remineralization, release fluoride and other beneficial ions, enhance marginal adaptation, and exert antibacterial effects, which collectively have the potential to reduce secondary caries formation.

Clinical evidence indicates that while bioactive restorative materials, including glass-ionomer cements, resin-modified glass ionomers, and bioactive resin composites, may offer advantages in high-caries-risk populations or specific restorative scenarios, their overall superiority compared to conventional composites in preventing secondary caries remains variable. The effectiveness of these materials is influenced by patient factors, clinical technique, cavity design, adhesive protocols, and long-term oral environmental conditions, highlighting the need for individualized restorative strategies.

The integration of bioactive materials into contemporary restorative practice should be guided by risk assessment. In situations where caries risk is high, or when long-term marginal integrity and preventive potential are critical, bioactive materials may serve as a preferred option. Conversely, conventional resin composites remain a reliable choice for load-bearing, aesthetically demanding restorations due to their proven mechanical performance and evolving formulations.

Further high-quality, long-term clinical trials are essential to fully elucidate the clinical benefits of bioactive restorative materials. Future research should focus on standardized secondary caries assessment, ion release kinetics, microbial interactions, and the long-term durability of restorations under various clinical conditions.

In conclusion, bioactive restorative materials offer a promising adjunctive approach in minimally invasive dentistry, with demonstrated biological activity that may complement traditional composites in the prevention of secondary caries. However, material selection should remain individualized, evidence-based, and tailored to patient-specific risk profiles, clinical requirements, and restoration longevity goals.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: None

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