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Literature Review

Remineralization Potential of Bioactive Composite Resins: A Systematic Review

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Abstract: To evaluate the clinical performance and potential of giomer-based materials in promoting the remineralization of dental structures through a systematic review of the literature. A comprehensive literature search was conducted using PubMed, Scopus, and Web of Science databases up to March 2024. "giomer," "S-PRG," "bioactive restorative materials," "remineralization," and "dental caries." Inclusion criteria comprised clinical studies involving human subjects, with follow-up periods of at least 6 months, evaluating outcomes such as caries recurrence, marginal adaptation, and material retention based on USPHS and ICDAS criteria. Out of the studies included, giomer-based sealants demonstrated a low incidence of secondary caries, with one study reporting only one case in a 48-month period, considered clinically insignificant. In terms of retention, only 6% of giomer sealants remained fully retained after 18 months in one study. For Class V restorations, retention ranged from 82.5% (alpha) to 17.5% (Charlie) depending on the study, and in Class I and II restorations, performance varied by location (occlusal vs. non-occlusal). Across multiple studies, giomer materials consistently showed superior surface finish and color matching compared to conventional materials. However, retention performance was often inferior. Giomer-based restorative materials containing S-PRG particles exhibit promising results in maintaining healthy dental structures and preventing caries progression, despite variable retention outcomes. Their aesthetic and marginal adaptation properties make them suitable for use in Class I, II, and V restorations. Further long-term clinical trials are necessary to strengthen evidence regarding their remineralizing potential.

Keywords: Bioactive Composite Resins, Dental Caries, Remineralization

Introduction

Dental caries is a widespread, chronic disease that leads to mineral loss and the formation of cavities in affected teeth. The primary cause of dental caries is the fermentation of dietary carbohydrates by bacteria in the oral cavity, which produces acids that lower the pH and lead to demineralization of tooth enamel. To address dental caries, preventive measures such as plaque control and dietary changes are essential. However, when caries progresses to the point of cavitation, restorative intervention is required. Traditional restorative materials include composite resins and glass ionomer cements, which have long been used for their aesthetic and functional properties.

Composite resins are favored for their superior mechanical properties, durability, and aesthetic results. They are particularly suitable for load-bearing restorations and provide a good match to natural tooth color. However, composite resins do not release fluoride, which limits their effectiveness in preventing further caries. Additionally, they are prone to polymerization shrinkage, which can affect their clinical longevity, especially in large restorations. Despite these advantages, the lack of fluoride release is a significant drawback when compared to other materials.

In contrast, glass ionomer cements offer the benefit of fluoride release, which can help prevent secondary caries by promoting remineralization of the surrounding tooth

structure. However, glass ionomer cements generally have lower mechanical strength compared to composite resins, making them less suitable for high-stress areas, such as posterior teeth. Their lower flexural strength and limited resistance to wear also constrain their use in large restorations. While glass ionomer cements have moderate clinical longevity, their mechanical properties and aesthetic appearance may not be ideal for all clinical situations.

Giomers, a newer class of restorative materials, are based on Pre-Reacted Glass ionomer (PRG) technology. These materials combine the fluoride-releasing properties of glass ionomer cements with the excellent mechanical strength and aesthetic qualities of composite resins. Giomers release fluoride ions that help remineralize teeth, similar to glass ionomer cements, but they also maintain good mechanical strength, making them suitable for both load-bearing restorations and aesthetically demanding areas. Additionally, giomers have been shown to stimulate the formation of sclerotic dentin, further enhancing their remineralizing effect. This makes giomers a promising option for caries treatment, particularly in Class I, II, and V restorations.

While giomers demonstrate superior mechanical strength and bioactive properties compared to glass ionomer cements, they still maintain the aesthetic and functional advantages of composite resins. Their ability to release fluoride and promote remineralization, coupled with their mechanical properties, positions them as an effective restorative material. However, it is important to note that the clinical evaluation of remineralization is often indirect. Therefore, outcomes such as secondary caries incidence and marginal adaptation serve as surrogate markers rather than direct evidence of remineralizing activity.

Thus, this study aims to conduct a systematic literature review to evaluate, in patients requiring restorative dental treatment, the use of giomers in comparison to other restorative materials regarding their ability to promote dental structure remineralization.

Methods

Study Design and Inclusion and Exclusion Criteria

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were used to guide the design of this study. The search strategy was based on population, intervention, comparison, and outcome. Only clinical studies on dental restorations associated with giomers (S-PRG, bioactive resins) were included. These studies had to be randomized controlled trials or clinical studies evaluating the performance of the material. Patients of any age could be included. There were no restrictions on the publication year. Comparisons were made with other restorative materials. The outcome measures included dental remineralization, presence of secondary caries, material retention, and marginal adaptation according to the United States Public Health Service (USPHS) and International Caries Detection and Assessment System (ICDAS) criteria.

Nevertheless, case reports, laboratory studies, treatment protocols, systematic reviews, personal opinions, letters, abstracts, posters, incomplete texts, duplicate studies, clinical studies with objectives different from the inclusion criteria, and studies in different languages with poor translation using online translators were excluded. Studies using non-standardized criteria were also excluded to minimize methodological heterogeneity and avoid bias in the interpretation of results.

Research Strategy

Adapted search strategies were employed for each of the selected databases: EMBASE, Latin American and Caribbean Health Sciences (LILACS), PubMed. In addition, grey literature search was conducted using Google Scholar. The reference management tool Mendeley® and the Rayyan® program were utilized to facilitate the article selection process.

The search keywords included: Remineralization, caries, giomers, and S-PRG. Mesh Terms, free terms, and boolean operators (AND, OR) were employed in the main databases. The search in the databases and grey literature was conducted and updated until June 2022. The search keywords varied according to the selected database, based on their scope. PubMed: (Bioactive resins) AND (dentin [MeSH Terms]); Giomer; giomer"[All Fields] OR "giomers"[All Fields]) AND "dentin"[MeSH Terms]); (giomer) AND (dental caries [MeSH Terms]); (s-prg) AND (dentin [MeSH Terms]); s-prg. LILACS: Dentin and giomers; s-prg and dentin; giomers; s-prg. EMBASE: Giomer and remineralization, giomer; S-PRG and remineralization. Google Scholar: Giomer and remineralization and laboratory studies; giomer and remineralization and clinical studies.

Article Selection

The article selection process consisted of three phases. In the first phase, three reviewers independently analyzed the titles and abstracts of articles to identify eligible studies using the online software Rayyan. The process was conducted in a blind manner, meaning that reviewers could not see each other's decisions throughout the process. In the second phase, two reviewers read the full texts of the eligible studies to determine the need for further exclusions based on the selection criteria. These studies were included for qualitative analysis, leading to the third phase of evaluation. In this phase, data extraction was performed, and a table with essential research topics was created. Studies that did not provide the minimum required data were excluded.

A total of 251 articles were initially selected for screening. All three reviewers conducted the screening independently and blindly. The first reviewer included 19 articles in the research, remained uncertain about 5 articles, and excluded 226 articles. Therefore, 90.4% of the selected articles were excluded, 2% were marked as "maybe," and 7.6% were included. The second reviewer excluded 223 articles, included 21 articles, and marked 6 articles as "maybe." The third reviewer excluded 237 articles and included 12 articles.

Overall, the articles were categorized as follows: 216 articles were excluded, 19 articles were in conflict, 9 articles were included without conflict, and 7 articles were marked as "maybe." However, based on the decision of two reviewers, these "maybe" articles were also excluded. In cases of conflict, majority decisions were used to resolve the discrepancies, resulting in an additional 8 articles included in the research. Therefore, a total of 16 articles were included in the review after the first and second phases of article selection.

Data Extraction

During the data extraction process, it was determined that one conflicting article required further evaluation. This evaluation was conducted by three reviewers, two of whom included the study. Therefore, an additional article was added to the research, resulting in a total of 17 included articles.

Data Collection Process

The data collection was performed by a primary reviewer. A table was created to collect data from the articles, which included information such as authors, primary objective, sample size calculation, study blinding, study design, number of patients, average age, number of males, cavity types, groups/number of restorations per group, isolation type, cavity conditions (caries, defective restorations, non-carious cervical lesions, sound teeth), application of phosphoric acid, adhesive system and application technique, restoration material used, light activation, and polishing technique.

For the results section, the following topics were used: Evaluation criteria used, follow-up time, caries recurrence, marginal adaptation, radiographic failures, clinical failures, and material retention, as well as the results and conclusions of the studies. In cases of missing data, this topic was labeled as "n.i. - not informed" without making assumptions for the missing or unclear information.

During the data collection process, additional articles were excluded from the research due to not meeting the necessary evaluation methods or having a primary objective that did not align with the research. This resulted in a total of 7 included articles. The entire process of study selection is depicted in Figure 1.

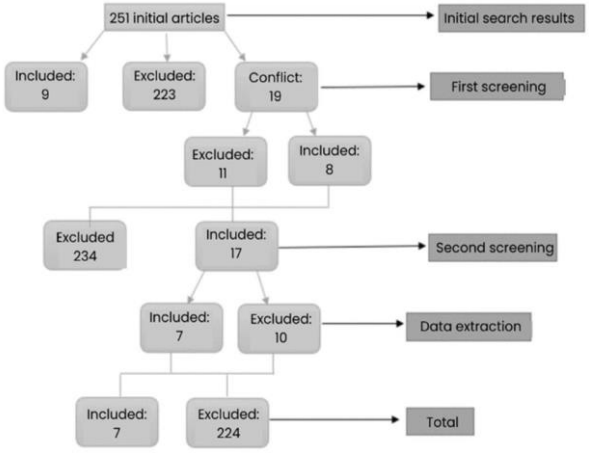

Fig. 1: PRISMA flowchart illustrating the article selection process

Risk of Bias Assessment

The risk of bias for each included clinical study was assessed using a table structured around six methodological domains: Random sequence generation, blinding of participants, blinding of operators, blinding of outcome assessors, completeness of outcome data, and selective reporting. These domains are based on the Cochrane Collaboration's Risk of Bias tool, which is widely recognized for evaluating randomized controlled trials.

The assessment was performed independently by two reviewers, previously calibrated using the same evaluation criteria to ensure consistency and reliability in the analysis. Although the reviewers were not blinded to the authors or institutions of the studies, any discrepancies were resolved through discussion and consensus.

To enhance transparency, a summary table was created (Table 1) presenting the risk of bias judgments for each domain across the included studies, categorized as "low risk," "high risk," or "unclear risk." This table supports the interpretation of the overall methodological quality and reliability of the evidence.

Furthermore, to summarize the clinical outcomes related to caries recurrence in the studies, an additional table was compiled with the following data for each included article: Study identification, evaluation time points, and observed outcomes regarding the progression or stability of carious lesions, based on USPHS and ICDAS criteria (Table 2). This synthesis aims to facilitate comparative analysis of the findings and support the discussion on the clinical effectiveness of giomer-based materials in preventing secondary caries.

Table 1: Risk of bias of the included studies

Reference	Sequence generation	Blinded patient	Blinded operator	Blinded examiner	Data of the addressed outcomes	Free from selective reporting
Akimoto *et al*. (2011)						
Jyothi *et al.* (2011)						
Kurokawa *et al*. (2015)						
Mu *et al*. (2020)						
Ntaoutidou *et al*. (2018)						
Penha *et al*. (2021)						
Priyadarshini *et al*. (2017)						

Table 2: Caries recurrence criterion

Reference	Evaluation time	Caries recurrence
Ntaoutidou *et al*. (2018)	6M/12M/18M	18 months: Initial ICDAS 0 (51) – ICDAS 0/32, ICDAS 1/8, ICDAS 2.1; Initial ICDAS 1 (54) – ICDAS 0/12, ICDAS 1/30, ICDAS 2/4
Mu *et al*. (2020)	6M/12M/18M	48M: 1
Priyadarshini *et al*. (2017)	6M/12M/18M	n.i.
Kurokawa *et al*. (2015)	6M/12M/18M	100% alfa
Penha *et al*. (2021)	6M/12M/18M	1M: ICDAS 0 / 25 (89,3%), ICDAS 2 / 3 (10,7%); 6M: ICDAS 0 / 23 (82,1%), ICDAS 1 / 3 (10,7%), ICDAS 2 / 2 (7,1%); 12M: ICDAS 0 / 18 (64,3%), ICDAS 1 / 7 (25%), ICDAS 2 / 3 (10,7%)
Jyothi *et al.* (2011)	6M/12M/18M	n.i.
Akimoto *et al*. (2011)	6M/12M/18M	6M: 53 alfa, 0 bravo, 0 charlie. 18M: 51 alfa, 0 bravo, 0 charlie

Results

During the article search, it was challenging to find studies that solely evaluated the presence of dental remineralization. Therefore, the evaluation consisted of analyzing articles that reported outcomes according to USPHS and ICDAS criteria, focusing on retention, marginal adaptation, secondary caries, and categorization of retention as "TR – total retention," "PL – partial loss," and "TL – total loss." Additionally, the conclusions and numerical results provided by the authors were included in the synthesis. These outcomes are comparatively summarized in Table 3, which compiles the main clinical outcomes evaluated across the included studies, namely caries recurrence, marginal adaptation, and retention performance, according to standardized criteria (USPHS and/or ICDAS).

According to Ntaoutidou *et al*. (2018), despite a higher loss of material in the test group, carious lesions did not develop. After 18 months, 62.7% (32/51) of restorations initially classified as ICDAS 0 remained unchanged, while 58.8% (30/51) of those initially ICDAS 1 also showed no progression. However, the material containing S-PRG particles had significantly inferior retention, consistent with Penha *et al*. (2021) who observed that lesions classified as ICDAS 2 remained stable after 12 months, despite low retention rates of the giomer-based sealant.

Mu *et al.* (2020) reported the presence of secondary caries at 48 months, though with no clinical significance. Akimoto *et al*. (2011) observed that secondary caries remained within the "alpha" rating during their respective follow-up periods.

Retention data also confirmed limitations in giomer performance. For Ntaoutidou *et al*. (2018), only 6% of sealed surfaces maintained complete retention at 18 months. Similarly, Penha *et al*. (2021) found 0% complete retention of giomer sealants after 12 months.

According to USPHS criteria, (Priyadarshini *et al*., 2017) reported that 17.5% (8 out of 46) of Class V restorations with giomer were rated as Charlie (failure), a higher failure rate compared to RMGIC and Ketac Nano. In contrast, Jyothi *et al.* (2011) found that 87.5% of 40 restorations remained in alpha, with no Charlie-rated restorations, and retention similar to RMGIC. Both studies noted superior surface finish and esthetics of giomer over the compared materials.

Table 3: Retention criterion

Reference	Evaluation time	Caries recurrence
Ntaoutidou *et al*. (2018)	6M/12M/18M	TR 6M/16,5%, 12M/8%, 18M/6%; PL: 6M/51%, 12M?33%, 18M/26%; TL: 6M/30%, 12M/51%, 18M/55%
Mu *et al*. (2020)	6M/12M/18M	n.i.
Priyadarshini *et al*. (2017)	6M/12M/18M	6M: 35 (87,5%) alfa, 0 bravo, 5 (125%) charlie; 12M: 33 (82,5%) alfa, 0 bravo, 8 (17,5%) charlie.
Kurokawa *et al*. (2015)	6M/12M/18M	n.i.
Penha *et al*. (2021)	6M/12M/18M	1M: TR 6 (21,4%), PR 15 (53,6%), TL 7 (25%); GM: TR 5 (17,9%), PR 12 (42,9%), TL 11 (39,3%); 12M: PR 7 (25%), TL 21 (75%)
Jyothi *et al.* (2011)	6M/12M/18M	T5D: 39 (97,5%) alfa, 1 (2,5%) bravo; 6M: 36 (90%) alfa, 4 (10%) bravo; 1A: 35 (87,5%) alfa, 5 (12,5%) bravo
Akimoto *et al*. (2011)	6M/12M/18M	6M: 53 alfa, 0 bravo, 0 charlie. 18M: 51 alfa, 0 bravo, 0 charlie

In Class I and II restorations, Mu *et al.* (2020) observed acceptable behavior in non-occlusal areas, though the material was slightly inferior in occlusal contact regions. Akimoto *et al*. (2011) found 100% of posterior restorations remained alpha after 18 months, while Kurokawa *et al*. (2015) confirmed clinically acceptable retention and marginal adaptation throughout the follow-up.

A subgroup analysis revealed that while studies on sealants tended to show lower retention rates, they consistently highlighted positive results in preventing cavities. On the other hand, studies that examined restorative procedures reported better aesthetic results and improved marginal adaptation, especially for restorations placed in areas that do not experience significant stress. This suggests that while sealants may be effective for caries prevention, restorative treatments may offer advantages in terms of appearance and durability in certain locations.

Regarding marginal adaptation, no study rated it as Charlie. In Kurokawa *et al*. (2015), proximal surfaces maintained 100% alpha classification, though occlusal areas showed minor changes, highlighting that degradation in adaptation was limited to more functionally demanding regions.

Discussion

The objective of this study is to conduct a systematic literature review on giomers and their ability to remineralize dental structures. A general analysis of giomeric material was performed, addressing its characteristics such as remineralization potential, retention, and marginal adaptation, in order to evaluate its suitability for dental restorations. As giomers are a relatively new material in dentistry, still not widely adopted, a comprehensive review of the existing studies is essential to provide a clinical conclusion about their effectiveness.

Giomers contain Pre-Reacted Glass-ionomer (PRG) in their composition, and more specifically, they incorporate Surface Pre-Reacted Glass-ionomer (S-PRG). This material has the ability to release fluoride, aluminum, boron, silicon, and strontium ions, which not only enhance its remineralizing properties but also contribute to the mechanical strength and clinical longevity of the material. One of the key features of giomers is their ability to stimulate dentin remineralization, resulting in the formation of sclerotic dentin due to ion release, particularly fluoride. These properties make giomers an attractive option for dental restorations.

In the studies reviewed, giomers were found to be suitable for use in Class I, II, and V restorations. These studies did not present significant clinical disadvantages when compared to other materials, supporting the idea that giomers are effective in various clinical situations. Specifically, giomers demonstrate the capacity for dentin remineralization through the release of ions, especially fluoride, which is critical for preventing further demineralization and promoting remineralization in occlusal and proximal areas. The study by Akimoto *et al*. (2011) also emphasized the efficacy of giomers in such restorations. However, despite their benefits, some studies, such as the one by Jyothi *et al.* (2011), highlighted the need for long-term evaluations to fully assess the performance of giomers in clinical practice.

One significant finding from the review was the difference in retention between giomers and other restorative materials. Specifically, the retention of giomers was found to be inferior when compared to traditional materials, especially when used as sealants with S-PRG particles. However, it is important to note that this lower retention was not clinically significant in restorations that did not have occlusal contacts, such as Class I, II, and V restorations. Although the material's retention was lower, its performance in terms of dentin remineralization and fluoride release remained favorable, suggesting that fluoride release could partially compensate for the retention issue. In clinical practice, the primary function of a restorative material is to not only restore the tooth but also to prevent further caries development. In this context, the ability of giomers to release fluoride and form fluoride-enriched mineral phases, such as fluorapatite, contributes to the long-term success of the restoration, even if retention is somewhat compromised.

Regarding the prevention of secondary caries, the performance of bioactive resins containing S-PRG particles was notable. According to the ICDAS criteria used by Ntaoutidou *et al*. (2018), initial caries lesions (ICDAS 0) remained unchanged in 32 out of 51 restorations after 18 months, and lesions initially classified as ICDAS 1 remained stable in 30 teeth. This demonstrates that giomers can effectively halt the progression of carious lesions. Despite the lower retention observed with surface sealants containing these particles, the ability to prevent secondary caries remained strong. Furthermore, in restorations using giomers, only a few cases of secondary caries were detected, and they were clinically insignificant. The fluoride release from giomers plays a significant role in this performance, as it helps form a protective layer of fluorapatite on the tooth surface, which is more resistant to future demineralization.

In conclusion, while giomers do present some challenges regarding retention, particularly in applications like sealants, their unique fluoride-releasing properties, ability to remineralize dentin, and low incidence of secondary caries make them a promising material for restorative dentistry. Nevertheless, the evidence presented in this review is based on a limited number of included studies (n = 7), which significantly constrains the statistical power and generalizability of the findings. Therefore, further long-term studies are needed to fully evaluate their clinical performance, particularly regarding retention over extended periods and in more challenging clinical scenarios.

Conclusion

Within the limitations of this literature review, it was possible to conclude that restorations with resins containing S-PRG particles presents notable caries-preventive effect due to sustained fluoride release. Furthermore, a positive clinical conclusion was reached regarding the performance of these materials in Class I, II, and V restorations based on their retention, color matching, and marginal adaptation.

However, direct evidence of remineralization remains limited, as most studies relied on clinical markers such as caries recurrence and marginal integrity. Although giomers offer superior aesthetics and bioactivity, their retention tends to be inferior in stress-bearing areas. Therefore, further studies are needed to assess the performance of these materials on dental remineralization quantitatively and qualitatively.

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Author's Contributions

Luiza Maria Schneider, Maria Ritha Veiga Colognese and Poliana Maria de Faveri Cardoso: Conceptualization and design of the research methodology; data acquisition and curation; and original draft preparation of the manuscript.

Márcio José Mendonça, Julio Katuhide Ueda and Veridiana Camilotti: Contributed to the development of the study design; data acquisition and validation; supervision of the research activity; writing, review, and editing of the manuscript; and approval of the final version for submission.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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