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Review Article

Impact of Different Antibacterial Substances in Dental Composite Materials: A Comprehensive Review

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ABSTRACT

Dental composites are commonly used in the treatment of dental caries, yet they can sometimes lead to marginal fractures and the development of secondary caries. This study aims to investigate the role of antibacterial agents incorporated into modern composites in the management of dental caries. A systematic review was conducted by searching relevant articles across Cochrane Library, Google Scholar, and PubMed databases. Studies published from 2011 to 2021 were selected, reviewed, and assessed for inclusion following the PRISMA guidelines. Ultimately, 10 studies were analyzed, including both experimental and in-vitro or in-vivo approaches, to explore new materials or evaluate the mechanical, antibacterial, and aesthetic effects of existing materials on dental composites and structures. The findings showed that antibacterial agents are effective in inhibiting the growth of caries-causing bacteria and in killing these bacteria. In addition, these materials showed beneficial effects such as regenerative properties, remineralization, and the ability to repel proteins, all of which positively influenced both dental composites and dental tissues. However, suboptimal material design could negatively impact the mechanical properties of the composites and the surrounding dental structures. Overall, the novel antibacterial agents incorporated into dental composites offer significant advantages in caries prevention, mineral restoration, dental tissue regeneration, and protein resistance.

Keywords: Aesthetic, Antibacterial, Composites, Agents, Dental, Mechanical

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Introduction

Dental conditions, such as tooth decay, trauma, and other complications, can lead to the deterioration of tooth structure. Over time, different materials have been employed to address these structural damages, with synthetic substances becoming the primary focus of dentistry since the early 1800s [1-3]. However, these materials have a significant drawback: they cannot fully replace or restore the natural tissue structures [1]. As a result, alternative materials have gained prominence in dental practices, attracting the attention of both researchers and practitioners. According to Zheng *et al*. [1], resin-based composites are now commonly used to restore tooth structure and secure crowns and veneers, gradually replacing dental amalgam in clinical applications.

Among the materials used to address dental structural damage, resin-based composites have garnered significant attention. According to Aminoroaya *et al*. [4], these materials have shown great promise in mimicking natural tooth structure within restorative dentistry. However, a key limitation of these composites is their susceptibility to bulk or marginal fractures and the potential development of secondary caries, which diminishes the durability of the restoration [4]. For example, Kasraei *et al*. [5] note that composite resins containing zinc oxide and silver lack antibacterial properties, even though these chemicals are known for their broad-spectrum antimicrobial effects. As a result, their use may contribute to an increased risk of secondary caries formation [5]. To address this issue, researchers and dental practitioners have investigated the incorporation of antibacterial fillers into resin-based composites. Stencel *et al*. [6], for instance, examined the use of silver sodium hydrogen zirconium phosphate (SSHZP) as an antibacterial filler to inhibit the growth of cariogenic bacteria associated with dental composite restorations. The inclusion of this filler proved effective in reducing bacterial presence on teeth after the application of composite materials.

Sun *et al*. [7] proposed the use of a new generation of antimicrobial dental polymers to prevent the onset of secondary caries and to extend the longevity of restorations made with resin-based composites. These materials are designed to inhibit biofilm formation on tooth surfaces, reduce the acid production by bacteria present after composite application, and prevent caries development [7]. In a similar context, Korkut *et al*. [8] demonstrated that bioactive glass incorporated into resin composites could effectively inhibit bacterial strains like Escherichia coli, Staphylococcus aureus, and Streptococcus mutans. Chen *et al*. [9] reviewed various antibacterial agents that have been successfully applied to dental restorative materials, both experimental and commercial, including leachable compounds, polymerizable monomers, and silver nanoparticles as filler particles.

Other studies have also demonstrated that new composite materials can effectively prevent bacterial colony growth and biofilm formation, reduce acid production, aid in tooth re-mineralization, and promote the healing of cracks. Yao *et al*. [10] discussed the beneficial effects of incorporating silver, chlorhexidine (CHX), and fluoride into dental polymers, highlighting their antibacterial properties, the role of fluoride ions in enhancing re-mineralization, and the self-healing capabilities of certain polymers, such as those utilizing capsule-based, vascular, and intrinsic healing systems. Angel Villegas *et al*. [11] further emphasized that resins containing zinc nanoparticles promote re-mineralization when applied to demineralized surfaces and offer enhanced strength, making them particularly effective for use in carious lesions. This study aims to explore the impact of antibacterial agents in dental composites on the properties of the resulting materials.

Materials and Methods

Search strategy

To identify relevant articles for this study, an online search was conducted using the Cochrane Library, Google Scholar, and PubMed databases. The search took place on July 7, 2021, utilizing the keywords “antibacterial materials in dental composites,” “dental composites,” and “effects of antibacterial materials in dental composites.” Titles and abstracts were carefully examined to determine their relevance, and only those aligning with the study’s objectives were selected for further eligibility assessment. Additionally, references cited within the selected articles were reviewed to identify other pertinent studies for inclusion in the analysis.

Study eligibility

After identifying relevant articles through a literature search and reviewing their titles and abstracts, an eligibility analysis was conducted to determine their suitability for inclusion in the systematic review. The selection process was guided by the following criteria:

1. The article must be published in conference proceedings or a peer-reviewed journal.
2. It must have been published between 2011 and 2021.
3. It must discuss the effects of antibacterial materials in dental composites.

Articles meeting these requirements and providing relevant information on the research topic were considered for inclusion. To refine the selection further and ensure a high-quality systematic review, additional exclusion criteria were applied:

1. Studies based on case reports or individual case studies were excluded.
2. Articles published as letters or editorial pieces in journals or periodicals were not considered.
3. Systematic reviews and literature reviews were excluded, as only primary research studies were included in the analysis.

Data extraction and analysis

Following the eligibility assessment, full-text manuscripts of the selected articles were obtained for final evaluation. The researcher made the ultimate decision on inclusion based on the established criteria. To assess potential biases in study design, methodology, analysis, and reporting—particularly in randomized clinical trials—the Cochrane Risk of Bias Tool was applied [12]. This helped determine whether any flaws in the studies led to an underestimation or overestimation of the effects of the antibacterial materials examined. The finalized set of articles was then used to extract relevant data, forming the basis for conclusive findings on the impact of antibacterial materials in dental composites. The extracted information was systematically categorized according to the study's objectives, with a thematic summary that also accounted for any identified risks of bias.

Results and Discussion

Study selection

The initial literature search resulted in a total of 78 articles with relevant titles, including 47 from PubMed, 30 from Google Scholar, and 1 from the Cochrane database. After identifying two duplicate articles, the remaining 76 underwent screening. Based on the predefined selection criteria, 60 articles were excluded, leaving 16 for further eligibility assessment. Among these, four were removed for being secondary sources—systematic reviews and literature reviews—while 2 others were excluded due to their findings being unrelated to the research topic. The entire selection process is illustrated in the PRISMA flowchart in **Figure 1**.

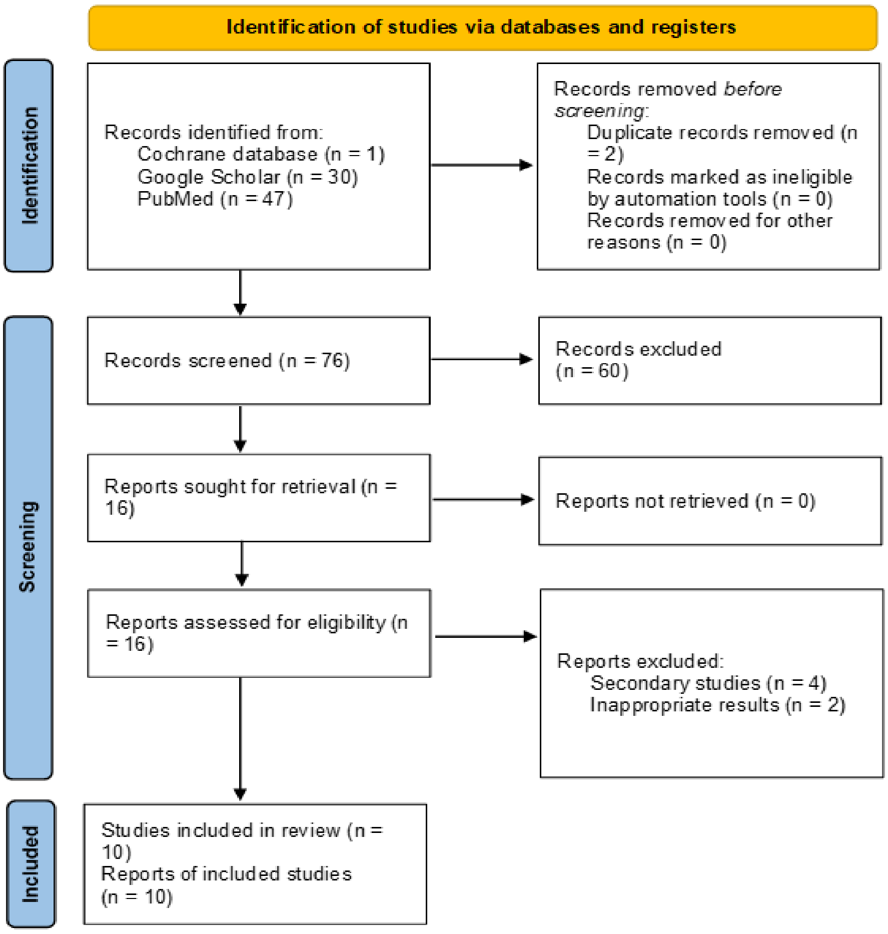

Figure 1. Study identification chart (PRISMA)

Study characteristics

The selected studies utilized in-vitro, in-vivo, and experimental approaches to examine the effects of antibacterial agents incorporated into dental composites. Each study investigated at least one antibacterial agent, with a maximum of three being analyzed within a single study. The primary focus was on evaluating the effectiveness of these materials in inhibiting bacterial growth, their bactericidal properties, and their impact on the physical and mechanical characteristics of the composites used in dental applications. Since these investigations were largely experimental, none of the studies involved clinical trials on patients.

Study findings

Table 1 outlines the research methodologies employed by the authors, the number of materials analyzed in each study, the conclusions drawn, and the assessment results based on the Cochrane risk of bias tool.

Table 1. Study overview

Authors	Design, year published	Material number	Findings	Risk of Bias
Hollanders *et al*.	In vitro analysis of restored enamel-dentine blocks, conducted in 2020.	30 blocks, using three materials	The antibacterial effectiveness of bonding materials diminishes over time. The tested materials consisted of conventional bonding composites, antibacterial bonding composites, and amalgam. As the blocks aged, deeper lesions were observed in those containing antibacterial bonding materials.	Additional bias: The study does not provide details on the extent to which the proposed materials were utilized. Bias risk: Moderate.
Hegde *et al*.	Experimental in-vitro research with quantitative statistical evaluation of control and restorative materials, completed in 2018.	Three materials	Nano-hybrid composites, glass ionomer cement (GIC), and silver amalgam exhibited an inhibitory effect against a Streptococcus bacterium, with silver amalgam demonstrating the strongest antibacterial activity.	Selection bias: The criteria for distinguishing between test and control materials are not provided. Bias risk: Low.
Peralta *et al*.	An experimental assessment of the mechanical and physical characteristics of resin-based materials, utilizing quantitative statistical methods, was performed in 2018.	Two materials	Certain antibacterial components in composites, such as Fermit inlay, effectively prevent Streptococcus mutans biofilm accumulation, whereas materials like Luxatemp LC and Bioplic continuously combat Enterococcus faecalis bacteria.	Additional bias: The authors fail to explain how the proposed materials were utilized. Bias risk: Low.
Chatzistavrou *et al*.	An experimental study focusing on the evaluation and characterization of newly designed dental materials incorporated into composites was conducted in 2014.	One material – glass ceramics	The integration of silver ions into bioactive glass-ceramics used in dental applications results in a durable material with antibacterial properties, which can also contribute to tooth regeneration.	Additional bias: The authors do not provide information on how the proposed materials were applied. Bias risk: Low.
Bariker and Mandroli	An experimental investigation utilizing the agar diffusion technique for assessment was carried out in 2016.	Two materials	Both Amalgomer CR and Fuji VII exhibited antimicrobial effects against various microorganisms responsible for severe childhood dental caries.	Additional bias: The authors do not explain the adoption or application of the proposed materials. Bias risk: Low.
Park *et al*.	An experimental approach involving the combination of MPC and MBN in varying proportions with orthodontic bonding agents, evaluating their antibacterial and remineralization properties, was conducted in 2020.	Two materials – MPC and MBN, mixed with bonding agents	The antibacterial, protein-repellent, and anti-demineralization properties of bonding agents were enhanced when MPC and MBN were added in optimal ratios.	Additional bias: The authors fail to justify their choice of the two materials. Bias risk: Low.
Yaghmoor *et al*.	Statistical evaluation using ANOVA and pairwise comparisons to analyze novel antibacterial composites, completed in 2020.	Composite with two materials – polylysine and monocalcium phosphate monohydrate	A controlled release of polylysine within carious gaps effectively eliminated bacteria and contributed to the prevention of recurrent caries.	Selection bias: The criteria for dividing materials into test and control groups are not provided by the authors. Bias risk: Low.

Yang *et al.*	Development of advanced antibacterial agents for incorporation into dental composites, undertaken in 2021.	One composite used	The incorporation of zinc oxide particles into nanoparticle composites maintained their structural integrity, preserving their regular shape and close-packed arrangement.	Additional bias: The authors do not explain excluding other materials. Bias risk: Low.
Al-Dulaijan *et al.*	Synthesis of composite materials, followed by experimental analysis of their ion release and recharge capabilities, was performed in 2018.	Two composite materials were produced and tested	The produced composites demonstrated commercially acceptable flexural strength and elastic modulus while effectively limiting biofilm formation and bacterial proliferation.	Additional bias: The authors do not justify their decision to exclude other materials. Bias risk: Low.
Zhang *et al.*	Experimental design and evaluation of an innovative approach to manufacturing antibacterial composites, conducted in 2014.	One antibacterial agent used	Dental composites embedded with chlorhexidine within mesoporous silica nanoparticles positively influenced the mechanical properties of the filler material.	Additional bias: The authors fail to explain their reasoning for excluding other methods. Bias risk: Low.

A review of ten studies assessed the impact of various antibacterial materials incorporated into dental composites, uncovering both positive and negative outcomes. These materials were shown to suppress the growth and proliferation of certain bacteria. Hegde *et al.* [13] evaluated the antibacterial effects of a nano-hybrid composite, GIC, and silver amalgam on *Streptococcus mutans* and found that all three materials demonstrated inhibitory properties against the bacteria. Among the 3, silver amalgam was found to be the most effective in curbing bacterial development. This suggests that such materials could help reduce the progression of dental caries by limiting the spread of the bacteria responsible for tooth decay [13]. Similarly, Yaghmoor *et al.* [14] concluded that polylysine (PLS) and monocalcium phosphate monohydrate composites showed significant antibacterial activity, killing residual bacteria, aiding dental restoration, and reducing the risk of recurring caries.

Peralta *et al.* [15] found that resin-based materials like Fill Magic and Bioplic exhibited strong antibacterial properties against Streptococcus mutans. Additionally, their research indicated that Luxatemp was effective in blocking the formation of *S. mutans* biofilms and preventing the growth of *Enterococcus faecalis* [15]. Some composite materials have a broader spectrum of antibacterial activity. Bariker and Mandroli [16] examined the antibacterial effects of Amalgomer CR and Fuji VII, both of which serve a restorative role in dental procedures. Their findings revealed that Amalgomer CR was able to inhibit the growth of *S. mutans*, *Actinomyces viscosus*, *S. salivarius*, *S. parasanguinis*, and *Lacticaseibacillus casei* [16], which are key contributors to early childhood caries. On the other hand, Fuji VII demonstrated antibacterial effects against only *S. salivarius* and *A. viscosus* [16].

Dental composites exhibit regenerative properties in addition to their antibacterial effects when applied to dental treatments. Chatzistavrou *et al.* [17] describe the significant advantages of incorporating silver ions into bioactive ceramic glass composites, emphasizing that this combination promotes tooth regeneration. Alongside the regenerative benefits, these composites offer enduring bactericidal properties, as the material effectively eliminates Enterococcus faecalis, a bacterium linked to pulp infections [17]. Silver ion-based composites can thus be integrated into natural extracellular matrix (ECM) processes. Furthermore, antibacterial materials also exhibit mechanical strength, mineralization abilities, and protein-repellent characteristics. According to Park *et al.* [18], the combination of 2-methacryloyloxyethyl phosphorylcholine (MPC) with mesoporous bioactive glass nanoparticles (MBN) in bonding agents enhances protein repulsion and strengthens the anti-demineralization properties of the agents. The antibacterial properties of this MPC-MBN blend include effective inhibition of *S. mutans* and *E. coli* [18].

The review discusses the development of rechargeable composites for orthodontic use, which also offer antibacterial properties. Al-Dulaijan *et al.* [19] introduced an innovative calcium phosphate nanocomposite, highlighting that earlier rechargeable materials lacked antibacterial functions. Their testing of this new concept showed it was effective in limiting biofilm metabolism, reducing lactic acid production, and preventing bacterial biofilms from forming colonies [19]. The incorporation of the antibacterial agent in the composite successfully helped inhibit dental caries growth without affecting the rechargeability of the traditional composite material.

Antibacterial materials in dental composites may lead to the formation of lesions as the composites age. Hollanders *et al*. [20] observed that antibacterial bonding agents influence the progression of dental caries, with lesions becoming larger and deeper as the materials degrade over time. Additionally, these agents can reduce the composite's overall properties. Yang *et al*. [21] found that incorporating antibacterial agents into composites resulted in a decline in both mechanical strength and aesthetic appeal, which is considered an undesirable effect. However, they also demonstrated that using spray-drying technology to integrate antibacterial agents helps preserve the structural integrity of composite nanoparticles, even after the agents are introduced [21]. In a similar study, Zhang *et al*. [22] showed that dental composites produced by encapsulating and controlling the release of chlorhexidine antibacterial agent maintained better mechanical strength and surface smoothness than composites prepared through direct mixing, which weakened the material's structure.

Conclusion

This systematic review examined 10 studies that evaluated the role of antibacterial agents in dental composites. These agents were incorporated into various materials, including nano-hybrid composites, amalgam, resin-based compounds, regenerative composites, and rechargeable composites. The reviewed evidence demonstrates that the antibacterial agents are effective in limiting the growth of bacteria such as *S. mutans*, *E. faecalis*, *S. salivarius*, *L. casei*, and *A. viscosus* which are commonly linked to dental caries, especially in children. In addition to their antibacterial effects, these materials contribute to dental regeneration, aid in remineralizing demineralized teeth, exhibit protein-repellent properties that help prevent caries and offer both treatment and prevention of dental caries. However, improper preparation methods that are not based on solid evidence can negatively affect the mechanical properties of the composites.

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