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Systematic Review of Restorative Dental Materials on Surface Root Caries Lesion

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Abstract: *This systematic review provides an update on the development and efficacy of direct restorative dental materials for root caries interventions from in vitro and clinical studies. PubMed, Embase, and Web of Science were searched using specific MeSH keywords. Full articles from September 2000 to October 2024 were collected. Additional articles were identified by reference retrieval and manual searching. Studies not related to restorative materials for root caries treatment, case reports, non-original articles, and/or articles not written in English were excluded. Bias risk assessment was performed for the clinical studies. Forty-two articles (eleven clinical studies and thirty-one in vitro studies) were included for analysis. Most in vitro studies indicated an excellent cariostatic effect of glass ionomer cement. Resin-modified glass ionomer restorations also presented reduced recurrent caries activity but had a lower efficacy than glass ionomer cement restorations. For composite resin restorations, the main material development strategies are to strengthen the tooth structure and integrate antimicrobial activity. The clinical studies offered limited data, so the most appropriate material for surface root caries treatment is still inconclusive. However, atraumatic restorative treatment (ART) is an alternative treatment for patients with limiting conditions. Further clinical studies are required to confirm the efficacy of bioactive materials.*

Keywords: *Root caries, Composite resin, Glass ionomer, Atraumatic restorative treatment, Resin-modified glass ionomer, Bioactive material*

INTRODUCTION

Due to increasing life expectancies, the World Health Organization has predicted that the elderly population will increase significantly by 2050 [1], with nearly 1.5 billion people—approximately 15%–20% of the world's population—aged 65 or older. The medical and dental status of elderly patients is a considerable factor in their quality of life. In the field of dentistry, dental caries (particularly dental root caries) and periodontal diseases are considered the main problems in older adults. A systematic review demonstrated that the average incidence of root caries was approximately half of the population for older adults [2]. Multiple species of cariogenic bacteria, including streptococci, actinomyces, lactobacilli, and bifidobacteria have been indicated as having a strong association with dental caries [3]. After bacterial biofilm formation, these bacteria, which are tolerant of acidic environments, can produce acid via sugar metabolism, altering the mineral composition of the tooth structure. However, caries formation at the tooth root differs from that at the crown due to the difference in composition, particularly regarding the inorganic components [3]. Approximately 90 wt% of enamel comprises inorganic minerals, whereas dentin has a lower inorganic composition of approximately 70 wt%. This leads to a faster degree of caries progression in root dentin, which means that the root area is particularly vulnerable to caries formation [4]. In addition, many individual factors associated with dental root caries have been identified, such as age, oral hygiene, gingival recession with root surface exposure, smoking, economic status, xerostomia, medication, and other drug use [5]. When cavitated caries lesions form, restorative procedures with material replacement of the lesion are commonly used to address the problem. Many restorative materials such as glass ionomer cement (GIC), resin-modified glass ionomer (RMGI), and composite resin (CR) have been introduced and used for root caries restorations. However, difficulties associated with the cavity position, access of the restoration site, and moisture control [6], combined with the risk factors described above, mean that the proper selection of restorative materials is a critical challenge for dentistry. Moreover, a new generation of materials has been developed to enable more precise surface root caries treatment. However, their efficacies on root caries prevention remain controversial. The objectives of this review are (1) to reveal the efficacy of direct restorative materials on root caries treatment in in vitro and clinical studies, and (2) to provide an update on the current and perspective concepts and development of direct restorative dental materials for root caries treatment.

Materials and Methods

Search and selection

One researcher performed the article selection process. The literature was electronically searched from three online databases: MEDLINE/PubMed, Cochrane Library/Embase, and Web of Science. The Medical Subject Headings (MeSH) database was used to select the search terms. The keyword search criteria for the different advanced searching systems were as follows:

- PubMed: (“Root Caries”[Mesh]) AND ((“Dental Materials”[Mesh] OR “Dental Atraumatic Restorative Treatment”[Mesh]))
- Embase: (Root caries) AND ((Dental materials) OR (Dental Atraumatic Restorative Treatment)
- Web of Science: (“Root Caries”) AND ((“Dental Materials” OR “Dental Atraumatic Restorative Treatment”))
- Publications from September 2000 to October 2024 were included (last search date: 17 October 2024). Duplicate articles were detected and excluded.

Inclusion and exclusion criteria

To conform with the objectives of the review, the identified articles were filtered using the following inclusion criteria:

- In vitro studies
- Clinical studies in humans
- Studies involving direct restorative materials for root caries
- Both abstract and full article available
- Written in English
- For studies that fulfilled all the inclusion criteria, the abstract was then checked against the following exclusion criteria:
- Studies not involving dental root caries
- Studies not involving direct restorative materials (e.g., those involving indirect restorative materials, varnishes, coating materials, or other chemical agents)
- Articles of case reports
- Articles that were not of original studies

- Articles that met at least one exclusion criteria were excluded. The full texts of the relevant articles were then retrieved and analyzed. Additional articles were added by checking the references from the final included articles and manual searching.

Results and Discussion

Data selection

After duplicate articles were excluded 42 studies were included in this study, of which 11 were clinical studies and 31 were in vitro studies.

Summary of the results

Glass ionomer cement (GIC)

become one of the most popular materials in restorative dentistry. This "acid–base cement" [5] is produced by mixing a polymeric acid aqueous solution with glass powder for 2–5 min, which triggers a setting reaction. This material introduces a therapeutic effect on the surrounding tooth structure via the release of fluoride ions [5]. For this reason, GIC has been used for clinical applications such as restorations and luting cements, bases, and liners. In this review, we focus solely on its restorative function for dental root caries. properties of GIC restorations have been widely analyzed, with a particular focus on the interesting cariostatic efficacy of GIC restorations on the root surface. Many studies have confirmed that GIC has the ability to reduce outer lesion depth In addition, the surrounding structure contacting the restoration, extending to 20 µm, has been shown to be protected from demineralization by the remaining calcium and phosphate content [6]. Hara *et al.* [7] reported that the cariostatic effect of GIC extended to 300 µm on root dentin using a microhardness assessment. Recently, micro-computed tomography (micro-CT), which can observe the tooth cross-section and mineral content at the same time, has been modified for observing the surrounding structure in experimental studies. Zan *et al.* [8] reported that GIC restorations had a protective effect on contacting dentin and maintained a higher subsurface mineral density compared to conventional CR and multi-ion-releasing composite restorations. Moreover, an acid-resistant zone was found between the interphase of the GIC restoration and the tooth structure by scanning electron microscopy (SEM) [9]. Based on the evidence of in vitro studies, it has been implied that conventional GIC restorations have a great ability to prevent caries on the root surface. However, few in vitro studies have investigated the mechanical properties of GIC, instead of focusing on the sealing ability of the material. Sidhu *et al.* [10] compared the microleakage values of GIC and CR restorations after treatment with and without thermocycling. They found that GIC restorations showed a greater sealing ability than CR restorations. Recently, experimental studies that combine intervention and chemical agents have been used to modify GIC restorations to enhance the therapeutic effect. Zhao *et al.* The criteria for restorative and surrounding structure follow-up, such as the presence of restorations, marginal integrity, marginal discoloration, anatomical form, and secondary caries, must be observed in many clinical manifestations. In this review, we categorized the criteria that were used in previous studies into three parts: restoration condition, tooth condition, and surrounding condition, Comparing the clinical efficacies of different materials has been the focus of many studies. McComb *et al.* [11] compared the incidence of recurrent caries in Class V restorations comprising GIC, RMGI, and CR in radiation-treated patients. The results showed that the restorative failure rate caused by anatomical deformation and marginal leakage of GIC restorations was higher than that of CR restorations in patients using daily fluoride tray application. Moreover, GIC restorations showed a lower incidence of recurrent caries in non-fluoride use patients [12]. De Moor *et al.* [13] compared the failure rate after two years between GIC and CR restorations using the United States Public Health Service (USPHS) criteria. Most of the clinical features, including color match, marginal adaptation, and marginal discoloration were clinically comparable, except for the anatomical form of GIC, which had a higher incidence of degradation than that of CR. Abbreviations: CR: Composite resin; GIC: Glass ionomer cement; Non-RCT: Non-randomized controlled trial; RCT: Randomized controlled trial; RMGI: Resin-modified glass-ionomer; USPHS: United States Public Health Service. Classification based on the reported study design as the type of study was not clearly indicated in the original article.

In addition to conventional restoration techniques, atraumatic restorative treatment (ART) has become popular in dentistry because it does not require local anesthesia, instead using low pressure, vibration, and noise [14]. Owing to the advantages of this technique, it has been used as a clinical treatment option in patients with limitations including children, patients with special needs, patients with anxiety, and patients in rural areas who cannot visit dental clinics. Briefly, after the soft cavitated carious lesion is removed using a hand instrument, an adhesive dental material such as high viscosity glass ionomer cement is used for restoration. Five studies have compared the clinical efficacies of conventional and ART techniques for root caries treatment. Cruz and Marin [15] compared the six-month postoperative success rate between ART and conventional restoration in 64 elderly patients. They found that the success rate of conventional restorations (92.9%) was significantly higher than that of ART (81.3%). In contrast, four clinical studies with follow up period of more than six months presented the success rates of these techniques as not significantly different [13, 14]. Moreover, after five years of clinical observation, the survival rate of ART (85%) was comparable with that of conventional techniques (79%) [16].

Composite resin (CR) and dental adhesive

Since CR has been clinically used as a restorative dental material, it has become popular in the dental field due to its advantages including good mechanical properties, ease of color matching with natural teeth, and ease of clinical application. However, when compared with other commercial materials, conventional CR has no cariostatic effect on dental root structure [13], which is an important property for successful root caries restorations. Many studies have been conducted based on the addition of bioactive agents into CR to improve its therapeutic effect. In addition, a CR-based dental adhesive system has been developed that boosts the antimicrobial activity, strengthens the surrounding structure, and prevents demineralization.

Composite resin (CR) and adhesive systems containing antimicrobial agents

Multiple bacterial species play an important role in root caries formation and periodontal destruction. Therefore, new generations of CR restorations and adhesive systems have been developed based on the addition of bioactive functions. For example, silver nanoparticles (AgNPs), 12-methacryloyloxydodecyl pyridinium bromide (MDPB), 2-methacryloyloxyethyl phosphorylcholine (MPC), dimethylaminohexadecyl methacrylate (DMAHDM), and pre-reacted glass ionomer (PRG) have been developed. Koc Vural *et al.* [17]. It has been confirmed to have strong antibacterial activity by destroying the bacterial membrane via a positive charge. Since MDPB molecules can be copolymerized, they can be incorporated into dental materials. For root caries treatment, an in vitro study has suggested that the incorporation of MDPB into adhesive inhibits the progression of artificial root caries formation [16]. In addition, CR restorations containing MDPB showed a protective effect against secondary caries formation, similar to RMGI restorations [15]. proved that the incorporation of <5 wt% MDPB into dental primer had no negative effect on the penetrating ability of the dental adhesive. Moreover, MDPB showed a strong suppression on *Streptococcus mutans* and *Lactobacillus casei*; at a concentration of just 4 wt%, the MDPB addition completely prevented the recovery of these bacteria. It is possible that this material may improve the longevity of the restoration trough and reduce hydrolysis in the hybrid layer. However, more studies are required to confirm this.

MPC is an inert biomedical membrane with the ability to inhibit non-specific protein adsorption related to cell adhesion and biofilm formation. Furthermore, this agent can bind with polymer matrixes, which are widely used in biomedical applications. In dentistry, MPC has been incorporated in many kinds of dental materials, such as denture base resins and CR restorations. Combinations of CR, MPC, and other bioactive agents have been observed to reduce protein adsorption abilities nearly 10-fold when compared with control groups. The restorations also retain good mechanical properties, including flexural strength, elastic modulus, and dentin shear bond strength [17]. An in vitro study confirmed that the newly developed nanocomposite demonstrated a strong antibacterial effect on several periodontal pathogens, including *Porphyromonas gingivalis*, *Aggregatibacter actinomycetemcomitans*, and *Fusobacterium nucleatum* [17].

Composite resin (CR) and adhesive systems containing remineralizing agents

In addition to antimicrobial agents, remineralization agents have also been incorporated into CR restorations to improve their therapeutic effect. For example, PRG, nanoparticles of amorphous calcium phosphate (NACP), and fluoroaluminosilicate glass have been used. PRG has been introduced as a glass filler that can release several types of ions, such as aluminum, boron, fluoride, sodium, silicon, and strontium ions. In addition to its antimicrobial effects PRG has also been confirmed to inhibit demineralization and induce remineralization Lo *et al.* [14] investigated the anti-caries behavior of adhesives and composite restorations containing PRG after artificial secondary caries formation for 14 days. They reported that a combination of adhesive and PRG-containing CR restoration reduced the outer caries lesion depth. In addition, no wall lesions were detected, and the thickness of the inhibition zone was increased. However, there is insufficient evidence regarding the efficacy of this material on root caries lesions. NACP is a precursor of bioapatite. It has been developed for use as a remineralizing agent for tooth structures. Moreover, this agent also has anti-demineralization properties because it mainly contains calcium and phosphate. It is present in many kinds of dental materials such as prophylaxis paste, adhesive systems, and CR. Several studies have also demonstrated the good bioactivity of several bioactive agents, including NACP. In addition to the materials development described above, retaining dentin quality is a key factor in successful root caries restoration. Several reports have mentioned that different dentin qualities affect the bond strength. Normal coronal dentin demonstrates the highest bond strength, followed by normal root dentin, affected root dentin, and finally infected root dentin. From microstructural observations of the resin–dentin interphase of affected and infected dentin, a highly porous-thick hybrid layer and an irregular shape for the resin tag were found in the remaining carious dentin [18]. For this reason, caries removal techniques should be considered for improving the success of restorations.

Resin-modified glass-ionomer (RMGI)

The material concept of RMGI has been developed to combine the good mechanical properties of CR and biological properties of GIC into a single material. A number of studies have compared the biological efficacy and mechanical properties of RMGI with those of other materials. [15] reported that, after flexural loading, RMGI (Fuji-II LC, GC) demonstrated a lower sealing ability than that of a flowable composite. Hara *et al.* investigated the cariostatic effect of fluoride-releasing materials, including GIC, RMGI, compomer, fluoride-containing CR, and conventional CR through microhardness parameters [7]. The results indicated that only GIC and RMGI presented a cariostatic effect. However, GIC presented a higher cariostatic efficacy than RMGI. reported that RMGI showed higher fluoride ion release than compomer and CR. In addition, RMGI resulted in a lower lesion depth and thicker radio plaque zone surrounding the restoration after 14 days of acidic challenge. When compared to amalgam, the RMGI restoration exhibited a higher potential for remineralization [18]. This implies that RMGI causes a cariostatic effect by increasing the mineral density around the restoration site via fluoride ion release. McComb *et al.* [11] investigated the incidence of recurrent caries and failure of cervical restorations that were treated by a same-arch treatment using conventional GIC (Ketac-Fil, 3M Co.), RMGI (Vitremer, 3M Co.), and CR (Z100, 3M Co.) after 6, 12, 18, and 24 months in 45 Canadian patients (18 years or older) with a history of radiotherapy in the head and neck regions. This clinical study indicated that GIC restorations showed significantly higher failure rates than RMGI and CR restorations, with higher marginal leakage and anatomical deformity.

Dental caries is considered a multifactorial oral disease. Many risk indicators for root caries have been reported, such as root caries prevalence at baseline [2], number of remaining teeth, plaque index, exposure of the root surface, coronal decay, and xerostomia [7]. However, understanding of the root structure, caries progression, and characteristics of restorative materials is important for the selection of restorative materials. At the dentin surface, dynamic mineral change can occur depending on the environmental conditions of the root surface. Demineralization, whereby the mineral composition of the tooth structure is removed, can occur due to acidity in the oral environment. When the pH reduces to 4.5–5.5, calcium and phosphate in the hydroxyapatite surface—the primary inorganic component of dentin—are released to neutralize the oral environment. On the other hand, supersaturated ions can also precipitate on the dentin surface [4]. Not only is the inorganic composition destroyed by acid-producing bacteria, but the organic composition also suffers from pathogens. The destruction of organic components has been hypothesized to occur according to three mechanisms [3]. The first hypothesis is that an acidic environment can reactivate MMP and cysteine cathepsins that are trapped in the dentin matrix during dentin formation, leading to self-proteolysis. The second hypothesis is that exposed proteins become denatured under acidic conditions. The last hypothesis is that bacteria produce proteolytic enzymes that affect the organic component in dentin. The majority of in vitro studies have simulated artificial caries formation by one of two methods. The first method uses one or more species of cariogenic bacteria, such as pioneer acidogenic species (*S. mutans*, *Streptococcus sobrinus*, *Actinomyces naeslundii*) or aciduric species (*Lactobacillus rhamnosus*, *L. acidophilus*), for experimental caries formation. The second method uses chemically induced caries-like lesions. The anticariogenic effect of restorative materials has been measured and demonstrated through various parameters such as the character of the lesion, including outer lesion depth, wall lesion formation, inhibition zone formation, mineral content, mineral density, mineral loss, log [amide I: HPO_4^{2-}], microhardness loss, and microleakage. Recently, many bioactive agents have been synthesized for use as relining materials, and their effect on the suppression of the bacterial activity has been evaluated. It can be assumed that the development of restorative materials for root caries not only focuses on the preventive effect but also aims to enhance the antimicrobial performance of the materials. Strengthening of the root dentin structure is another strategy for achieving root caries intervention. Fluoride offers numerous advantages, including acid neutralization, prevention of demineralization, enhanced remineralization, and fluoridated apatite formation; therefore, fluoride-releasing materials are commonly used in dentistry for caries prevention. Regarding the results from many in vitro studies, GIC restorations have the greatest caries-preventing effects among direct restorative materials, the higher effectiveness of GIC can be explained by the effect of the material matrix on the ion-releasing behavior. Because of the higher hydrophilicity of the GIC matrix, the released fluoride ions can easily diffuse into the contacting structure, in comparison to resin-based matrixes, which act as a barrier and obstruct ion distribution. To improve the effectiveness of resin-based materials containing fluoride-releasing glass fillers, the acidity of the resin matrix can be increased; however, this may lead to stronger dissolution of the fluoride-containing filler, resulting in excessive fluoride release. Furthermore, it may have an adverse effect on the mechanical properties, such as an increase of water absorption. In addition, the remaining smear layer in the restorative–dentin interphase can have a negative effect on the caries-preventing behavior of fluoride-releasing restorative materials, as the released fluoride ions can be blocked from entering the dental substructure. These remineralizing agents are good alternatives for root caries prevention. However, there are still limited data regarding the effects of these agents on the root dentin structure and root caries formation, and further studies are required.

Despite the multiple advantages of ART, including painlessness, ease of application, low cost, and release of fluoride from GIC, the long-term efficacy of these restorations has been questioned when compared with conventional techniques due to the limiting conditions during restorative procedures. In addition, moisture control, lack of polishing, operator errors, and remaining affected dentin were identified as being responsible for ART failures [6]. Surprisingly, four clinical studies reported that the survival rate of both ART and conventional techniques were comparable at over two years follow up. Nevertheless, it is possible that ART could be an optional treatment under limiting conditions. Almost all the included clinical studies on ART used GIC as the main restorative material [13-15]. Only one study compared RMGI-based ART to conventional techniques [17]. Owing to this lack of data, the efficacy of different materials for ART is not presented in this review. Further research and evidence are required to understand the efficacy of ART with different materials. Interventions that combined chemical agents (e.g., chlorhexidine, SDF, fluoride varnish) and restoration by ART have been introduced and studied in children, with some advanced benefits. However, there is still a lack of evidence for these combined root caries treatments. The elderly population are considered particularly vulnerable to root caries. Multifactorial genetic and epigenetic factors further correlate with this risk factor. One factor that is thought to worsen root caries formation is impaired salivary function. Saliva plays a key role in the self-cleaning of the oral cavity by inducing mechanical flushing and immunoactivity. Some studies have indicated that the level of saliva production and immunoglobulins [6] is not affected by age. However, some patients who take medication, receive head and neck radiation therapy, or suffer from systemic disease are found to have impaired salivary function or xerostomia (reduced saliva flow), which can be a cause of root caries. Two clinical studies compared the effectiveness of restorative materials in patients undergoing radiotherapy, who were either daily fluoride users or non-fluoride users. The results of both studies indicated that fluoride supplements could prevent caries formation with less influence of the restorative material. Interestingly, without fluoride supplements, the incidence of caries formation with GIC restorations was lower than that with RMGI or CR restorations [12, 16]. Moreover, other factors such as diet, microbiome, oral hygiene, and systemic disease are crucial risk factors for pathogenicity and root caries progression [6]. The burden of tooth loss due to dental caries or periodontal disease also seems to be a common risk factor for the elderly population; those with 20 or more remaining teeth have been indicated to have better physical health than those with fewer than 20. Thus, it can be inferred that the number of remaining teeth may relate to quality of life in old age. The success of this policy proved that such campaigns can encourage good oral condition and health.

Mechanical failure has been indicated as an important factor for observing the effectiveness and durability of dental restorations. Marginal defects are a clinical sign of other complications such as staining, postoperative sensitivity, pulpal irritation, and the development of secondary caries. Material characteristics such as polymerization shrinkage, water resorption, solubility, elastic modulus, and shear bond strength may influence marginal gap formation [10]. In addition, difficulties in accessing the restoration site and moisture control are critical challenges for clinical situations, especially for the gingival margin. For resin-based materials, the relationship between water resorption and dimensional change has been studied. Hygroscopic expansion of the restoration produces stress against the lateral wall, which may cause debonding and marginal defects. In addition, an increase of osmotic pressure from some components in the resin matrix, such as glass filler additions, has been identified as a cause of swelling [10]. However, when compared to hydrophilic materials such as GIC and RMGI, CR restorations present less water uptake within six months. Polymerization shrinkage is another cause of CR restoration failure. However, incremental filling techniques have been designed to decrease the stress concentration in the cavity wall, and are recommended to reduce microleakage. Besides the materials effects described above, occlusal loading may also lead to marginal gap formation. Restorations at the root area rarely suffer from direct forces from chewing; however, the distribution of the occlusal load can generate localized tension on the restoration.

A few papers have reported a correlation between microleakage in in vitro and in vivo testing, and the impact of material type on restorative failure. da Mata *et al.* identified factors associated with early failure in Class V restorations after two years follow up using multivariable analysis. Practitioner errors, elderly patients, glass ionomer and flowable composites, bur-preparation, and moisture contamination were identified as increasing the probability of failure. Thus, it is assumed that the type of restoration is a relative cause of restorative failure.

Daily brushing with fluoride toothpaste is widely recommended for caries prevention. Inevitably, dentifrice particles in toothpaste may be harmful for the surface of restorations through abrasive wear. Rougher surface texture, loss of proper contour, and more color staining are all complications that can arise in restorations after long-term use. Two clinical studies reported that the mechanical failure rate of GIC restorations is significantly higher than that of CR restorations [12, 16]. This can be explained by the wear-resistant nature of CR. the effect of loading, material type, and pH on the rate of material wear in vitro. They found that CR restorations had a higher wear resistance than GIC restorations at high load and acidity. The filler content and acid tolerance of the resin matrix improve the wear resistance of CR restorations compared to that of GIC restorations.
Research and development of restorative materials and techniques is focused on improving caries prevention through two strategies: strengthening the root structure and hindering microorganisms. However, the basic properties of restorative materials affect their clinical performance. Fluoride-releasing materials have been widely studied and used as restorative materials for root caries. GIC and RMGI restorations present preventive effects against root caries formation, as shown in in vitro studies. Nevertheless, the limited data on the mechanical properties of the root dentin structure mean that the mechanical efficacy of these materials on root dentin are not well known. However, the incidence of mechanical failure in GIC restorations has been higher than that of CR restorations in several clinical studies [11, 12, 16]. Another limitation of our research is that the in vitro studies on GIC restorations could not be assessed for risk of bias owing to the differing nature of the study designs and the different purposes of the in vitro studies, which makes it difficult to determine appropriate criteria. In agreement with Tran *et al.*'s recent assessment, we posit that a comprehensive guide for solving this problem should be developed. Overall, while no universal material for root caries prevention has been identified, the impact of restorative materials on root caries formation is clear. Various bioactive agents can be incorporated into restorative materials to improve the bioactivity toward carious microorganisms, which may be a good alternative in the future. However, the long-term mechanical properties and biocompatibility of these materials should be investigated, along with clinical trials of new protypes.

Conclusion

Based on the evidence and limitations of this review, the following conclusions can be drawn.
From in vitro studies:

- Among direct restorative materials, GIC and RMGIC present a high potential for secondary caries prevention.
- A lack of cariostatic effect of CR was identified, while antimicrobial effects and tooth strengthening behavior improve the effectiveness of CR and adhesive systems on surface root caries treatment.

From clinical studies:

- Owing to limited data, the most appropriate material for surface root caries treatment cannot be identified. Further studies are required to confirm the clinical efficacy.

ART is an optional treatment for root caries treatment under limiting conditions.

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