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Review Article

Efficacy of early caries-arresting medications

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Abstract

Dental caries remains one of the most widespread and persistent chronic diseases globally, affecting individuals across all age groups and socio-economic backgrounds. It is primarily caused by the demineralization of tooth enamel and dentin due to acidic by-products from bacterial metabolism within dental biofilms. While traditional caries management has long relied on restorative interventions—often involving the irreversible removal of decayed tooth structure—this approach does not address the underlying etiology of the disease and may lead to a restorative cycle of repeated treatments over a lifetime. Recent advances in preventive and non-invasive dentistry have catalysed the development and clinical implementation of caries-arresting medicaments, which offer the potential to halt or reverse disease progression without the need for invasive procedures. Among these, silver diamine fluoride (SDF), resin infiltration (RI), casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), and glass ionomer cement (GIC) have emerged as leading therapeutic agents due to their demonstrated efficacy, biocompatibility, and patient-centered benefits. These medicaments operate through distinct mechanisms—including remineralisation, antimicrobial activity, and physical lesion stabilization—and are particularly beneficial for populations with limited access to dental care, including paediatric, geriatric, and medically compromised individuals. Moreover, their use aligns with the principles of minimal intervention dentistry, aiming to preserve natural tooth structure and enhance long-term oral health outcomes. This review critically evaluates the current evidence on the clinical and in vitro effectiveness of SDF, RI, CPP-ACP, and GIC in arresting caries progression. It aims to provide insight into these interventions, their comparative advantages, limitations, and potential roles within integrated caries management strategies.

Keywords: Dental caries, Resin infiltration, Glass ionomer cement.

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1. Introduction

Caries management has evolved significantly over the past century, shifting from an entirely surgical-restorative approach to a preventive and non-invasive paradigm.[1] The emphasis on disease prevention has led to the development of robust protocols, such as Caries Management by Risk Assessment (CAMBRA), which focuses on managing factors that shift the risk of developing novel carious lesions.[2] Despite these efforts, dental caries, characterized by the demineralization of tooth structure due to bacterial acid production, continues to be a major global public health concern.[3] Socio-economic disparities, changes in political climate affecting health policy, inadequate access to professional dental care, and lack of preventive awareness contribute to its widespread prevalence, particularly in developing nations and vulnerable populations.[4]

Traditional restorative treatments, including direct and indirect restorations, focus on the removal of decayed tissues and replacement with synthetic materials, which, although effective, do not address the root cause of caries formation.[5] [Additionally, these interventions require substantial clinical expertise, equipment, and patient compliance, limiting their accessibility in resource-limited settings.[6] The advent of caries-arresting medicaments offers a promising alternative to conventional treatments, enabling early intervention and potentially reducing the need for invasive procedures.[7]

In order to properly select an appropriate method of treatment for a carious lesion, it is first necessary to establish a systematic classification of the extent of such a lesion. The International Caries Detection and Assessment System (ICDAS) is a globally recognized classification system designed to standardize the detection, diagnosis, and monitoring of dental caries across different stages of lesion

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progression.[8] ICDAS is based on visual, tactile, and radiographic examination, providing a comprehensive and reproducible method for assessing carious lesions at varying degrees of severity (**Figure 1** A-C). The system ranges from ICDAS Code 0 (sound tooth surface) to ICDAS Code 6 (extensive cavitation with visible dentin involvement).[9]

ICDAS 0 indicates a sound tooth surface with no evidence of caries, as the enamel remains intact without visible discoloration or defects. In ICDAS 1, an early-stage active lesion appears as a faint white or brown opacity that becomes visible only after drying, signifying the initial demineralization of enamel without cavitation. As the lesion progresses to ICDAS 2, it becomes distinctly visible even on a wet tooth, with more pronounced discoloration while still lacking surface cavitation.[10] When caries reaches ICDAS 3, localized enamel breakdown occurs, leading to micro-cavitation without exposure of the underlying dentin. By ICDAS 4, the lesion extends deeper, presenting as a visible dark shadow beneath the enamel due to demineralized dentin, although the outer enamel may still appear largely intact. Further deterioration is seen in ICDAS 5, where a distinct cavity forms with visible dentin exposure, making the lesion easily detectable without magnification or drying. At the most advanced stage, ICDAS 6, the tooth exhibits an extensive cavity with significant dent in exposure, often leading to structural weakening and potential pulpal involvement.

Caries-arresting medicaments function through various mechanisms, such as promoting remineralisation, inhibiting bacterial growth, and forming protective barriers over lesions.[11] These medicaments are particularly valuable in paediatric, geriatric, and medically compromised populations, where invasive procedures pose additional challenges.[12] Given the increasing emphasis on minimal intervention dentistry, researchers and clinicians continue to explore and refine these agents for improved efficacy, safety, and patient acceptability.[13] While in cases of ICDAS 1-4 lesions it is possible to apply caries-arresting medication as a method of definitive treatment, more advanced stages of caries can also benefit from such medications in efforts of delaying restorative treatment and delaying disease progression.[14]

The effectiveness of caries-arresting medicaments is influenced by several factors, including application technique, frequency of use, patient-specific risk factors, and the presence of adjunctive preventive measures, such as dietary modifications and oral hygiene maintenance.[15] Understanding these dynamics is crucial for optimizing their use in diverse clinical settings. Moreover, ongoing research is focused on enhancing formulations, incorporating novel bioactive materials, and developing combination therapies to maximize their preventive and therapeutic potential.[16]

This review aims to provide a comprehensive evaluation of the most commonly used caries-arresting medicaments, focusing on their mechanisms of action, clinical effectiveness, limitations, and comparative advantages. By analysing existing clinical and in vitro studies, this review will also discuss future directions and emerging innovations that could further revolutionize caries management in both preventive and therapeutic contexts.

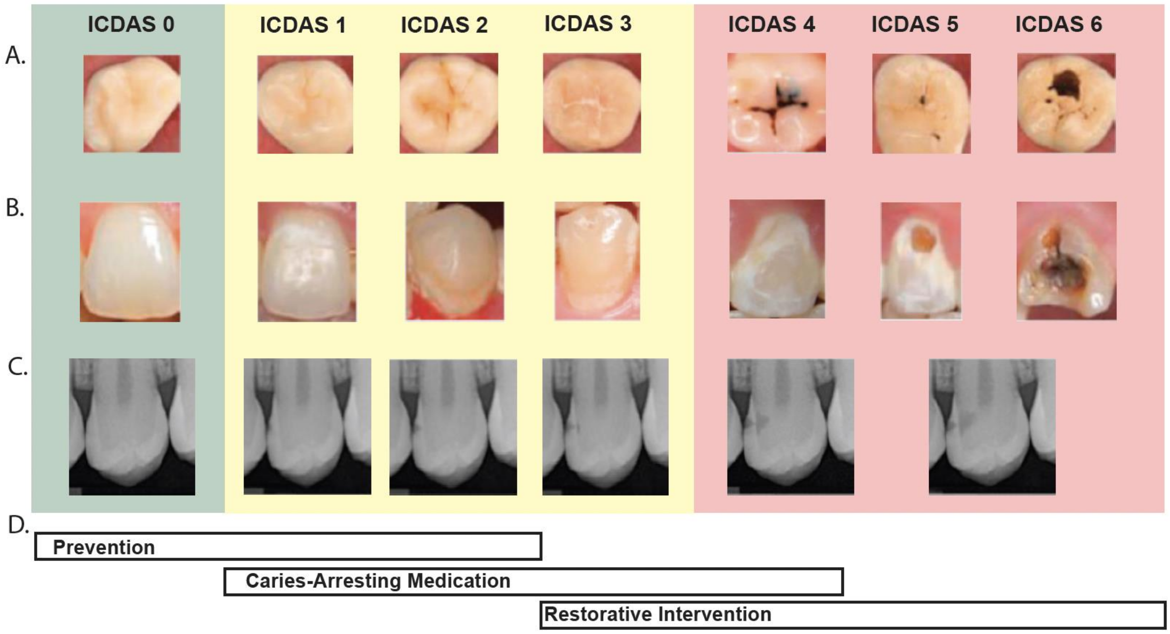

Figure 1: ICDAS classification: ICDAS clinical lesson presentation (A) occusal and (B) cervical tooth regions, and (C) radiographically. (D) Treatment concentration for each ICDAS stage

2. Silver Diamine Fluoride

Silver diamine fluoride (SDF) has gained attention as a minimally invasive alternative to conventional restorative treatment, offering a cost-effective and efficient method for arresting active caries. The technique has been widely adopted in populations where conventional restorative care is challenging to implement.[17] SDF exerts its caries-arresting effect through a combination of antimicrobial action and remineralisation. The silver component has strong antibacterial properties, disrupting bacterial cell walls and inhibiting enzymatic activity essential for cariogenic bacteria like *Streptococcus mutans*. Meanwhile, fluoride enhances remineralisation by forming fluorapatite, which increases enamel resistance to acid dissolution.[18] Additionally, SDF induces the formation of a sclerotic dentin layer, providing a physical barrier that protects against further decay.[19]

Numerous studies have demonstrated the high efficacy of SDF in arresting caries progression. A systematic review by Zhao et al. reported that annual application of 38% SDF arrests over 80% of active carious lesions in primary teeth.[20] Another randomized clinical trial by Zhi et al. found that SDF was significantly more effective than fluoride varnish in preventing lesion progression.[21] Furthermore, SDF has shown comparable efficacy in arresting root caries in elderly populations.[22]

The use of SDF presents several advantages in caries management. It is a non-invasive and painless procedure, making it particularly useful for treating young children, elderly patients, and those with special needs.[23] Additionally, SDF requires minimal clinical equipment, reducing treatment costs and improving accessibility in low-resource settings. Its strong antimicrobial properties contribute to long-term caries control, preventing new lesion formation.[24] Unlike conventional restorations, SDF application is rapid and does not require anaesthesia or drilling, improving patient compliance and reducing chairside time.[25]

Despite its benefits, SDF has certain limitations. The most commonly cited drawback is the black discoloration of treated lesions, which may be esthetically undesirable for anterior teeth.[26] Additionally, while SDF arrests caries progression, it does not restore the lost tooth structure, necessitating follow-up interventions such as glass ionomer cement restorations or aesthetic masking techniques.[27] Some patients may experience mild irritation or transient metallic taste following application, though adverse reactions are rare.

Future research is focused on optimizing SDF formulations to minimize staining while maintaining efficacy. The combination of SDF with potassium iodide (KI) has shown promise in reducing discoloration, although further clinical trials are needed to confirm its long-term effects.[28] Additionally, integrating SDF into comprehensive caries management protocols, including its use alongside minimally invasive restorative techniques, may further improve treatment outcomes.[29] Advances in biomaterials and nanotechnology could also lead to enhanced formulations with improved esthetic and antibacterial properties.[30]

3. Resin Infiltration

Resin infiltration (RI), introduced as an intermediate technique between remineralisation and traditional restorative procedures, aims to halt caries progression by occluding porous lesion structures with resin material. This technique has gained traction in treating non-cavitated proximal and smooth surface lesions, particularly in young patients and those at high caries risk.[31] Resin infiltration is based on the penetration of low-viscosity resin into the porous network of demineralized enamel. The key steps in the process include:

1. Lesion conditioning: The lesion surface is treated with hydrochloric acid (HCl) to remove surface barriers and enhance porosity.
2. Resin application: A low-viscosity resin, commonly a methacrylate-based material, is applied to the lesion. The resin infiltrates the porous enamel by capillary action.[32]
3. Polymerization: After sufficient infiltration, the resin is light-cured to create a mechanically stable structure within the lesion, preventing further demineralization and bacterial invasion.[33]

Resin infiltration presents a strong track record as a highly effective method for arresting caries progression. A systematic review by Doméjean et al. found that RI significantly reduced lesion progression in non-cavitated proximal caries compared to untreated lesions.[34] Furthermore, a randomized controlled trial by Ekstrand et al. reported that RI provided a superior outcome in preventing lesion advancement compared to fluoride varnishes.[35] A clinical study by Meyer-Lueckel et al. further confirmed that RI effectively halted lesion progression in primary and permanent teeth, with high patient acceptability.[31] Additionally, a long-term follow-up study by Paris et al. demonstrated that resin infiltration maintained its caries-arresting effect for up to three years, reinforcing its durability as a non-invasive intervention. A meta-analysis by Desai et al. also highlighted that RI not only arrested lesion progression but also enhanced enamel translucency, improving the esthetic outcomes for patients.[36]

Resin infiltration presents several advantages as a minimally invasive technique for managing carious lesions. Although historically derived from the restorative paradigm, it does not require drilling or mechanical removal of enamel, making it a conservative treatment approach. Additionally, it offers significant aesthetic benefits as the resin-infiltrated lesions seamlessly blend with the natural enamel, making it an appealing choice for patients concerned about dental appearance. Another key advantage is its immediate effect; the technique quickly stabilizes lesions and prevents further demineralization, thereby halting caries progression. Moreover, its non-invasive nature enhances patient compliance, particularly among children and individuals with dental anxiety, as it reduces discomfort and fear associated with conventional restorative procedures.[37]

Despite these benefits, RI is not without limitations. It is only effective for non-cavitated lesions, restricting its application to early-stage caries and making it unsuitable for advanced lesions with cavitation. The technique also requires precise application, including appropriate lesion preparation and adequate resin penetration, making it technique-sensitive and dependent on operator skill.[38] Furthermore, while short-term studies support its effectiveness, the long-term durability and efficacy of RI remain uncertain, necessitating further research to evaluate its sustained benefits.

Future advancements in resin infiltration focus on improving material properties and expanding indications. The incorporation of antibacterial and bioactive components into resin formulations could enhance their preventive effects. Additionally, research is exploring the integration of nanotechnology to improve infiltration depth and mechanical stability.

4. Casein Phosphopeptide-Amorphous Calcium Phosphate

Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) is a bioactive agent that enhances enamel remineralization by delivering essential minerals directly to demineralized tooth surfaces.[39] This paper discusses the role of CPP-ACP in arresting carious lesions and its potential as a conservative alternative to traditional treatments.

CPP-ACP is a nanocomplex that binds to bioavailable calcium and phosphate, maintaining them in a soluble, non-crystalline state. The casein phosphopeptides (CPP) stabilize these ions, preventing their premature precipitation and enhancing their ability to diffuse into enamel and dentin.[40] CPP-ACP localizes at the enamel subsurface, where it increases the concentration of free calcium and phosphate ions, facilitating remineralisation and reversing early-stage carious lesions.[41] Additionally, CPP-ACP has been shown to inhibit bacterial adhesion and acid production, reducing the cariogenic potential of plaque biofilms.

A limited number of studies have demonstrated the effectiveness of CPP-ACP in remineralising early carious lesions and preventing lesion progression. A randomized clinical trial by Aref et al. found that daily application of CPP-ACP significantly increased remineralisation of white spot lesions in orthodontic patients.[43] Similarly, a meta-analysis by Cochrane et al. reported that CPP-ACP, when used in conjunction with fluoride, enhanced remineralisation compared to fluoride alone.[44] Another longitudinal study by Shen et al. indicated that CPP-ACP application led to a reduction in lesion size and mineral loss in both primary and permanent dentition.[42]

CPP-ACP offers several advantages in non-invasive caries management. It enhances remineralisation by delivering bioavailable calcium and phosphate ions directly to demineralized enamel, promoting lesion repair without the need for restorative intervention. Unlike traditional fluoride therapies, CPP-ACP remains effective in both neutral and acidic environments, providing continuous mineral availability for sustained remineralization.[45] Additionally, CPP-ACP has been shown to reduce dentinal hypersensitivity and improve enamel hardness, making it a versatile therapeutic agent.[46] Its non-invasive nature and ease of application make it an attractive option for paediatric and geriatric populations, as well as individuals with dental anxiety.

The efficacy of CPP-ACP is dependent on frequent application, as the remineralisation effect is temporary and requires continuous replenishment. Additionally, CPP-ACP's effectiveness in arresting cavitated lesions remains unclear, as it primarily targets early-stage enamel demineralization.[44] Patients with a casein allergy may also be unable to use CPP-ACP-based products, limiting its applicability.[39] Further long-term studies are needed to assess the durability of CPP-ACP treatment and its role in comprehensive caries management strategies.

Ongoing research is exploring novel formulations of CPP-ACP to enhance its efficacy and bioavailability. The integration of CPP-ACP with fluoride and other bioactive materials, such as hydroxyapatite nanoparticles, has shown promising results in optimizing remineralisation potential.[47] Additionally, advancements in nanotechnology may allow for targeted delivery systems that improve CPP-ACP retention on enamel surfaces, prolonging its protective effects.[42] Future clinical trials should focus on assessing the long-term impact of CPP-ACP on caries prevention and lesion arrest in diverse populations.

5. Glass Ionomer Cement (GIC)

Glass ionomer cement (GIC) is increasingly used as a non-invasive or minimally invasive alternative for caries management, particularly in the context of atraumatic restorative treatment (ART) and in populations with limited access to dental care.[48] The use of GIC for caries arrest is supported by its remineralisation potential, fluoride-releasing properties, and ease of application.

GIC is composed of an acid-base reaction between polyalkenoic acid and ion-leachable glass particles, forming a stable matrix that adheres to tooth surfaces without the need for additional bonding agents.[49] The key mechanisms through which GIC arrests caries progression include:

1. Fluoride release: GIC acts as a fluoride reservoir, continuously releasing fluoride ions that enhance remineralisation and inhibit bacterial metabolism.
2. Chemical adhesion to tooth structure: Unlike composite resins, GIC chemically bonds to enamel and dentin, forming an intimate seal that reduces microleakage and secondary caries risk.[51]
3. Biocompatibility and anti-bacterial properties: The polyacrylic acid component of GIC contributes to its antibacterial effects, reducing microbial colonization and caries activity.
4. Rehydration and ion exchange: GIC absorbs calcium and phosphate from saliva, aiding in the remineralisation of adjacent tooth structures.

Clinical studies have demonstrated the effectiveness of GIC in arresting caries, particularly in paediatric and geriatric populations. A systematic review by Mickenautsch et al. found that high-viscosity GIC used in ART was comparable to composite resin and amalgam restorations in terms of longevity and caries prevention.[52] Additionally, research by Frencken et al. highlights that GIC restorations significantly reduce bacterial viability within carious dentin, thereby preventing lesion progression.[53] Another clinical trial by Schwendicke et al. confirmed that GIC restorations successfully arrest carious lesions when applied in minimally invasive techniques.[54]

GIC offers several advantages in non-invasive caries management. It provides sustained fluoride release, which promotes remineralisation and offers long-term protection against recurrent caries. Its chemical bonding properties eliminate the need for etching and extensive tooth preparation, making it an ideal material for ART and geriatric dentistry. Moreover, its moisture tolerance allows for successful application in settings with limited dental infrastructure, enhancing its utility in community-based interventions.[53]

Glass ionomer cement exhibits lower mechanical strength compared to composite resins and amalgam, making it less suitable for high-load-bearing restorations.[49] Additionally, its wear resistance is inferior to resin-based materials, requiring periodic maintenance or protective coatings. Although fluoride release provides caries resistance, its long-term effectiveness in preventing new lesions depends on patient compliance and adjunctive fluoride exposure.[52]

Research is focused on improving the physical properties of GIC to enhance its durability and wear resistance. The incorporation of nano-hydroxyapatite and bioactive glass particles into GIC formulations has shown promising results in increasing its mechanical strength and remineralisation potential. Additionally, the development of resin-modified glass ionomer cements (RMGICs) aims to combine the benefits of GIC with enhanced mechanical properties and improved esthetics.[49] Future clinical studies should explore the long-term outcomes of GIC in caries arrest and its integration into comprehensive caries management protocols.

Glass ionomer cement is a highly effective material for the arrest of active carious lesions, particularly in minimally invasive and preventive dentistry. Its fluoride-releasing capabilities, chemical bonding to tooth structures, and ease of application make it a valuable tool in modern caries management. While challenges remain regarding its mechanical properties, ongoing research and material advancements continue to enhance its clinical utility. The integration of GIC into preventive and therapeutic protocols underscores its significance in contemporary dental practice, particularly for underserved populations.

6. Conclusion

The advancements in non-invasive and minimally invasive caries management strategies have significantly transformed the approach to dental care. Traditional restorative interventions, while effective, often involve extensive removal of tooth structure and high costs, making them less accessible in resource-limited settings. Caries-arresting medicaments such as silver diamine fluoride (SDF), resin infiltration (RI), casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), and glass ionomer cement (GIC) provide viable alternatives that not only arrest caries progression but also promote remineralisation and preserve tooth integrity. These materials cater to diverse patient populations, including paediatric, geriatric, and medically compromised individuals, who may struggle with conventional restorative treatments.

Each of these medicaments functions through distinct mechanisms that contribute to their efficacy in caries arrest. SDF offers a strong antimicrobial effect and promotes dentin sclerosis, making it a widely used option for high-risk patients, despite its drawback of tooth discoloration. Resin infiltration penetrates the porous enamel to stabilize early lesions without affecting tooth esthetics, making it an appealing choice for anterior teeth. CPP-ACP, through its bioactive mineral-releasing properties, aids in remineralisation and enamel repair, though its effectiveness requires frequent application. GIC, known for its fluoride-releasing capacity and chemical bonding to enamel and dentin, plays a crucial role in both preventive and restorative dentistry, especially in the context of atraumatic restorative treatment (ART).

Despite their benefits, these caries-arresting agents also present certain limitations that need to be addressed. The longevity and retention of resin infiltrants require further study, as their long-term durability remains uncertain. While CPP-ACP is effective in remineralisation, it is not sufficient as a standalone treatment for cavitated lesions. Additionally, patient compliance with these non-invasive therapies, particularly regarding the reapplication of CPP-ACP and fluoride-based treatments**,** significantly impacts their success. The search for improved formulations, such as SDF with potassium iodide to minimize staining or nano-enhanced GIC for greater mechanical strength**,** continues to be an area of active research.

In conclusion, non-invasive caries arrest strategies represent a major shift toward preventive and conservative dentistry**,** reducing the need for extensive restorative procedures. Although classifications, such as ICDAS, provide great a great system for caries classification and treatment, the disease should still be viewed as a spectrum, without any clear-cut borders and thus clear-cut treatment modalities. Prevention via CAMBRA should always be the most commonly used weapon in the arsenal of fighting caries and is to be deployed beyond ICDAS 0 and up to the progression of the lesion into early dentin. It is also appropriate to supplement prevention with early lesion arresting though ICDAS 4, whereas conventional restorative approach may be appropriate as early as ICDAS 3 (Figure 1 D). Factors contributing to caries and caries history should be considered when selecting appropriate treatment modality. The combination of multiple approaches—such as using SDF followed by GIC restorations or CPP-ACP alongside fluoride varnish applications should also be considered for optimization of caries control. Ultimately, integrating these techniques into comprehensive preventive dental programs will play a critical role in reducing the global burden of dental caries and improving oral health outcomes across diverse populations.

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8. Conflict of Interest

None.

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