**RESEARCH PAPER**

# "Silver Diamine Fluoride in Paediatric Dentistry: Current Evidence, Clinical Applications, and Future Directions"

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**Abstract**
*Background*
Silver diamine fluoride (SDF) has emerged as a minimally invasive agent for managing early childhood caries (ECC), a major public health challenge with high prevalence in low-income populations. Conventional restorative approaches often face barriers such as cost, accessibility, and child cooperation.
*Aim*
This narrative review aims to synthesize current literature on the use of SDF in ECC, focusing on its mechanism of action, clinical effectiveness, patient-centered outcomes, and future directions.
*Methodology*
A narrative review approach was adopted, analyzing published studies and clinical trials on SDF application in ECC. Evidence was examined regarding its efficacy, limitations, and adjunctive techniques such as the SMART approach, light curing, and diode laser irradiation.
*Results*
Evidence suggests that SDF is highly effective in arresting ECC, with success rates ranging from moderate to high across diverse populations. Adjunctive methods show promise in enhancing outcomes. Limitations include black staining of carious lesions and parental acceptance concerns.
*Conclusion*
SDF represents a cost-effective, simple, and clinically effective alternative to conventional restorative approaches for ECC. While aesthetic concerns remain, its role in public health programs and minimally invasive pediatric dentistry is significant. Further research is needed on long-term outcomes and parental perceptions.
*Clinical Significance*
SDF offers a practical solution for ECC management, particularly in resource-limited settings. Its ease of application and high efficacy make it suitable for community-based programs, though strategies to address aesthetic drawbacks are essential for wider acceptance.

**Keywords**
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## Introduction

Early childhood caries (ECC) is defined as the presence of one or more decayed, missing, or filled tooth surfaces in any primary tooth in a child under six years of age [1]. ECC is a multifactorial disease influenced by dietary habits, oral hygiene practices, socioeconomic status, and access to dental care. Globally, ECC prevalence ranges from 23% to 90%, with higher rates observed in disadvantaged communities [2,3]. The consequences of untreated ECC include pain, infection, impaired nutrition, and negative impacts on growth and development.

Traditional management of ECC often involves restorative procedures such as fillings or crowns, which require specialized equipment, trained personnel, and patient cooperation. These interventions are frequently challenging in young children due to behavioural issues and limited access to pediatric dental services [4]. As a result, there has been growing interest in minimally invasive approaches that prioritize disease control, patient comfort, and cost-effectiveness.

Silver diamine fluoride (SDF) has emerged as a promising agent in this context. SDF is a colorless liquid containing silver and fluoride ions, which act synergistically to arrest caries progression. Silver provides antimicrobial action, while fluoride promotes remineralization of tooth structure [5]. The simplicity of application, low cost, and high efficacy make SDF particularly suitable for community-based programs and resource-limited settings [6].

Despite its advantages, SDF use is not without limitations. The most notable drawback is the black staining of carious lesions, which may affect parental acceptance and aesthetic outcomes [7]. Additionally, questions remain regarding long-term durability, optimal application protocols, and potential adjunctive methods to enhance effectiveness. This review aims to synthesize current evidence on the use of SDF in ECC, highlighting its clinical outcomes, patient-centered perspectives, and future directions.

## Background

The use of silver compounds in dentistry dates back to the early 20th century, when silver nitrate was employed as an antimicrobial agent [8]. However, its limited remineralization potential restricted widespread adoption. The development of silver diamine fluoride combined the antimicrobial properties of silver with the remineralizing effects of fluoride, offering a dual mechanism of action [9].

Mechanistically, SDF arrests caries by precipitating silver ions into dentin, forming a protective layer of silver phosphate and calcium fluoride. This inhibits bacterial growth, reduces collagen degradation, and enhances mineral density [10]. Clinical trials have consistently demonstrated high rates of caries arrest following SDF application, with effectiveness ranging from 65% to 90% depending on lesion type and follow-up duration [11,12].

Public health programs in countries such as Japan, China, and the United States have incorporated SDF into ECC management strategies, citing its simplicity and cost-effectiveness [13]. In India, pilot studies have shown promising results in community settings, particularly among underserved populations [14]. However, concerns regarding aesthetics and parental acceptance remain significant barriers to widespread implementation [15].

**Thematic Review of Literature**

**1. Clinical Effectiveness of SDF**

Multiple randomized controlled trials and longitudinal studies have consistently demonstrated the high efficacy of silver diamine fluoride (SDF) in arresting early childhood caries (ECC). Reported arrest rates range from 65% to 90%, depending on lesion type, concentration, and frequency of application [16]. For instance, Chu et al. documented that biannual application of 38% SDF arrested 91% of carious lesions in primary teeth after 18 months, a figure that surpasses most conventional preventive agents [17]. These findings underscore SDF's reliability as a minimally invasive intervention in paediatric populations.

Comparisons with fluoride varnish consistently reveal superior outcomes for SDF. While fluoride varnish primarily enhances remineralization, SDF combines this effect with potent antimicrobial activity, thereby offering a dual mechanism of action [18]. This synergy explains why SDF is particularly effective in high-risk populations, where conventional preventive measures often fail to halt disease progression.

Mechanistically, SDF penetrates dentin tubules and precipitates silver phosphate and calcium fluoride deposits. These compounds inhibit bacterial metabolism, disrupt biofilm formation, and strengthen the mineral content of affected dentin [16]. Silver ions denature bacterial proteins and enzymes, while fluoride ions promote remineralization of demineralized enamel and dentin. This dual action not only halts caries progression but also creates a protective barrier against reinfection, contributing to its sustained effectiveness.

Clinical effectiveness has also been demonstrated across diverse populations and settings. In community-based programs in Asia and Latin America, SDF has shown remarkable success in reducing ECC prevalence, even when applied by trained auxiliaries rather than dentists. Such evidence highlights its scalability and feasibility in resource-limited environments. Moreover, longitudinal studies confirm that SDF maintains caries arrest over extended follow-up periods, with minimal need for reapplication beyond biannual schedules.

Importantly, SDF's effectiveness is not limited to posterior teeth or cavitated lesions. Studies have shown comparable arrest rates in anterior teeth, though parental acceptance is lower due to aesthetic concerns. This suggests that the clinical effectiveness of SDF is universal across tooth types and lesion locations, even if its practical application requires careful case selection.

**2. Preventive Strategies and Public Health Integration**

Silver diamine fluoride (SDF) has been successfully integrated into school-based and community dental programs worldwide, demonstrating its potential as a scalable public health intervention. In Hong Kong, outreach programs applying SDF biannually reduced ECC incidence significantly compared to control groups, highlighting its effectiveness in large-scale preventive strategies [19]. These programs were particularly impactful because they targeted preschool children in underserved communities, where access to restorative dental care is limited. The simplicity of SDF application allowed trained auxiliaries to deliver care efficiently, reducing the burden on paediatric dentists and expanding coverage.

Similar initiatives in rural India have demonstrated both feasibility and cost-effectiveness, especially in resource-limited settings [20]. Pilot studies revealed that SDF could be applied in school environments with minimal equipment, requiring only cotton rolls and microbrushes. This low-cost approach enabled widespread adoption without the need for dental chairs, suction devices, or complex restorative materials. Importantly, the reduction in ECC prevalence translated into improved oral health outcomes and decreased absenteeism from school due to dental pain.

Public health adoption of SDF is facilitated by several unique advantages. First, its simplicity of application means that dental auxiliaries, hygienists, and even trained community health workers can administer treatment after appropriate training. Second, its minimal equipment requirements make it suitable for outreach programs in rural and underserved areas. Third, its high efficacy in caries

arrest ensures measurable outcomes within relatively short follow-up periods, which is critical for program evaluation and policy advocacy.

Beyond individual programs, SDF has been incorporated into national and regional oral health strategies. For example, in the United States, the American Academy of Paediatric Dentistry has endorsed SDF as a viable option for ECC management, particularly for children with special health care needs or limited access to dental services. In Japan, SDF has been used for decades in school dental programs, contributing to significant reductions in ECC prevalence.[21] These examples illustrate how SDF can be embedded into preventive frameworks at both community and national levels.

Cost-effectiveness analyses further strengthen the case for public health integration. Compared to conventional restorative care, SDF requires fewer resources, less chair time, and minimal infrastructure. Studies have shown that the cost per child treated with SDF is substantially lower than that of traditional interventions, making it an attractive option for governments and NGOs seeking to maximize impact with limited budgets. Moreover, the ability to arrest caries progression reduces the need for future restorative care, thereby lowering long-term treatment costs [22].

Despite these advantages, challenges remain. Parental acceptance of SDF in public health programs is influenced by cultural perceptions of aesthetics. While posterior teeth are generally acceptable sites for SDF application, anterior teeth often raise concerns due to visible black staining. Effective communication strategies, including parental education and counselling, are essential to improve acceptance. Additionally, policymakers must balance the benefits of disease control with the ethical obligation to inform parents about potential aesthetic outcomes.

In summary, the integration of SDF into school-based and community dental programs has proven effective, feasible, and cost-efficient. Its scalability, simplicity, and high efficacy make it a cornerstone of preventive dentistry in resource-limited settings. With appropriate parental education and policy support, SDF has the potential to transform ECC management at the population level, reducing disparities in oral health and improving the quality of life for millions of children worldwide [23].

**3. Adjunctive Techniques (SMART, Light Curing, Lasers)**

To address aesthetic concerns and enhance durability, several adjunctive methods have been explored in combination with silver diamine fluoride (SDF). These innovations aim to balance the proven efficacy of SDF with improved parental acceptance and restoration longevity.

**1. SMART Technique (Silver Modified Atraumatic Restorative Treatment)** The SMART approach combines SDF application with glass ionomer cement (GIC) restoration. After SDF arrests the lesion, GIC is placed to seal the cavity, restore form and function, and mask the characteristic black discoloration [24]. This dual strategy not only improves aesthetics but also prevents food impaction and enhances lesion durability. Clinical studies have shown that SMART achieves comparable caries arrest rates to SDF alone, while significantly improving parental acceptance. Moreover, GIC's fluoride release provides an additional preventive effect, reinforcing the long-term benefits of the treatment.

**2. Light Curing of SDF** Experimental protocols have investigated the use of curing lights to enhance SDF penetration into dentin and potentially reduce discoloration [25]. The rationale is that photopolymerization may stabilize silver compounds within the lesion, improving retention and minimizing leaching. Preliminary laboratory studies suggest improved depth of penetration and reduced surface staining, though clinical evidence remains limited. Larger randomized trials are needed to confirm whether light curing can meaningfully improve both clinical and aesthetic outcomes.

**3. Diode Laser Irradiation with SDF** Diode lasers have been explored as an adjunct to SDF application, leveraging their antimicrobial and dentin-hardening effects [26]. Laser irradiation may enhance the antibacterial activity of silver ions, reduce bacterial colonization, and improve lesion hardness. Early clinical trials report synergistic effects, with higher rates of caries arrest and improved restoration integrity compared to SDF alone. However, laser use requires specialized equipment and training, which may limit its feasibility in community settings.

These adjunctive approaches highlight ongoing innovation aimed at balancing efficacy with aesthetics. The SMART technique currently has the strongest evidence base, offering practical benefits in both clinical and public health contexts. Light curing and diode laser irradiation remain promising but experimental, requiring further validation before widespread adoption. Importantly, adjunctive methods add complexity, cost, and chair time, which may reduce the accessibility advantage of SDF in resource-limited environments. Thus, while adjunctive techniques expand the clinical toolkit, their role should be carefully considered based on patient needs, parental preferences, and available resources [27].

**4. Parental Acceptance and Aesthetic Concerns**

The black staining of carious lesions following silver diamine fluoride (SDF) application remains the most significant barrier to its widespread adoption. While the clinical effectiveness of SDF is well established, parental perceptions often determine whether treatment is accepted, particularly in Paediatric dentistry where aesthetics

carry strong social and cultural weight. Surveys consistently reveal that parents value the non-invasive nature of SDF and appreciate its ability to avoid drilling, anaesthesia, and costly restorative procedures. However, many express reservations about the permanent black discoloration of treated lesions, especially when anterior teeth are involved [28].

Acceptance tends to be higher when SDF is applied to posterior teeth, where staining is less visible, or when combined with restorative materials such as glass ionomer cement in the SMART technique [29]. This suggests that parental concerns are primarily aesthetic rather than functional. In fact, studies show that when parents are informed about the high success rates of caries arrest and the avoidance of invasive procedures, many are willing to accept staining in posterior teeth as a trade-off for disease control.

Cultural differences also influence acceptance. In some communities, parents prioritize health and cost-effectiveness over aesthetics, while in others, visible discoloration is perceived as socially unacceptable. For example, surveys in Asian populations report relatively higher acceptance compared to Western populations, where cosmetic expectations are stronger. This highlights the need for culturally sensitive communication strategies when introducing SDF into public health programs.

Effective communication and education are critical in improving parental perceptions. Dentists and public health workers must explain the mechanism of SDF, its benefits, and the reasons for discoloration in clear, empathetic language. Visual aids, before-and-after photographs, and demonstrations of adjunctive techniques (such as SMART restorations) can help parents understand that aesthetics can be managed. Moreover, framing SDF as an interim solution until definitive restorative care is possible often increases acceptance, as parents view staining as temporary rather than permanent.

Another strategy involves emphasizing the broader benefits of SDF: reduced pain, improved child cooperation, and avoidance of general anaesthesia. Parents are more likely to accept aesthetic compromises when they understand that SDF prevents more invasive procedures. In addition, involving parents in shared decision-making—where they weigh the risks and benefits—has been shown to increase satisfaction and compliance.

In summary, parental acceptance of SDF hinges on balancing aesthetics with health outcomes. While staining remains a barrier, acceptance is higher in posterior teeth, when combined with restorative materials, and when parents are adequately informed. Addressing cultural perceptions, providing clear communication, and offering adjunctive options are essential strategies to enhance acceptance and ensure the successful integration of SDF into pediatric dental practice and public health programs.

**5. Safety and Adverse Effects**

Silver diamine fluoride (SDF) is generally considered safe, with minimal adverse effects reported in both clinical and community settings. The most common minor reactions include mild gingival irritation at the site of application and a transient metallic taste, both of which resolve spontaneously without intervention [30]. Importantly, systemic toxicity is negligible due to the very small quantities of SDF used in pediatric dentistry. A typical application involves less than 25 μL of 38% solution, corresponding to approximately 11 mg of silver and 5 mg of fluoride—well below toxic thresholds established by the World Health Organization and the U.S. Environmental Protection Agency.

Long-term safety data remain reassuring. Multiple longitudinal studies have followed children for up to 24 months after SDF application, with no evidence of systemic adverse effects, hypersensitivity reactions, or developmental disturbances [31]. Laboratory toxicology studies confirm that the absorbed fluoride dose is far lower than that associated with fluorosis, and the silver content is insufficient to cause argyria or other systemic conditions. This makes SDF particularly suitable for repeated applications in young children, including those with special health care needs.

From a regulatory perspective, SDF has been approved for use in several countries, including Japan, China, and the United States. In 2014, the U.S. Food and Drug Administration (FDA) cleared SDF as a Class II medical device for treating dentinal hypersensitivity, though its off-label use for caries arrest has become widespread and is endorsed by the American Academy of Pediatric Dentistry. The World Health Organization has also listed SDF as an essential medicine for dental caries management, reflecting its global importance in public health dentistry.

Rare adverse events have been documented, including localized staining of soft tissues if accidental contact occurs, but these effects are temporary and self-limiting. No serious systemic complications have been reported in pediatric populations. Importantly, SDF is contraindicated in patients with silver allergy, ulcerative gingivitis, or stomatitis, though such conditions are uncommon in children.

In summary, the safety profile of SDF is highly favorable. Its minimal adverse effects, negligible systemic toxicity, and strong regulatory endorsements support its widespread use in pediatric dentistry. Long-term data continue to reinforce its suitability, making SDF a reliable and safe option for managing ECC across diverse populations.

**6. Limitations and Controversies**

Despite strong evidence of efficacy, several controversies persist regarding the use of silver diamine fluoride (SDF) in early childhood caries (ECC). These debates center on optimal application frequency, long-term durability, and aesthetic outcomes, reflecting the balance between scientific evidence and practical realities in pediatric dentistry.

**1. Application Frequency and Protocols** While biannual application of 38% SDF has been shown to achieve arrest rates exceeding 90% [21], some studies suggest that annual application may be sufficient in low-risk populations. Others argue that more frequent applications (every 3–6 months) may be necessary in high-risk groups to maintain effectiveness. The lack of consensus on standardized protocols complicates clinical practice and public health implementation. This variability underscores the need for further longitudinal studies to establish evidence-based guidelines.

**2. Long-Term Durability of Caries Arrest** Although short-term outcomes are consistently positive, questions remain about the long-term durability of SDF treatment. Most clinical trials report outcomes within 12–24 months, leaving uncertainty about whether arrested lesions remain stable over several years. Some authors argue that SDF should be considered an interim measure until definitive restorative care is possible, particularly in cases where cavitation compromises function or aesthetics [21]. Others contend that SDF can serve as a primary treatment modality, especially in public health programs where access to restorative care is limited [32].

**3. Aesthetic Outcomes and Parental Acceptance** The black staining of carious lesions remains the most visible limitation of SDF. While posterior teeth are generally acceptable sites for application, anterior teeth often raise parental concerns. This aesthetic drawback has led some clinicians to restrict SDF use to posterior dentition or to combine it with restorative materials (SMART technique) to mask discoloration. The controversy lies in whether aesthetics should outweigh disease control, particularly in populations where untreated ECC leads to pain, infection, and impaired quality of life[33].

**4. Ethical and Policy Considerations** Ethical debates also surround the use of SDF. Informed consent is critical, as parents must understand the trade-off between caries arrest and permanent staining. Some critics argue that widespread adoption without adequate parental education risks undermining trust in dental care. Conversely, public health advocates emphasize that the benefits of disease control and cost-effectiveness justify its inclusion in national ECC prevention programs, even if aesthetic compromises are unavoidable[34].

**5. Research Gaps and Controversies** Finally, controversies persist regarding adjunctive methods. While SMART, light curing, and diode laser irradiation show promise, evidence remains limited, and their added complexity may reduce accessibility. There is also debate about whether SDF should be positioned as a stand-alone treatment or as part of a broader minimally invasive dentistry framework. These unresolved questions highlight the need for ongoing research, particularly long-term clinical trials and studies on parental perceptions [35].

**Discussion**

The accumulated evidence strongly supports the effectiveness of silver diamine fluoride (SDF) in arresting early childhood caries (ECC). Across multiple randomized controlled trials, arrest rates consistently exceed those achieved with conventional fluoride varnish, underscoring SDF's potential as a first-line intervention in Paediatric dentistry [21]. Its simplicity of application, minimal equipment requirements, and ability to be delivered in community settings make it particularly valuable in resource-limited environments, where access to restorative care is often restricted [21].

Nevertheless, the literature highlights important limitations. The most prominent drawback remains the black staining of carious lesions, which negatively impacts parental acceptance, especially for anterior teeth [5]. While adjunctive techniques such as the SMART approach or restorative overlays can mitigate aesthetic concerns, these add complexity, cost, and chair time, potentially reducing the accessibility advantage of SDF [10]. This tension between efficacy and aesthetics reflects a broader challenge in pediatric dentistry: balancing disease control with parental expectations for cosmetic outcomes.

Another area of debate concerns the optimal frequency and concentration of application. Biannual application of 38% SDF has demonstrated high efficacy, but some studies suggest that annual application may suffice in low-risk populations [21]. Conversely, in high-risk groups, more frequent application may be necessary to maintain caries arrest. The absence of standardized global protocols complicates clinical decision-making and highlights the need for further longitudinal studies to establish evidence-based guidelines.

The long-term durability of caries arrest also requires further investigation. Most studies report outcomes within 12–24 months, leaving uncertainty about whether arrested lesions remain stable over several years. Some authors argue that SDF should be considered an interim measure until definitive restorative care is possible, while others advocate for its inclusion as a primary treatment modality in public health programs. This divergence reflects differing priorities: clinical aesthetics versus population-level disease control.

From a public health perspective, SDF offers a cost-effective solution to ECC management, particularly in underserved populations. Its

integration into school-based programs has demonstrated significant reductions in ECC prevalence [8]. The ability to deliver treatment outside traditional dental clinics—by trained auxiliaries or community health workers—makes SDF uniquely suited for outreach initiatives. However, widespread adoption requires careful consideration of cultural perceptions, parental education, and policy support. Ethical considerations also arise regarding informed consent, given the aesthetic consequences of treatment [9]. Parents must be fully informed of the trade-off between disease arrest and permanent staining to ensure trust and compliance.

Overall, the discussion emphasizes the balance between clinical efficacy and patient-centered concerns. SDF represents a paradigm shift toward minimally invasive dentistry, offering a practical, effective, and scalable solution to ECC. Yet, its limitations necessitate ongoing innovation, particularly in developing adjunctive methods that preserve efficacy while improving aesthetics. Future research should focus on long-term outcomes, parental perceptions, and integration into public health frameworks. By addressing these challenges, SDF can fulfill its potential as both a clinical and public health cornerstone in paediatric dentistry.

**Conclusion**

This narrative review synthesizes current evidence on the use of silver diamine fluoride (SDF) in managing early childhood caries (ECC). Findings consistently demonstrate that SDF is highly effective in arresting caries progression, offering a simple, low-cost, and minimally invasive alternative to conventional restorative approaches. Its dual mechanism of antimicrobial action and remineralization underpins its clinical success, particularly in high-risk populations where traditional interventions are often inaccessible or impractical.

Despite these advantages, aesthetic concerns remain a significant barrier to parental acceptance, especially for anterior teeth. The characteristic black staining of carious lesions challenges the widespread adoption of SDF in clinical practice. Adjunctive techniques such as the SMART approach, restorative overlays, and experimental methods like light curing or diode laser irradiation show promise in mitigating these limitations, though further research is needed to establish their long-term outcomes, cost-effectiveness, and feasibility in community settings.

From a public health perspective, SDF has proven feasible and impactful. Its integration into school-based and community dental programs has demonstrated measurable reductions in ECC prevalence, particularly in underserved populations. The simplicity of application, minimal equipment requirements, and ability to be delivered by trained auxiliaries make SDF uniquely suited for large-scale preventive strategies. However, successful public health adoption requires robust parental education, culturally sensitive communication, and policy support to address aesthetic concerns and ensure informed consent.

In conclusion, SDF represents a valuable tool in the armamentarium against ECC and embodies the principles of minimally invasive dentistry. Its role in pediatric dentistry is likely to expand as evidence accumulates and adjunctive methods evolve. Future research should focus on optimizing application protocols, enhancing aesthetic outcomes, and evaluating long-term effectiveness across diverse populations. With appropriate integration into clinical practice and public health programs, SDF has the potential to significantly reduce the global burden of ECC, improve child oral health, and advance equity in access to dental care.

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