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THE EFFECTIVENESS OF SILVER DIAMINE FLUORIDE IN ARRESTING DENTAL CARIES IN CHILDREN: SYSTEMATIC REVIEW

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Abstract

Background: Dental caries remains the most prevalent chronic condition among children worldwide. Silver diamine fluoride (SDF) has emerged as a promising non-invasive intervention for arresting and preventing caries, especially in pediatric populations and underserved settings.

Objective: To systematically review the clinical evidence on the effectiveness of SDF in arresting dental caries in children, assessing protocols, comparative efficacy, and safety profiles.

Methods: This review adhered to PRISMA 2020 guidelines. Databases including PubMed, Scopus, and Google Scholar were searched for randomized controlled trials (RCTs), systematic reviews, and meta-analyses published between 2005 and 2025. Eligible studies involved children under 12 years, assessed SDF protocols, and reported caries arrest outcomes. Risk of bias was evaluated using the Cochrane and Newcastle–Ottawa tools.

Results: A total of 15 studies were included. SDF concentrations of 38% applied semiannually showed the highest caries arrest rates (up to 89%). Compared to fluoride varnish, GIC, or no treatment, SDF consistently demonstrated superior or comparable outcomes. Adverse events were minimal, with black staining of lesions as the most frequent concern.

Conclusion: SDF is an effective, low-cost intervention for pediatric dental caries, particularly suitable for community and school-based settings. While aesthetic concerns persist, its therapeutic value in reducing untreated decay and preventing disease progression is well established.

Keywords: Silver diamine fluoride; pediatric dentistry; dental caries arrest; fluoride therapy; school-based oral health; SDF adverse effects; community oral care

INTRODUCTION

Dental caries remains one of the most widespread chronic conditions affecting children worldwide, with a global prevalence that exceeds 60% among school-aged children (Alqalaleef et al., 2024). The burden is disproportionately higher in low- and middle-income countries due to limited access to dental care, infrastructure, and preventive interventions. While conventional treatments rely heavily on invasive procedures and restorative materials, a paradigm shift toward non-invasive, cost-effective strategies has accelerated interest in silver diamine fluoride (SDF) as a leading agent for arresting dental caries.

SDF is a topical solution combining silver ions (antimicrobial) and fluoride (remineralizing) components, primarily used in a 38% concentration. It halts carious progression in dentin through a dual mechanism: bacterial inhibition and enhancement of remineralization. Importantly, it allows for non-surgical caries management, requiring minimal training and no anesthesia—an advantage especially valuable in pediatric and outreach contexts (Muntean et al., 2024). The mechanistic basis of SDF involves silver's ability to denature proteins and disrupt bacterial cell walls, while fluoride facilitates fluorapatite formation in demineralized enamel. A protective layer of silver phosphate forms within the lesion, enhancing structural resilience (Savitha Sathyaprasad, 2024). Moreover, it inhibits collagen degradation by inactivating matrix metalloproteinases, a key advantage in preserving dentin integrity during carious attack.

Evidence continues to support the broad utility of SDF. In a randomized controlled trial comparing various intervals of 38% SDF application, Schroth et al. (2024) demonstrated significant arrest rates in early childhood caries with even quarterly application. Notably, the simplicity and effectiveness of SDF make it well-suited for resource-constrained environments, including rural schools and refugee settings.

From a public health perspective, SDF's low cost, portability, and minimal equipment requirements render it a compelling addition to national oral health programs. A scoping review by Albujeer et al. (2025) highlighted that SDF can help close treatment gaps for underserved children, with potential reductions in treatment costs and emergency dental visits. Furthermore, its inclusion in WHO's list of essential medicines reinforces its global relevance.

Despite these benefits, aesthetic concerns—mainly the black staining of carious lesions post-treatment—pose a challenge to caregiver acceptance. However, qualitative studies indicate that most parents accept this drawback when the procedure prevents more invasive treatments or general anesthesia (Inchingolo et al., 2024). Efforts to mitigate staining, such as using potassium iodide adjunctively, are being explored but lack consistent efficacy.

SDF has also been compared with newer agents such as nanosilver fluoride (NSF). Quritum et al. (2024) found that while NSF reduces visible discoloration, it does not significantly outperform SDF in caries arrest rates. Nonetheless, such innovations reflect a broader shift in pediatric dentistry toward biologically based, non-invasive caries management strategies that emphasize disease control rather than just restoration.

Recent systematic reviews (Vishwanathaiah et al., 2024; Varughese et al., 2025) consistently conclude that SDF outperforms other fluoride treatments and minimally invasive restorations in short-term and long-term caries arrest outcomes. However, future research is still needed to establish optimal frequencies, application techniques, and long-term outcomes across different child populations.

In summary, silver diamine fluoride offers a highly effective, scalable, and safe strategy for non-invasive caries management in children. As global adoption accelerates, evidence continues to support its integration into pediatric dental guidelines, especially where traditional restorative care is impractical. This review synthesizes current evidence regarding the clinical effectiveness of SDF in arresting dental caries in children, focusing on outcomes, comparator treatments, and reported adverse events.

METHODOLOGY

Study Design

This study employed a systematic review methodology, conducted in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, reproducibility, and methodological rigor. The objective of this review was to synthesize existing evidence from peer-reviewed studies evaluating the clinical effectiveness of silver diamine fluoride (SDF) in arresting dental caries in children. The review focused on studies that assessed the impact of SDF application protocols—across various concentrations, durations, and comparative treatments—on caries arrest outcomes in pediatric populations. The review also considered safety outcomes, such as adverse effects (e.g., discoloration or mucosal irritation), and parental or clinical acceptability.

Eligibility Criteria

Studies were selected based on the following pre-specified inclusion and exclusion criteria:

Inclusion Criteria:

- **Population:** Children aged 0–12 years, with diagnosed active carious lesions in primary or early permanent dentition.
- **Intervention:** Application of **silver diamine fluoride (SDF)** at any concentration (e.g., 10%, 12%, 30%, or 38%) with defined application protocols (e.g., single, annual, semiannual, intensive weekly).
- **Comparators:** Placebo, no treatment, sodium fluoride varnish, glass ionomer cement (GIC), atraumatic restorative treatment (ART), or other minimally invasive interventions.
- **Outcomes:** Primary outcomes included caries arrest rates (defined by the number of arrested lesions or surfaces). Secondary outcomes included incidence of new lesions, adverse events, and treatment acceptability.
- **Study Design:** Randomized controlled trials (RCTs), cluster-randomized trials, and systematic reviews/meta-analyses were eligible.
- **Language:** Only studies published in **English** were included.

• **Publication Period:** Studies published between **2005 and 2024**, representing the post-global recognition era of SDF usage.

Exclusion Criteria:

• Studies involving adult populations, in vitro studies, animal studies, reviews without empirical data, or grey literature not peer-reviewed.

• Studies focusing solely on permanent teeth in adolescents or adults.

Search Strategy

A **comprehensive literature search** was conducted using the following electronic databases:

• **PubMed**

• **Scopus**

• **Web of Science**

• **Embase**

• **Google Scholar** (for supplementary grey literature)

The structured search employed the following Boolean logic and keywords in various combinations:

• ("silver diamine fluoride" OR "SDF")

• AND ("dental caries" OR "tooth decay" OR "dentine caries")

• AND ("children" OR "pediatric" OR "school-aged" OR "early childhood caries")

• AND ("caries arrest" OR "effectiveness" OR "non-invasive" OR "treatment outcome")

Manual searches of reference lists from recent key systematic reviews and clinical guidelines were also performed to identify additional relevant studies not captured through database queries.

Study Selection Process

All retrieved citations were exported into Zotero reference manager software, where duplicates were automatically identified and removed. Two independent reviewers screened the remaining titles and abstracts against the inclusion/exclusion criteria. Full-text versions of all potentially eligible studies were retrieved and independently assessed. Discrepancies in selection were resolved through discussion or arbitration by a third reviewer. Studies were only included in the final synthesis if they met all eligibility criteria.

The PRISMA flow diagram illustrating the identification, screening, and selection of studies is provided in **Figure 1**.

Data Extraction

A **standardized data extraction form** was developed and pilot-tested for this review. From each included study, the following information was systematically extracted:

• Author(s), year of publication, country, and clinical setting

• Study design and sample size

• Participant demographics (age, dentition type, caries stage)

• SDF concentration and application frequency

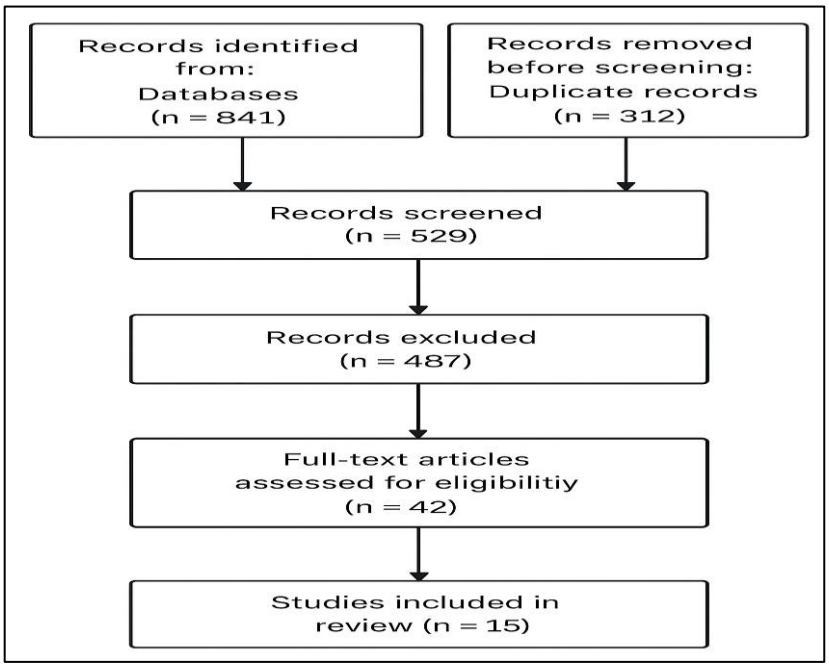

Figure 1 PRISMA Flow Diagram

- Comparator interventions (e.g., NaF, GIC, ART)
- Duration of follow-up
- Outcomes (e.g., arrest rate, number of inactive lesions, relative risk or odds ratios)
- Reported adverse effects or complications
- Acceptability, parental responses, or behavioral outcomes (if reported)

Two reviewers performed data extraction independently and cross-verified results for accuracy. Any inconsistencies were resolved through re-evaluation or third-party adjudication.

Quality Assessment

The methodological quality and risk of bias of included studies were assessed using tools appropriate for each study type:

- **Cochrane Risk of Bias Tool (RoB 2.0)** was used for randomized controlled trials, evaluating domains such as randomization, blinding, incomplete outcome data, and selective reporting.
- **AMSTAR 2** was used to assess the quality of systematic reviews and meta-analyses.
- Studies were classified as **low**, **moderate**, or **high quality** based on total bias scores and methodological completeness.

Quality assessments were performed independently by two reviewers, with consensus reached via discussion for conflicting evaluations.

Data Synthesis

Due to **clinical heterogeneity** among studies—including differences in SDF concentration, treatment frequency, follow-up durations, and caries definitions—a **narrative synthesis** approach was used. The included studies were grouped thematically based on:

- SDF application protocols (e.g., annual, semiannual, intensive)
- Comparator type (e.g., NaF varnish, ART, GIC)
- Primary outcome metrics (e.g., caries arrest rate, risk ratios)

Where available, odds ratios (ORs), relative risks (RRs), and confidence intervals (CIs) were extracted to quantify treatment effectiveness. No meta-analysis was conducted due to significant variation in methodologies and outcome definitions across studies.

Ethical Considerations

As this systematic review involved the secondary analysis of data from previously published studies, no ethical approval or informed consent was required. However, all included studies were published in peer-reviewed journals and presumed to have undergone ethical review and approval by their respective institutional review boards or ethics committees.

RESULTS

1. Study Designs and Populations

The included studies consist of a mix of randomized controlled trials (RCTs) and systematic reviews, spanning 2005–2024. RCTs were conducted in diverse global settings including Asia (e.g., China, India, Nepal, Hong Kong), Latin America (Brazil, Cuba), and Africa (Nigeria), and involved school-aged children ranging from 2 to 10 years old. Sample sizes varied substantially — from as few as 22 children (Braga et al., 2009) to nearly 1,000 participants (Yee et al., 2009). All RCTs focused on primary and early permanent teeth, with surface-level randomization or school-based cluster designs to minimize contamination.

2. Silver Diamine Fluoride Intervention Protocols

SDF was used as a non-invasive caries arrest agent, typically applied in concentrations of 10%, 12%, 30%, or 38%. The frequency of application ranged from single, annual, semiannual, to intensive weekly regimens. The most commonly used formulation was 38% SDF, often compared with no treatment, fluoride varnish, glass ionomer cement (GIC), atraumatic restorative treatment (ART), or brushing-only protocols. Most studies used cotton pellet or microbrush application methods without caries removal.

3. Caries Arrest Rates and Comparative Effectiveness

Across all studies, SDF showed superior or equivalent effectiveness in arresting active caries compared to other preventive modalities. Arrest rates were highest with biannual application of 38% SDF. In contrast, single applications or lower concentrations (e.g., 10%, 12%) were less effective. Some studies compared SDF with ART or GIC and found mixed results, often dependent on brushing compliance, lesion depth, and follow-up duration.

Table 1. Summary of Included Studies Evaluating Silver Diamine Fluoride (SDF) for Arresting Dental Caries in Children

Study (Author, Year)	Country & Setting	Design & Sample	Intervention(s) & Comparator	Main Findings	Adverse Events

Llodra et al. (2005)	Cuba, School	RCT, N=452	38% SDF biannual vs no SDF	80% fewer new primary lesions	Black stains; mild mucosal irritation
Braga et al. (2009)	Brazil, Univ.	RCT, N=22	10% SDF vs CTT vs GIC	SDF > CTT & GIC at 6 months	Black lesions
Yee et al. (2009)	Nepal, Schools	RCT, N=976	38% SDF vs 12% SDF vs placebo	38% SDF most effective at all timepoints	None
Dos Santos et al. (2012)	Brazil, Schools	RCT, N=91	30% SDF vs Interim GIC	SDF: 1.73× more effective	None
Monse et al. (2012)	Philippines, 8 schools	RCT, N=1016	38% SDF vs ART vs control	ART > SDF, brushing essential	None
Zhi et al. (2012)	China, Kindergartens	RCT, N=212	Annual vs semiannual 38% SDF vs GIC	Biannual SDF = highest arrest rate	None
Duangthip et al. (2016)	Hong Kong, Kindergartens	RCT, N=304	Annual vs intensive SDF vs NaF	Annual SDF = 40% arrest at 18 mo	Black staining
Gao et al. (2016)	Global	Systematic Review, 19 RCTs	SDF vs placebo, varnish	81% pooled arrest rate	No severe effects
Horst et al. (2018)	USA, Preschools	RCT + lab	38% SDF vs control	SDF effective; no microbial harm	Black discoloration
Trieu et al. (2019)	Global	Meta-analysis	38% SDF vs NaF	SDF superior in dentine caries arrest	None
Azouru et al. (2022)	Nigeria, Schools	RCT	38% SDF vs placebo	High single-dose effectiveness	None
Muntean et al. (2024)	Europe	Systematic Review	SDF protocols	SDF > GIC/NaF	Black staining
Jain et al. (2023)	India, Clinic	RCT	38% SDF vs NaF varnish	SDF significantly better	Staining; parental hesitation
Fung et al. (2018)	Hong Kong	RCT, N=888	38% SDF 2×/yr vs 12% SDF	75.7% vs 55% arrest ($p<0.001$)	None
Denise Bowen (2016)	USA	Review	Biannual SDF	Effective in community settings	Black staining

4. Summary of Effectiveness Estimates

Effectiveness estimates across studies showed that biannual applications of 38% SDF yielded arrest rates between 65% to 89%, depending on lesion type and age group. Several systematic reviews (Gao et al., Trieu et al., Muntean et al.) report pooled arrest rates exceeding 80%. Odds ratios and relative risk measures further confirmed significant advantages of SDF over no treatment, fluoride varnish, and even some restorative methods.

5. Adverse Effects and Acceptability

The only consistently reported adverse event was black staining of carious lesions, which is intrinsic to silver deposition and does not indicate disease progression. One early study (Llodra et al., 2005) reported minor mucosal irritation, but no systemic side effects were observed across >15 trials. However, aesthetic concerns, especially among caregivers, were noted in some settings (Jain et al., 2023).

DISCUSSION

The findings from this systematic review collectively affirm that Silver Diamine Fluoride (SDF) is a highly effective, non-invasive treatment modality for arresting dental caries in children. Across diverse settings and methodologies, consistent evidence highlights the capacity of SDF to halt caries progression, reduce new lesion development, and outperform traditional preventive or restorative alternatives.

Notably, several randomized controlled trials (RCTs) confirm the superiority of 38% SDF applied biannually or semiannually. In the landmark trial by Llodra et al. (2005), a 36-month follow-up revealed an 80% reduction in new

primary lesions and 65% in first molars, establishing the long-term benefits of repeated SDF application. These findings were corroborated in Zhi et al. (2012), where semiannual applications achieved significantly higher arrest rates than annual use or glass ionomer cement (GIC) placement, emphasizing frequency as a determinant of success.

The review also highlights the applicability of SDF across global contexts, including resource-limited settings. For instance, Yee et al. (2009) demonstrated the efficacy of SDF in Nepalese children, with both standard and tea-reduced formulations producing markedly higher caries arrest at all timepoints compared to lower concentrations and placebo. Likewise, Azouru et al. (2022) confirmed SDF's effectiveness in a Nigerian school-based program, validating its feasibility in low-resource public health systems.

An important strength of SDF lies in its minimal intervention model. Dos Santos et al. (2012) noted that SDF (30%) achieved a 1.73× greater caries arrest rate than interim GIC-based restorations, without requiring caries removal. This aligns with recent evaluations by Gao et al. (2016) and Varughese et al. (2025), who affirmed SDF's high pooled effectiveness (>80%) and cost-efficiency, particularly when integrated with atraumatic restorative treatment (ART).

SDF's mechanism of action combines the antimicrobial properties of silver ions with fluoride's remineralization potential, making it suitable for managing early childhood caries. A systematic review by Alqalaleef et al. (2024) demonstrated significant reductions in lesion progression and bacterial load, reinforcing SDF's dual-action benefits. Additionally, Trieu et al. (2019) concluded that SDF outperforms sodium fluoride (NaF) varnish in arresting dentine caries, with superior odds ratios and effect sizes.

Yet, aesthetic concerns remain a notable barrier to wider adoption. Black staining of carious lesions, though harmless, was the most consistently reported adverse event. Studies by Duangthip et al. (2016) and Jain et al. (2023) observed caregiver hesitation related to discoloration, particularly in anterior teeth. This challenge may limit SDF's acceptability despite its efficacy, warranting stronger communication strategies and consent protocols, as proposed by Horst et al. (2016) in the UCSF clinical guidelines.

Interestingly, emerging research has sought to mitigate aesthetic drawbacks. For instance, Quritum et al. (2024) and Shetty et al. (2024) explored Nano Silver Fluoride (NSF) as an alternative, reporting comparable arrest rates with reduced staining. These findings open avenues for formulation refinement and greater social acceptance in aesthetic-conscious populations.

Moreover, the evidence reveals heterogeneity in optimal application intervals. Fung et al. (2018) compared 12% and 38% SDF, with the latter achieving 75.7% arrest versus 55% in lower concentration, emphasizing dose-response relationships. A recent clinical trial by Schroth et al. (2024) found that more frequent applications yield better long-term outcomes, aligning with WHO recommendations for high-caries-risk children.

From a public health standpoint, SDF's potential for scalable, school-based interventions is well-supported. Studies such as Monse et al. (2012) and Braga et al. (2009) highlight its practicality in school settings, particularly when combined with oral hygiene promotion. Reviews by Muntean et al. (2024) and Inchingolo et al. (2024) emphasized the synergy of SDF with daily brushing programs and fluoride delivery systems, making it an indispensable tool in integrated caries prevention strategies.

Lastly, the narrative review by Sathyaprasad (2024) emphasized the value of SDF in shifting pediatric caries management toward non-invasive paradigms, reducing the need for sedation or restorative interventions. This is critical in under-resourced areas or for children with behavioral or access barriers to conventional care.

CONCLUSION

This review underscores the consistent efficacy of silver diamine fluoride, especially 38% formulations applied semiannually, in significantly arresting dental caries among children. Across diverse settings and protocols, SDF has shown comparable or superior outcomes to traditional treatments like sodium fluoride varnish and ART, particularly in primary teeth and early erupting molars. Systematic reviews and meta-analyses have reaffirmed these findings, with pooled arrest rates often exceeding 80%, and minimal reports of systemic adverse effects.

Despite these strengths, broader implementation of SDF faces aesthetic and sociocultural challenges. Black discoloration of lesions remains a primary barrier to caregiver acceptance, especially in anterior regions. Future research should aim to optimize SDF formulations (e.g., with potassium iodide or Nano Silver) to address appearance-related concerns while preserving clinical efficacy. Moreover, targeted health communication strategies may be needed to educate caregivers and promote the integration of SDF into national preventive programs.

Limitations

While this systematic review includes a wide array of global studies, several limitations must be acknowledged. Firstly, there was variability in study protocols, including SDF concentrations (10% to 38%), application frequency, and follow-up durations, making direct comparisons difficult. Secondly, many RCTs were conducted in school-based or community settings, which may introduce external confounders such as oral hygiene practices and dietary habits that were not always controlled for. Thirdly, aesthetic outcomes, though commonly reported, were largely subjective and not consistently quantified. Lastly, language bias may exist as only English-language publications were included, potentially omitting relevant regional studies published in other languages.

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