

Is Silver Diamine Fluoride Really a Magic Alternative in Pediatric Caries Management?

Shreepriya Singhania¹, Nandlal Bhojraj², Raghavendra Shanbhog³

ABSTRACT

Aim and objective: To review the success of silver diamine fluoride (SDF) in the management of caries in children.

Background: The current concept of caries management is based on a biological approach. When it comes to children with early childhood caries, managing their behavior along with effective and comprehensive caries management is necessary for which an algorithm-based approach is discussed. Silver diamine fluoride acts as a tertiary preventive procedure that reduces the negative consequences of established disease (cavity) and restores, thus improving the child's quality of life. It is a magic bullet that comprises antibacterial actions of silver and remineralizing effects of highly concentrated fluoride.

Review results: Previous systematic reviews have reported the success of SDF in arresting caries in primary teeth and root caries in adults. Caries removal is not a prerequisite; therefore, SDF application is suitable when other modalities of caries management are unavailable or impractical. Apart from staining the arrested lesion black, no significant complication of SDF use among children was reported.

Conclusion: Even though the black staining was unappealing, a significant number of parents chose SDF over advanced pharmacological behavior management techniques and it is really the magic alternative in children as it supports the contemporary "biological approach" for caries management.

Clinical significance: In such times of the COVID-19 pandemic, SDF allows the interruption of aerosol-generating procedures and serves as interim treatment procedure to arrest dentin caries to prevent development of pulpitis which further requires intervention using aerotor. Most of all, SDF application is child-friendly and provides exceptional success rates when used where indicated.

Keywords: Caries management, Dental caries, Pediatric dentistry, Silver diamine fluoride, Silver fluoride bullet.

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BACKGROUND

Dental caries is a chronic disease that frequently affects children all over the world. Even though there has been a reduction in caries indicators in recent years, dental caries, similar to diseases associated with community disparity, is heavily shifted toward lower socioeconomic groups.¹ "Early childhood caries (ECC), the presence of 1 or more decayed, missing, or filled tooth surfaces (dmfs) in any primary tooth in a preschool-aged child", has been on the rise in many countries and is recognized as an important public health concern by the American Dental Association.²

If ECC remains untreated, it has effects on the growth of the child, their body weight, oral health-related quality of life and both attendance and performance at school.^{3,4} Management of this disease is challenging as children having dental caries often have multiple carious lesions. Almeida et al. reported that children with ECC taken up under general anesthesia have a greater tendency to have their permanent teeth affected by caries.⁵ Since adult dental disease finds its roots in the early years of life, effective caries prevention for children is a requisite.

Caries risk assessment along with dietary advice, toothbrushing (toothpaste) advice, fissure sealants, and fluoride varnish are the few principal evidence-based preventive interventions for a child that is delivered by the oral healthcare team.⁶⁻⁸ Previous literature shows that when the salivary components are inadequate and the bacterial challenge is high, the caries prevention that occurs as a result of remineralization (naturally or as a result of fluoride agents) suffers. Therefore, there is a pressing need to find alternatives for biofilm modification and to intensify the remineralization process which will further help in minimizing the caries experience, thus uplifting

¹⁻³Department of Pediatric and Preventive Dentistry, JSS Dental College and Hospital, Mysuru, Karnataka, India

Corresponding Author: Shreepriya Singhania, Department of Pediatric and Preventive Dentistry, JSS Dental College and Hospital, Mysuru, Karnataka, India, Phone: +91 9901785584, e-mail: shreepriyasinghania94@gmail.com

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overall oral health.⁹ Whenever dental caries prevention fails, a child is subjected to an increased risk of pain and infection. Therefore, the disease must be addressed without delay to manage this risk.

Thus, this article aims to review the current concepts for caries management and whether silver diamine fluoride (SDF) can be used as a successful alternate caries management agent in children.

Understanding Caries Management: Current Concepts

In 2018, Meyer et al. proposed an algorithm that can be referred to by clinicians when selecting disease management strategy and a behavior for early childhood caries.¹⁰ This algorithm guides dental health professionals while providing counsel to caregivers about benefits, risks, and alternative options.¹⁰ Advanced pharmacological behavior guidance techniques like general anesthesia and sedation are often needed to carry out restorative procedures, requiring tooth preparation in children including children with special

healthcare needs. These paths have additional health risks and drawbacks (e.g., mortality risks, neurological deficits in young children), and often are inaccessible due to increased costs.¹¹ Moreover, “repeated or lengthy use of general anesthetic and sedation drugs during surgeries or procedures in children younger than three may affect the development of children’s brains”.¹²

For such children whose caregivers are reluctant to pursue pharmacological management alternatives and those who cannot be sedated safely, non-surgical management strategies may provide reasonable alternatives to traditional restorative care. Children who are uncooperative for treatment due to age or intellectual disability as well as those who are obese or medically compromised and may be at increased risk of a compromised airway require minimal intervention approaches for non-surgical caries management.

The current guidelines on “Use of Vital Pulp Therapies in Primary Teeth with Deep Caries Lesions” published by the “American Academy of Paediatric Dentistry” in 2017 recommended that no vital pulp therapy procedure; namely, indirect pulp therapy, direct pulp capping, or pulpotomy is superior to the other. The systematic review and meta-analysis showed that success after 24 months with indirect pulp therapy was 94.4%, with direct pulp capping was 88.8%, and after pulpotomy was 82.6%. Moreover, the success of indirect pulp therapy was independent of the medicament used.¹³ Therefore, the choice of vital pulp therapy in primary teeth with deep carious lesions should be based on a biological approach.

According to a recently updated Cochrane systematic review for the management of dental caries in primary and permanent dentition (which included eight trials in the analyses), biologically orientated techniques (partial, stepwise, and no-caries removal) when compared with complete caries removal concluded that the biological approach had greater clinical benefits over entire caries removal in the management of asymptomatic vital teeth. No significant differences were found in the longevity of the restorations. There was no significant difference even in the numbers of patients experiencing pulpal pain or infection post biological approach or complete caries removal. Additionally, there were significantly reduced pulp exposures.¹⁴ The use of SDF is one such biological approach for caries management among others such as Hall crowns.

Silver Diamine Fluoride

Interest in the use of silver diamine fluoride (SDF) has been rapidly increasing. Even though SDF had been used off-label for caries arrest; was recently approved (code D1354) as an interim caries arresting medicament.¹⁵ The first product to become commercially introduced in the United States in 2015 was advantage arrest containing 38% SDF. Systematic reviews conclude that SDF meets the “US Institute of Medicine’s 6 quality aims” which are safety, effectiveness, efficiency, ease of application, patient-centered, and equitable.¹⁶

Silver diamine fluoride, a transparent colorless liquid, is a combination of the remineralizing effects of fluoride and the antibacterial effects of silver. Thirty-eight percent SDF contains silver particles (280,000 ppm) and 38% (44,800 ppm) fluoride ion, i.e., 5% fluoride, 25% silver, 8% ammonia, and 62% water at pH 10.¹⁶

The tooth structure which is under attack by the acidic bacterial metabolic products is reinforced by the fluoride component. Moreover, SDF as a whole may also interfere and modify the biofilm causing bacterial cell death. This results in an imbalance in a local

environmental niche that promotes demineralization of dental tissues.¹⁷ Therefore, SDF becomes a unique modality available to address the carious process by altering the bacterial actions along with promoting remineralization (Tables 1 and 2). There is increased deposition of silver and fluoride in demineralized than non-demineralized dentin. Respectively, treated demineralized dentin has a higher resistance to caries bacteria than treated sound dentin. Wakshlak et al. concluded that “when bacteria killed by silver ions are added to living bacteria, the silver is re-activated, so that effectively the dead bacteria kill the living bacteria in a zombie effect”.¹⁸

Silver diamine fluoride is indicated for interim treatment (non-surgical caries management) for patients who cannot receive traditional restorative due to pre-cooperative behavior because of age, cognitive, or physical disabilities; patients at high caries risk having many carious lesions that cannot be addressed in a single visit, unaffordability, and inaccessibility resulting from low socioeconomic status and poor awareness.

Silver diamine fluoride is indicated for cavitated caries on crown or root surfaces which are cleansable, asymptomatic, and do not have pulpal involvement. Ideally, these conditions require a

Table 1: Mechanism of action of silver as a component of silver diamine fluoride

<i>Antibacterial activity</i>	<i>Effect on dentin minerals and dentin collagen</i>
<ul style="list-style-type: none"> • Mark and Barillo 2014 Interaction occurs between silver and enzymes that block the ETS in bacteria. 	<ul style="list-style-type: none"> • Seto and Coworkers 2017 Hardening after SDF application is attributed to its reaction with silver and not with classic fluoride-mediated remineralization.
<ul style="list-style-type: none"> • Lansdown 2002 When silver ions bind to the amino acids inside the bacterial cell, an organometallic complex is formed which breaks down releasing silver ions inside the cell which may cause bacterial DNA and RNA inactivation and cell membrane damage leading to the death of the bacterial cell. 	<ul style="list-style-type: none"> • Mei, Ito et al. 2013; Mei et al. 2017 Silver chloride is the principal precipitate after SDF application.
<ul style="list-style-type: none"> • Russel and Hugo 1994 Interaction between silver and thiol group present in enzymes deactivates enzymes resulting in bacterial cell death. 	<ul style="list-style-type: none"> • Mei, Ito, Cao, Lo et al. 2014 Clinically visible coal-black color indicates the presence of arrested caries.
<ul style="list-style-type: none"> • Russell and Hugo 1994 Silver ions result in DNA mutation eventually leading to bacterial cell death. 	<ul style="list-style-type: none"> • Tjaderhane et al. 2013 Silver indirectly protects dentin collagen by inhibiting dentin collagenase. In comparison to silver nitrate and sodium fluoride solutions, silver from SDF was attributed to being a moderate inhibitor of MMP-8 and MMP-9 and a stronger inhibitor of cathepsins B and K.
<ul style="list-style-type: none"> • Slawson et al. 1990 Silver ions can form an electrostatic bond with bacterial cells, resulting in inhibition of organism movement or resulting in membrane leakage or rupture. 	

Table 2: Mechanism of action of fluoride as a component of silver diamine fluoride

<i>Antibacterial activity</i>	<i>Effect on dentin minerals</i>	<i>Effect on dentin collagen</i>
<ul style="list-style-type: none"> Fluoride causes inhibition of acid production in the dental plaque. 	<ul style="list-style-type: none"> Fluoride may react with apatite in multiple ways. <ul style="list-style-type: none"> Ion exchange between fluorides and hydroxyl ions Fluorapatite crystal growth from supersaturated solutions Dissolution of apatite and formation of calcium fluoride. (Ogard et al. 1994) 	<ul style="list-style-type: none"> In an <i>ex vivo</i> study with SDF treated primary teeth (exfoliated), a relatively smooth dentin surface with exposure of a few dentinal collagen fibers was appreciated in the arrested carious lesions. (Mei, Ito, Cao, Lo et al. 2014)
Fluoride in the form of hydrogen fluoride can directly inhibit cellular enzymes and enhance the membrane permeability toward protons. This is the mechanism by which it inhibits plaque metabolism. (Koo 2008)	Previous research found that the fluoride content in the apatite increased when the SDF concentration increased. (Mei et al. 2017) Thus, it was concluded that the reaction of SDF with calcium and phosphate results in the formation of fluorohydroxyapatite.	By comparing SDF with silver nitrate and sodium fluoride solutions, it was suggested that fluoride strongly inhibits MMP-2, MMP-8, and MMP-9. (Mei et al. 2012)

radiographic verification.¹⁶ It is also indicated for caries prevention in high-risk groups. It is contraindicated in people with silver allergy and stomatitis or ulcerative gingival conditions.

The growing interest in SDF revolves around its five presumed attributes: ease and simplicity of use (paint on), control of pain and infection, minimal personnel requirement, affordability of material, time and training (one minute, once per year), and its non-invasive nature.¹⁹ Thus, SDF has the unique ability to be a magic bullet of silver-fluoride, which can both halt the cariogenic process and prevent caries.

Current Evidence on Efficacy of “The Magic Bullet”: SDF

Caries Arrest on Deciduous Teeth

A Systematic Review and Meta-analysis was conducted by Gao et al. of which eight studies that used 38% SDF to arrest dentin caries in primary teeth were included for meta-analysis (Zhi et al., 2012; Yee et al., 2009; Llodra et al., 2005; Chu et al., 2002; Yang et al., 2002; Fukumoto et al., 1997; Ye, 1995; Wang, 1984). “After SDF treatment the mean percentage of dental caries that got arrested was 81% (95% CI, 68% to 89%; $p < 0.001$)”. Several studies used SDF percentages other than 38% such as 30, 12, and 10% but it was concluded that SDF with higher concentration (38%) demonstrated a statistically significant caries-arresting effect in

children. These studies did not report significant complication despite the high fluoride concentration (44,800 ppm in 38% SDF).²⁰

Fung et al. conducted a study including children between 3 and 4 years where SDF 12 and 38% was applied annually and semi-annually. It was found that the caries arrest was improved with the higher concentration of SDF and that the caries arrest improved by 15% on the increasing frequency of application from annual to semi-annual. The caries arrest rates of were significantly different among the four groups namely upper anterior (77%), lower anterior (93%), upper posterior (42%), and lower posterior teeth (53%) (χ^2 test, $p < 0.001$). Fung et al. also reported that “Children with a higher Visible plaque index score had a reduced chance to have their caries arrested with once a year SDF application”.²¹ However, the caries arrest rates could be improved by increasing the frequency of SDF application for such children.²⁰ Fung et al.’s trial also concluded that large occlusal caries lesions in posterior teeth covered with visible plaque had a comparatively lower chance to become arrested ($p < 0.001$).²¹

Previous literature also reported that SDF was superior to glass ionomer cement or fluoride varnish in its caries arrest potential in primary teeth.^{20,22} Chu et al. also suggested that removal of caries was not a prerequisite before SDF application.²⁰

Chibinski et al. reported that at 12 months, the caries arrest as a result of SDF application was 66% higher than any other product with active ingredients and it was 76% higher than caries remaining untreated.²³

Under a comprehensive caries management program, the AAPD recommends the use of 38% SDF as it is efficacious in caries arrest.²⁴ Arrest rates ranges from 60 to 91% depending on tooth surface, tooth location, presence of plaque, and application frequency. Unfortunately, it is not an option for treating pulpally involved teeth.

Therefore, it can be concluded that SDF of a higher concentration (38%) was significantly efficacious in arresting caries in the primary teeth. Bi-annual application improved caries arrest than annual application. The caries arrest efficacy of SDF is inversely related to the presence of visible plaque. The caries arrest rate was found to vary with the tooth type and region; maximum in the lower anterior region and minimum in the upper posterior region.

Caries Arrest on Permanent Teeth in Children

A review article by Rosenblatt et al. based on a single clinical trial by Llodra et al. in 2006 ($n = 373$) that comments on caries arrest after SDF in the permanent dentition. It concluded that around 77% of SDF-treated active caries became inactive in both deciduous and permanent molars.²¹ Another trial with a small sample size of 22 children concluded that SDF had a better success rate than toothbrushing or glass ionomer restorations at 3 and 6 months. However, there was no significant difference in controlling non-cavitated lesions at 30 months.²⁵

The presence of caries arrest activity of SDF in cavitated permanent molars in children can be concluded from previous literature; however, its efficacy in controlling non-cavitated lesions is questionable and needs more evidence.

Caries Prevention in Children

Rosenblatt et al. conducted a review that included two trials to evaluate SDF’s caries prevention potential. In conclusion, a preventive percentage of 70.3% (>70% on primary teeth and >60% on permanent teeth) was obtained. In the trial conducted by Llodra et al., primary molars as well as permanent molars were included.

They concluded that in a span of 36 months, development of new caries in permanent teeth was significantly reduced in the SDF group (0.4 new lesions) than water control group (1.1 new lesions). Similarly, in deciduous teeth, there were 0.3 new lesions in the SDF group, whereas the water control group had 1.4 new lesions.¹⁹ Chu et al. conducted a trial in preschool children including only the maxillary anterior teeth and found that in the SDF group, the average number of new lesions at 30 months was 0.47. However, with 4 yearly applications of fluoride varnish there were 0.7 new lesions and 1.58 new lesions in the control group (water).²²

Therefore, from previous evidence, it can be concluded that SDF has a considerable preventive activity that is observable both in primary and permanent teeth in children. It has been shown to provide better prevention than fluoride varnish in one of the studies. More clinical trials comparing the preventive activity of SDF with other preventive agents are required to provide generalizable results.

Caries Prevention on Permanent Teeth

Liu et al. conducted a trial and concluded that the sites of pit/fissures having dentinal caries on treatment with SDF, FV, and sealant did not show a significant difference at 24 months.²⁶ Monse et al. found that the effectivity of one-time SDF application was less as compared to atraumatic treatment restorations after 18 months.²⁷

It can be concluded that if pits and fissures on permanent teeth have progressed to dentinal caries, SDF, fluoride varnish, and sealants demonstrate a comparable outcome after 2 years. Caries preventive activity of SDF on permanent teeth in adults requires more investigations in the form of clinical trials.

Caries Arrest and Prevention in the Elderly

In 2017, Hendre et al. in their systematic review on the use of SDF in adults included three studies on prevention and arrest of root caries. They concluded that in a study of 24 and 36 months, the preventive fraction obtained for SDF was 24 and 71%, respectively. In the third study which was conducted for a span of 30 months, SDF had a 100% greater fraction for prevention than placebo for the progression of caries. Therefore, the use of SDF is recommended for elderly who are at a greater risk for root caries and for management of dentin sensitivity.¹⁶

Toxicity and Side Effects

The clinical trials reported till now suggest that over 4,000 children have been treated without any major adverse events.²⁴ There were no cases of acute toxicity. Toxicology studies have only been done on adults using the equivalent of 1/5 of a drop. Drops are 30% larger than originally reported. A drop of SDF measuring 32.5 µL contains 1.64 to 1.76 mg of fluoride and 8.08 to 8.71 mg of silver.

Previous literature does not report any acute adverse effects after SDF application in either children or adults. Metallic taste and transient irritation of the gingiva are the minor side effects that have been reported in few participants. Only one study published on adults aimed at studying gingival erythema following SDF application 24 hours and a week after concluded that in a span of 24 hours there were a few participants who developed mild erythema of gingiva which healed itself within a week.²⁸ A recent clinical trial was done on young children suggested that 1 week after application, the prevalence of toothache and gingival pain was 6.6%, gum swelling was 2.8%, and gum bleaching was 4.7% as reported by the parents.¹⁶

The main disadvantage following SDF application is the darkening of the carious tooth, which becomes difficult for parental acceptance. A study conducted in Hongkong compared parental satisfaction regarding their child's tooth appearance through a self-rated questionnaire after 30 months of 12 and 38% SDF which was applied semi-annually and annually for both formulations. It was concluded that the concentration and frequency of application did not significantly affect parental satisfaction. The overall parental satisfaction ranged from 71 to 62%.²⁹ A comparative survey in the United States reported that parents were more acceptable of staining on posterior teeth as compared to anterior teeth. Despite the unappealing anterior staining, there were parents who would significantly choose SDF for management of caries in their child over dental rehabilitation under general anesthesia. Most studies strongly recommend an informed consent so that the parents are well informed about the benefits and shortcomings of this treatment modality.¹⁶

Potassium iodide application to control or reverse the staining after SDF is painted on the tooth has been studied by many investigators. Some commercial products have combined both components; SDF and KI (Riva Star, SDI, Baywater, Victoria, Australia). However, it has been reported that in adults, potassium iodide application was ineffective in reversing the staining on root surfaces, more so in the long term.³⁰

The undesirable effects of SDF are not only outweighed by its desirable properties in most cases but a significant number of parents are willing to compromise esthetics to avoid more invasive/risky scenarios for the delivery of treatment. Moreover, no toxicity or adverse events associated with its use have been reported till date.

CLINICAL APPLICATIONS

Clinicians may make a decision regarding the frequency of SDF application based on patient needs, fluoride exposure, individual caries risk factors and consider individual social determinants of health and this judgment should apply to both young and adult patients.

Before application of SDF, lip balm or petroleum jelly is applied on the lips then tooth isolation is achieved using cotton rolls. The cavitated lesion is cleaned and air-dried after which SDF is applied over the affected area for durations ranging from 10 to 3 minutes and allowed to dry. Post application rinsing is not mandatory.¹⁶

The World Health Organization's report on "Public Health Interventions against Early Childhood Caries" in 2016, recommended that SDF is efficient in arresting dentinal caries in deciduous teeth and preventing recurrence following treatment.¹² "It recommends its use as an alternative procedure for tertiary prevention to reduce the negative impact of established disease (cavity) by restoring function and reducing disease-related complications and to improve the quality of life for children with early childhood caries".

CONCLUSION

Silver diamine fluoride is really the magic alternative for pediatric caries management. It supports the conservative and contemporary "biological approach" requiring no caries removal with caries lesion arrest rates being >70%. It is child friendly as it requires no anesthesia and no drills, thereby reducing the chair side time.

CLINICAL SIGNIFICANCE

In such times of the COVID-19 pandemic, interruption of aerosol-generating procedures is a step that is unavoidable for the safety of dental health professionals and the patients. Even though the presence of asymptomatic dental caries is not an emergent procedure, leaving it untreated will cause the tooth to continue to undergo destruction, resulting in pulpal involvement which may in turn require treatment involving aerosol-generating procedures. Therefore, SDF can be used to break this vicious cycle and help as an interim treatment procedure to arrest dentin caries. However, it must strictly not be used where it is not indicated.

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