

Silver Diamine Fluoride - The New Normal in Pediatric Oral Care : A Review

Abstract:

Introduction: Dental caries is the most commonly observed oral lesion and can affect function and esthetics of teeth in children, cause pain and severe lesions, malnutrition, psychological effects, if left untreated ultimately affecting their oral-health related quality of life. There are various treatment and preventive approaches but certain factors make it difficult to achieve the required outcome like behavior issues, socio-economic status, etc. Minimal intervention or invasive dentistry is gaining popularity, especially during and post-COVID era; it becomes the need of the hour. Silver Diamine Fluoride is one such caries management strategy that has started becoming popular for its various beneficial properties against caries both in normal and children with special health care needs, cost-effectiveness, easy application, and no intervention methodology.

This article aims to bring forward detailed information about Silver Diamine Fluoride which is a promising caries management technique during and post-COVID era.

Key words: Silver Diamine Fluoride, COVID-19 Dental Practice, Minimal Invasive Dentistry, SMART Technique, Dental Caries, Arresting Caries

Body of The Manuscript:

1. Introduction:

Dental caries, according to Shafer in 1993, is defined as an irreversible microbial disease of the calcified tissues of the teeth, characterized by demineralization of the inorganic portion and destruction of the organic substance of the tooth, which often leads to cavitation. It is one of the major health problems witnessed in a large population and the most widespread communicable disease. The mean prevalence of dental caries was observed to be similar at 5 years and 12 years at 49% and there is an increase from 15 years (60%) to 35-44 years (78%) and peaks at 65-74 year group (84%) [1]. Enamel caries involves the dissolution of highly mineralized tissue due to acid attack from the bacteria and dentinal caries involve both mineral demineralization and degradation of the organic matrix of type I collagen fibre network. [2]

It can affect a part of the population in a very aggressive manner and early stages with fast progression. Overall, it may affect the oral health-related quality of life and ultimately, the

general well being of the child. It has been reported that children developing caries in the primary dentition (ECC) are at three times more risk of developing caries in permanent dentition (Alm A et al, 2007).

The conventional methods to treat caries involve mechanical cavity preparation followed by restorations. This type of management is technique sensitive, comparatively expensive and the major requirement is the cooperation of the patient, especially in children. The behavioral issues in children make this process complicated which leads to inadequate

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management of caries and thus, the disease progresses and early loss of teeth may occur. [3] Advanced forms of behavior management may be incorporated like Nitrous oxide, moderate sedation, and general anesthesia but it is not practically possible in all patients in India mainly due to a combination of populations with different socio-economic backgrounds. [4]

Modern dentistry is undergoing a paradigm shift from surgical management of caries to medical management, mainly aiming at preserving the sound tooth structure using non-invasive methods, especially the no-drill technique. Hence, Minimal Intervention Dentistry is moving to the center stage of oral health care. [5] Arresting caries using MID is also beneficial in the management of caries at a community level. In this COVID era, it is important and safer to practice MID to prevent and minimize the viral infection along with providing better caries management.

Silver Diamine Fluoride (SDF) is a no drill technique and the focus is on arresting caries and prevention of new lesion. Studies have shown that it is almost twice as effective as fluoride varnish. [6] It has shown a remarkable success rate in the last 4 decades in both clinical and in-vitro studies.

What is SDF?

Silver Diamine Fluoride is a colorless alkaline topical fluoride solution and the commonly used concentration is 38%. It has been known with several other names since 1969, namely ammoniated silver fluoride, silver diammine fluoride, ammoniacal silver fluoride, diamine silver fluoride, silver fluoride diamine, diammine silver fluoride. It has two ammine groups (NH₃) and not two amine groups (NH₂). Hence, the correct name would be Silver Diammine Fluoride. [7]

It is alkaline with a pH between 8 and 10 and can be kept at a constant concentration and do not require any reducing agent. The first use of Silver Diamine Fluoride in dentistry was with a concentration of 38%. It is also available at a lower concentration of 12 but is less effective than 38% in arresting dental caries in children. [8-9]

Evolution of SDF

The medicinal use of silver is known since 1000BC as water stored in silver vessels portrayed antimicrobial properties of silver compounds when exposed to light or filtration. [10] In 1891, Stebbins postulated caries arrest and the reduction was due to antibacterial action and black rust formation of silver nitrate leading to the formation of a sclerotic protective layer. AgF solution was introduced in Western Australia as a part of the school dental programme in the 1970s (Craig et al). Silver Diamine Fluoride was studied by Nishino in 1969 as a Ph.D. thesis at Osaka University, Japan and this showed high antimicrobial properties and increased fluoride content along with reduced hypersensitivity and occlusion of dentinal tubules by the formation of a precipitate. [11] Later, the Central Pharmaceutical Council of the Ministry of Health and Welfare of Japan approved Diammine Silver Fluoride as a cariostatic agent and was commercially available as Saforide. [12]

Composition

SDF consists of ammonia, silver, and fluoride and the fluoride content can vary from brand to brand (Table 1). The commonly used concentration is 38% (44,800 ppm) fluoride ion. At pH 10, 38% SDF has 25% silver, 8% ammonia, 5% fluoride, and 62% water. Silver acts as a broad-spectrum antimicrobial. Its ions work as silver bullets and produce a zombie effect. Fluoride promotes the remineralization of the carious lesion. Ammonia helps to keep the solution at a constant concentration for a certain period. [13-14]

Table 1 shows various commercially available brands for SDF: [3,15-16]

SDF (%)	BRAND	MANUFACTURER	COUNTRY	INGREDIENTS	PACKAGE
38	e-SDF	Kids-e-dental, Mumbai	India	SDF	5-mL dropper bottle
38	Advantage Arrest	Elevate Oral Care	United States	SDF	8-mL dropper bottle
10	Cariostatic	Inodon Laboratorio	Brazil	SDF	5-mL dropper bottle
12 and 30	Cariestop	Biodinamica	Brazil	Fluoridic acid, silver nitrate, ammonia	5-mL or 10-mL dropper bottle
30	Bioride	Dentsply	Brazil	SDF	5-mL dropper bottle
38	Fluoroplat	NAF laboratorio	Argentina	SDF	5-mL dropper bottle
38	Saforide	Toyo Seiyaku Kasei	Japan	SDF	5-mL dropper bottle
38	EAgamin	Tedesquim SRL	Argentina	SDF	5-mL dropper bottle
30-35	Riva Star	SDI Dental Ltd	Australia	Unit 1: silver, fluoride, ammonia; unit 2: potassium, iodine, methacrylates	Unit 1: 0.05 mL; unit 2: 0.10 mL

Advantages:

Various systematic reviews have validated the effectiveness of SDF in arresting and preventing caries in the primary dentition. Also, it meets the US. Institute of Medicine's six quality aims (Crystal and Niederman). Clinical trials have shown it to be safe with no major adverse effects. Control of pain and infection, ease and simplicity of use, affordability, the minimal requirement of personnel time and training, and non-invasiveness add to the benefits of SDF, especially in children. [17] It is patient-centered and can be used in various health and community settings.

SDF and COVID-19:

As mentioned earlier, in this COVID era, SDF can play the role of better alternative due to its advantages, and also, a very minimal treatment time, approximately 1-3 minutes is required, with no-drill technique, SDF can be considered as a magic alternative in caries management.

Mechanism of Action:

The effectiveness of SDF occurs by the combination of silver nitrate and fluoride. Three mechanisms can explain the arresting or preventing dental caries which are as follows:

1. Antibacterial action on cariogenic bacteria.
2. Promotes remineralization and inhibition of demineralization of enamel and dentin.
3. Collagenase inhibition leading to a reduction of the dentine collagen matrix.

A squamous layer, partially plugging the dentinal tubules is formed on topical application of SDF on exposed dentin. Silver in SDF reacts with sulfhydryl groups of proteins and deoxyribonucleic acid (DNA), and alters hydrogen bonding and inhibiting respiratory processes, the unwinding of DNA, synthesis of the cell wall, and cell division. It can help in inhibiting biofilm formation which can be appreciated in the first 7 days after application. [18] An inhibitory effect on matrix metalloproteinase has also been noted and the degradation of organic collagen matrix is reduced. [19-20]

Silver diamine fluoride has shown inhibition properties towards cariogenic strains of *S. mutans* at a concentration of 0.12 micromole/ml or more along with inhibition of dextran-induced agglutination of *S. mutans* at 0.59 micromole/ml. These anti-*S. mutans* effect is mainly due to the silver ions contained in SDF. [21] Also, it is effective against *Actinomyces naeslundii* on dentin surfaces. This justifies the antibacterial effect of SDF.

The silver ions can penetrate the lesions and remain there to show their effects (25–30 microns into the enamel, 200–300 microns into the dentin, and up to 2 mm into a deep carious lesion). The penetration of the F⁻ ion of Silver Diamine Fluoride goes to a depth of 50–100 μ when it is applied on dentin under in vivo conditions (Shimooka). It releases calcium fluoride and silver phosphate by reacting with mineral hydroxyapatite, which thus helping in the prevention and hardening of dental caries. The Ag₃ PO₄ precipitates on the tooth surface are insoluble and the CaF₂ functions as a reservoir of fluoride to aid in the formation of fluorapatite. Fluorapatite thus formed are more resistant to dissolution due to acids produced by the bacteria in the oral environment than hydroxyapatite. [22]

The mineral content of dentin is directly related to its microhardness. Hence, the assessment of changes in microhardness can help in determining the changes in the mineral content of the dentin. Studies have shown an increase in microhardness of dentin after treatment with SDF. [23] This can be attributed to the fact that there is a formation of less soluble or virtually insoluble calcium fluoride, silver phosphate, and silver protein that get precipitated on dentin surface and thus, loss of calcium and phosphorous from the carious lesion is reduced, also aiding in remineralization.

The presence of these silver compounds like silver oxide and silver phosphate contributes to the black staining of the carious lesions after application. Potassium Iodide and Glutathione Bio-Molecule have been reported to minimize the discoloration caused due to SDF (V Nguyen et al, 2017 and M Sayed et al 2018, respectively).

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3.1 Arresting Caries

Caries arresting property of SDF can be increased significantly if it is reapplied from 1-year post-treatment. The

one-time application in arresting dental caries has shown effectiveness ranging from 47% to 90%, depending on the size of the lesion, location of the tooth, and lesion. Anterior teeth have shown an increased rate of caries arrest when compared to posterior teeth. The caries arresting property of SDF decreases over time and 50% of arrested surfaces may become active in 6-24 months after a single application of 38% SDF. An in vitro study done by Gupta et al showed the highest zone of bacterial inhibition with SDF. Sinha et al. have put forward the remineralizing, rehardening, and antimicrobial properties of SDF via an in vivo study.

SDF Arresting Caries in Primary Dentition:

The SDF panel of the American Academy of Pediatric Dentistry (AAPD) recommends the usage of 38% SDF to arrest the cavitated caries lesions of primary teeth with low-quality evidence. A systematic review revealed that SDF is 89% more effective than any other alternative treatment or placebo in arresting dental caries in the primary dentition (Chibinski et al.). Children with a visible plaque or large lesions have shown lesser possibilities of caries arrest [24-25]. According to Fung et al., increasing the frequency from annual to semiannual in children with poor oral hygiene will improve the rates of caries arrest.

A systematic review showed that 38% SDF concentration had a higher chance than 12% SDF in arresting dentin caries in primary teeth (Tolba et al.).

3.2 Caries Prevention

The application of SDF only to carious lesions have shown excellent prevention in other tooth surfaces. Fluoride-releasing glass ionomer cement (GIC) can depict this effect but the effect is limited for a short time and to the surfaces adjacent to the treated surfaces. Direct application to the healthy surfaces of the tooth can also help in preventing caries in children.[26-27] Also, the SDF application done annually prevents caries more than four times the application of fluoride varnish in a year in both children and adults.[28]

In permanent first molars, Monse et al. demonstrated that one-time application of 38% SDF on the occlusal surfaces of permanent first molars of 6- to 8-year-old children did not

prove to be an effective method of prevention of the onset of new dentinal caries lesions in children but studies done by Llodra et al. and Liu et al. have shown confirmatory results regarding the prevention of new carious lesions in first permanent molars with the help of SDF.

Llodra et al. also quoted that SDF showed better efficacy in arresting decay in primary dentition than permanent first molars.[29]

3.3 SDF and ECC

As mentioned above, ECC is the most prevalent oral disease in children, and difficulty in behavior management for conventional caries management procedures can hamper the child from getting proper dental care. Anterior teeth are the most commonly affected which can affect the esthetics. Also, the function of teeth and jaw growth and overall well being and quality of life of children like malnutrition, reduced confidence, etc are also affected. Hence, SDF acts as a magic tool to prevent and arrest caries in young children especially.

3.4 Sensitive teeth and SDF as Desensitizing agent.

SDF can be used in hypersensitive dentin as it occludes dentinal tubules by the formation of a squamous layer. Hence its usage in lesions like erosion or abrasion where mechanical and thermal sensation increase dentinal hypersensitivity is justified.

3.5 SDF and Root Canal Treatment

SDF has shown potent antimicrobial effect when used as an irrigant solution in a concentration of 3.8% for root canal treatment [30] and the blackening of dentin by silver component is not a major issue. It can effectively decrease the microbial load within a root canal by its inhibitory effects on bacterial cell wall synthesis, DNA unwinding, and cell division. Mathew et al. has reported the effectiveness of SDF in decreasing the bacterial load from the canal wall and circum-pulpal dentin.

It is recommended to apply 1:10 dilution of the 38% SDF solution three times at 24-hour intervals. (Hiraishi N, Yiu CK, King NM, et al 2010.) According to a few studies, both

sodium hypochlorite and proved to be effective against *Enterococcus faecalis* biofilms and thus, can be a potential antimicrobial root canal irrigant. [31]

3.6 SDF and Indirect Pulp Capping

Studies have reported that SDF does not cause inflammation or pulp necrosis with adequate induction of tertiary dentin formation and hence, can be a potential indirect pulp therapy agent for deep cavities. [32]

4. Indications:

SDF can be indicated in the following cases: [5]

1. High caries risk individuals with active cavitated lesions on any surface of the anterior or posterior primary teeth and permanent first molars.
2. Individuals having behavioral or medical management problems (children with special healthcare needs) with cavitated dental caries lesions, in whom local or general anesthesia is not preferable or delayed like in cases of pre-cooperative children.
3. Individuals with several cavitated dental caries lesions requiring multiple dental visits.
4. Cavitated dental caries lesions difficult to manage.
5. Individuals or communities who lack access to dental care.
6. Active cavitated dental caries without pulp involvement
7. As part of the silver modified atraumatic restorative technique (SMART)
8. Dentinal hypersensitivity
9. Molar incisor hypomineralization (MIH)
10. Recurrent caries (secondary caries) at the restoration margins
11. Incipient interproximal lesions
12. Disinfecting the root canal system
13. Indirect pulp treatment (IPT)
14. Arresting caries in teeth nearing exfoliation to maintain them.
15. As a substitute to sealants in children who cannot cooperate with the sealant procedure.
16. Financial constraints

9. Contraindications: [33]

Though there are no serious adverse effects reported, the following are the contraindications:

1. Known silver allergy
2. Presence of oral soft tissue ulcerations or stomatitis, especially if the ulcer can come in contact during application of SDF
3. Active cavitated caries with pulp involvement.
4. Refusal of consent by parents/guardians due to concerns with the color change.

10. Clinical Technique: [33, AAPD-2017]

10.1 Patient and Practitioner preparation:

- a. Once the clinical assessment is done, explain the procedure to the parents and guardians along with the discoloration that will occur post-application of SDF.
- b. Obtain signatures on informed consent (Illustration)
 - a. Emphasizing on this pandemic situation, the initial appointment can be done using teledentistry and the procedure can be explained during the face-to-face video call or informative videos, and pamphlets can be sent to the patient via electronic methods. Informed consent can also be obtained through electronic methods.
 - d. Basic universal precautions should be taken and plastic-lined bib and glasses can be provided to the patient.
 - d. A protective layer of petroleum jelly can be applied over the lips and mucosa and adjacent soft tissues to prevent transitory henna-appearing tattoo due to contact with SDF.
 - e. Isolate the teeth with cotton rolls or alternative methods.
 - f. Usage of plastic dampen dish as SDF has the ability to corrode glass and metal.
 - f. Be careful with non-cavitated (white spot) lesions in permanent anterior teeth as this may cause unwanted staining if it comes in contact with SDF while applying the primary teeth.
 - g. Dispose of the used gloves, cotton rolls, and the micro brush carefully into a plastic bag.

10.1 Application of SDF:

- a. Remove the plaque and other gross debris from the cavitated lesion to increase the contact of SDF with affected dentin. Although soft caries removal is not necessary but may be considered to improve the esthetics as this minimizes tooth discoloration.
- b. Dry the lesion with a gentle flow of compressed air. Even cotton rolls or gauze can be used.
- c. Dispose a drop of SDF in a dappen dish (one drop is enough to treat 5-6 teeth in a single appointment). Bend and dip the micro brush in the solution and remove the excess by dabbing on the side of dappen dish.
- d. Apply SDF only on the affected areas.
- e. Dry with a gentle flow of compressed air at least for 1 minute.
- f. Use cotton or gauze to remove the excess SDF and isolate the area for 3 minutes, when possible.

10.2 Application Time:

Clinical studies have reported time for 10 seconds to 3 minutes, ideally should be 1 minute with a gentle flow of compressed air until the solution is dry. A current review has reported that there is no effect of the time period on the outcome of SDF. [34] In case of shorter application time, it is recommended to evaluate and reapply during recall visits.

Biannual or three times a year application have shown better results.

10.3 Post-operative Instructions:

No postoperative limitations are explained by the manufacturer. Eating and drinking immediately post-application is acceptable. The use of fluoridated toothpaste is advisable. Though, several SDF clinical trials recommended no eating or drinking for 30 minutes – one hour. [8,35]

10.4 Follow-up:

Follow up can be done 2-4 weeks after the initial treatment to check the status of the arrest of the lesions treated. Reapplication and additional SDF application at recall appointments can be considered. SMART technique can be

used to restore the carious lesion during recall visits to improve the esthetics using composite or GIC. If not restored, it is advisable to reapply at least biannually to improve the results. [36]

11. What is SMART Technique?

It is Silver Modified Atraumatic Restorative Technique Protocol using SDF alongside atraumatic restorative treatment (ART) [37]. It combines 3 proven clinical techniques as follows:

1. Caries arrest with SDF
2. Partial caries removal
3. Placement of GIC restoration

The clinical procedure for the same is as follows:

1. Preparation of cavosurface margins without removing axial decay.
2. Removal of biofilm and pellicle using pumice in the surrounding area to be treated.
3. Application of polyacrylic acid to cavosurface margins or clean surfaces of teeth for 10 seconds
4. Rinsing off polyacrylic acid for 10 seconds, and then blow-drying.
5. GIC can be dispensed for 10 seconds and applied over pits and fissures and preparation.
6. GIC should not be touched or moved after 30 seconds from the start of the mix.
7. Allow setting for 2 minutes from the start of the mix before finishing and polishing after placement of GIC.

12. What Is SMITR Technique?

Silver Modified Interim Therapeutic Restoration is a procedure in which 38% SDF is applied after partial removal of carious tissue using hand instruments. Then, an intermediate material like a dentin substitute, MTA or GIC is placed immediately to restore or seal the cavity. A Finally, a stainless steel crown is placed on the treated tooth after a reasonable time which serves as an interim or final restoration. The main purpose of this technique is to camouflage the discoloration caused by SDF and enhance the

esthetics. Also, dentin substitutes have shown excellent biocompatibility in sealing caries treated with SDF. [38]

13. Adverse Reaction, Disadvantages and Safety Margins

1. There are no reported deaths or systemic adverse effects associated with topical SDF in published clinical trials using topical silver diamine fluoride [45].
2. The maximum recommended limit is one drop per 10 kg of body weight per treatment visit at weekly intervals [46]
3. Pulpal damage is unlikely with the application of SDF but application on exposed pulp should be avoided. Lesion close to pulp requires periodic monitoring after the application of SDF.
4. Esthetics:

The tooth discoloration is another major concern and hence, parents should be informed prior and informed consent should be taken from them.

Potassium Iodide and Glutathione Bio-Molecule have been reported to minimize the discoloration caused due to SDF (V Nguyen et al, 2017 and M Sayed et al 2018, respectively).

5. Various other adverse effects have been explained in literature as follows: (AAPD, 2017)
 - a. Metallic or bitter taste.
 - b. Temporary staining or tattoo on the skin which resolves in 2-14 days.
 - c. Mucosal irritation/lesions resulting from contact with SDF which resolves within 48 hours.

6. Other Clinical Considerations:

It has to be kept in mind that SDF will not treat or eradicate dental caries. It only breaks or arrests the carious process on the treated surfaces, along with assisting in remineralization, if the oral environment is conducive.

SDF will not restore tooth structure and function to normal. Hence, to improve the function or occlusion and other clinical outcomes, it is important to restore the tooth surfaces in later stages.

14. Conclusion:

SDF has been there for more than 40 years but recently it has started to gain popularity due to its various advantages mentioned in this article. It definitely justifies to be a magic alternative in caries management in various clinical scenarios including children with special health care needs, where conventional techniques are difficult to be performed. It has greater potential to be used in both individual and community levels. Various authors have also justified the efficacy of SDF with no serious complications.

Also, keeping in mind the COVID-19 pandemic situation, the best alternative in managing caries seems to be SDF, especially in 38% concentration. Hence, SDF can be a game-changer and a magic bullet in the COVID and post-COVID era in minimally invasive dentistry and caries management.

But again, the regular oral hygiene practices have to be practiced by the children and adults along with better dietary intake, as SDF is just an adjunct in the management of caries.

Black discoloration of the tooth is a hallmark of SDF which is a major concern issue among parents and children which should be explained before-hand to the parent or guardian and elderly patient and various studies can be planned in this field to minimize the discoloration.

Various studies should be done in Indian children to determine the efficacy of SDF in long run, combinations of SDF with various restorative materials, adverse effects, effects on permanent dentition, root caries, and factors affecting SDF success.

Informed Consent for Silver Diamine Fluoride

Date:	Name of the Clinic:
<ul style="list-style-type: none">• Silver Diamine Fluoride is an antibacterial liquid used to arrest caries and may require repeated application.• Procedure: Dry the tooth - Apply SDF on the caries lesion – Dry the Solution and Tooth• I am not a suitable candidate for SDF because of: 1. Silver allergy 2. Mouth ulcer or stomatitis	

3. Any other Concern-----

- SDF can only arrest the caries and prevent the progression. It will not improve the esthetic or function of the teeth and further restorations may include extra charges.
- The treated area will turn black permanently. Healthy tooth structure will be spared from staining. Stained cavitated lesions can be managed with tooth colored restorations later.



Before SDF Application After SDF Application

- Accidental application to adjacent soft tissues like skin, lips, mucosa, etc may lead to staining but is temporary and will disappear in one to three weeks.
- Metallic taste may be experienced which will go away.
- Though SDF is known to arrest caries, the outcome is not guaranteed. In case of progression of caries, further intervention may be required like reapplication, restorations, pulpal lesions management or crowns.
- Patient has to maintain healthy diet and proper oral hygiene measures along with usage of fluoridated toothpaste.

I, (Parent or guardian)-----, have read the instructions and details carefully and give my consent to treat my child (name)-----, aged----- with SDF. I have also discussed all my concerns with the dentist and have willfully signed this consent form.

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