# Role of Silver Diamine Fluoride in Dentistry

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## Abstract

Dental caries is the most prevalent disease in primary, mixed, and permanent dentition. Many preventive and treatment strategies were used in the last decades. Silver diamine fluoride (SDF) is a promising nontoxic material which proves to be a turning point concerning conservative dentistry if the patient and dental practitioners are adequately educated regarding it. Several advantages have been reported related to the use of SDF, including the procedure being pain-free and drill-free, patient- and doctor-friendly caries control strategy, and management of dentinal hypersensitivity.

**Keywords**
- dental caries
- silver
- fluoride
- staining
- arresting caries

## Introduction

One of the primary reasons for the replacement or failure of the direct restoration in both primary and permanent dentition is secondary caries.[1] Secondary caries is defined as carious lesion occurring in dental tissue at the interface between the restoration and the tooth.[2] This problem can be attributed to high caries risk of the patient,[3] the type restorative material used,[3-5] and adhesive interface degradation in composite restoration.[6] Strategies based on antimicrobial materials have been proposed for prevention of secondary caries, which includes antibacterial restorative materials,[7] fluoride-releasing materials,[7-9] chlorhexidine- and silver-releasing materials,[10-12] silver diamine fluoride (SDF),[13,14] fluoride rinses, and chlorohexidine and fluoride protective varnish.[15-18] The fluoride varnish has a disadvantage of reducing the bond strength of composite to dentine.[19]

Silver diamine fluoride ($AgF(NH_3)_2$) is a promising material having useful applications in clinical dentistry. It is a colorless, alkaline (pH ~10) agent which has been used for 50 years in dentistry.[20-23] It is usually available in a 8-mL bottle containing 38% SDF. One bottle of SDF can be used for the treatment of 125 sites. It has fluoride for remineralization, and silver as an antibacterial agent. This combination makes SDF a better prospect for prevention and control of caries compared with fluoride therapy like sodium fluoride varnish.[24] Ammonia is another element of SDF, which is responsible for keeping the constant solution level for a more extended period.[25] SDF is considered as a safe and effective material, which, along with the potential to prevent dental caries, has a role in the inhibition of oral biofilm formation and treatment of hypersensitivity.[25,26] SDF is a proven, cost-effective treatment modality.[24] Animal studies related to SDF showed that histologically, there is no alteration of pulpal tissue in SDF-treated tooth, showing that SDF possesses minimal adverse effects.[27] The primary role of SDF is to prevent or treat caries conservatively.

In the 1960s, Japan approved the use of SDF as a therapeutic agent to arrest dental caries in children.[25] Since then, SDF started gaining popularity in many other countries like Argentina, Brazil, China, Portugal, and Australia due to the cost-effectiveness and simple application.[25] In 2014, Food and Drug Administration (FDA) cleared the first use of SDF to manage early childhood caries, prevent pits and fissure caries in erupting permanent molars, prevent root caries in the older people, sterilize infected root canals, and treat dentinal hypersensitivity (►**Fig. 1**). Being a painless modality, it is particularly indicated in noncooperative patients and children.

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**Fig. 1** Application of SDF in dentistry. SDF, silver diamine fluoride.

## Effect of SDF on Dental Caries

Dental caries is the most common chronic dental disease affecting 60 to 90% of school-going children. In a recent study, dental caries was found to be shockingly prevalent, affecting 80% of the population of the Kingdom of Saudi Arabia. It is responsible for the loss of 50% of the missing teeth. In light of this problem, a global goal for 2020 was set up by World Health Organization (WHO) and Federation Dentaire Internationale (FDI) to guide the policymakers to help reduce the prevalence of caries and improve the oral health status of their population. Dental caries is a process of destructive chemical dissolution of dental hard tissues. This process is caused by the metabolism of dietary sugars and carbohydrates by the virulent bacteria, resulting in acid production and a decrease in pH of the biofilm covering the tooth surface. This acid results in loss of minerals from the surface of the tooth, resulting in the initiation of the carious lesion. Dental caries causes demineralization of enamel and dentine as well as degradation of type-I collagen of dentin. Dental caries, once developed, has adverse physical and psychological consequences such as pulp necrosis, cellulitis, distance infection, limitation of smiling and eating, and lower self-esteem and confidence.

Dental caries management in the last decade was focused on two main approaches—prevention, to limit the progress of caries at an early stage, and treatment, which includes drill and fills. The minimal invasive philosophy in caries management includes conservative management of caries with as little loss of dental hard tissue as possible.[28] Strategy based on SDF has emerged as a technique which follows this philosophy. It can be used to arrest and prevent dental caries. The application of SDF on cavitated lesions increases the microhardness of dentin in a depth of 150 µm. This results in enhancement of the surface against the microorganisms.[29,30]

Moreover, treating demineralized enamel with SDF showed a lower overall mineral loss.[31] Interestingly, it was demonstrated that when the enamel and dentin powder were mixed with SDF, there was a significant increase in the production of calcium fluoride and silver phosphate.[32] Therefore, application of SDF on carious lesion results in the formation of a highly remineralized layer rich in calcium and phosphate content. Besides, inhibition of collagen type-I degradation was also observed.[33-35] The matrix metalloproteinases (MMPs) and cysteine cathepsins possess an essential role in enzymatic degradation of collagen. The fluoride in SDF is proposed to have a potent inhibitory effect on the proteolytic enzymes, MMP-2, MMP-8, and MMP-9.[34] A study performed by Hannah et al revealed that when MMP-9 was incubated with 150 ppm of fluoride, a reduction of 79% was observed within a few minutes.[36] The inhibitory effect of fluoride on MMP was shown to be due to the electronegativity of fluoride ions.[37] SDF, when applied over a carious lesion, confirmed a significant colony-forming unit (CFU) reduction of *Streptococcus mutans*, *Lactobacillus acidophilus*, and *Candida albicans*.[38] One study showed that SDF was able to reduce the number of *S. mutans* and *Lactobacillus* to a significantly low number within a week.[39] Another study reported that the growth of cariogenic bacteria like *S. Mutans*, *S. sobrinus*, *L. acidophilus*, *L. rhamnosus*, *A. naeslundii*, and *Staphylococcus aureus* significantly decreased after the application of 20 ppm of silver nitrate solution.[25,26]

Today, the standards for the WHO goal appear to be achievable by using SDF as a caries preventive agent and a product to manage early childhood caries.[25,40] American Academy of Pediatric Dentistry (AAPD) recently concluded that 38% of SDF is currently the best evidence-based material to arrest caries for children, adults, and patients with special needs.[41]

### Mechanism of Action of Anticaries Activity

The ability of silver to prevent caries is due to its positively charged ions which adhere to the bacterial cell wall and prevent bacterial aggregation.[42] SDF has been hypothesized to exert its antibacterial action in several possible ways. First, the silver ions in SDF can interact with life-sustaining, crucial bacterial enzymes, and block the electron transport system.[43] SDF can also communicate with the thiol group of the enzymes and cause enzyme deactivation, resulting in bacterial cell death.[44] Second, the silver ions can bind electrostatically to anionic portions of the bacterial cell membrane or cell walls, resulting in inhibition of bacterial movement or cause membrane to leak or rupture.[45] The silver compound is responsible for bacterial cytoplasmic extrusion because of the high reactivity of silver ions with phosphorous components and sulfur-containing proteins in the bacterial cell wall.[26]

Another mechanism by which SDF exerts its antibacterial action is through the interaction of its silver ions with bacterial deoxyribonucleic acid (DNA). Unless the DNA is contained within the nucleus, such as in eukaryotic cells, the interaction between the silver ions and bacterial DNA can result in the mutation of the DNA and bacterial cell death.[44] Moreover, silver ions can prevent the bacterial aggregation process by electrostatically binding to phosphorus in DNA.[26] Lastly, the silver ion can bind to amino acids of the bacteria to form an organometallic complex.

## Effect of SDF on Dental Hypersensitivity

Dental hypersensitivity is characterized by varying severity of pain, initiated by the thermal, chemical, tactile, evaporative, or osmotic stimulus. The most widely accepted theory of its pain mechanism is that the mentioned stimuli can cause inward or outward fluid displacement in dentinal tubules, which activates intrapulpal nerve endings.[46,47] SDF has been shown to reduce the dentinal hypersensitivity in various studies.[48-50] It prevents or treats dentinal hypersensitivity by occluding the dentinal tubules. The occlusion is achieved due to precipitation of proteins in dentinal tubules by silver ions.[51] Moreover, fluoride ions in SDF can form calcium fluoride when these ions react with free calcium. The calcium fluoride can block the dentinal tubules.[52]

## Effect of SDF on Bond Strength of Restorative Materials

Correct adhesion of filling materials to dentin is always desirable. However, the bond degradation is shown to occur with the time, which might result in caries and replacement of the restoration.[13,53] The usage of fluoridated materials in restorative dentistry could potentially improve the longevity of the tooth-filling material and decrease the probability of secondary or "recurrent" caries. Thirty-eight percent of SDF can form a caries-resistant layer when applied to dentin. SDF has shown to increase dentin hardness because of the obturation of dentinal tubules with cariostatic silver ions. A cariostatic reaction between SDF and the adhesive restoration interface has been observed because of the local release of fluoride. The fluoride is responsible for remodeling of tooth minerals from hydroxyapatite to fluorapatite.

Furthermore, SDF prevents calcium and phosphate loss from dentin and inhibits MMP activity which ensures a durable adhesion between the filling and the dentin.[54] Additionally, SDF facilitates the reparative dentin formation and produces a bioactive link with adhesive restorations.[13] The major reactionary products resulting from the interaction of hydroxyapatite with SDF was found to be $CaF_2$ and $Ag_3PO_4$.[55] It has been shown that when dentin treated with SDF was refreshed, the bonding strength of composite restoration was found to be highest as compared with just rinsing for 15 seconds. It was also shown that two-step self-etch adhesive and the universal adhesive used after phosphoric acid etching performed better when compared with universal adhesive alone on SDF-treated dental tissue. Additionally, SDF has been shown to perform better with the use of self-etch technique.[56]

Moreover, it was found that SDF + potassium iodide (KI) had no adverse effect on the bond strength of GIC to dentine and did not interfere with fluoride uptake into the demineralized dental tissue.[57] SDF/KI combination has been shown to improve the microtensile and shear bonding strength of dentin with GIC significantly.[13] On the other hand, a study reported contradictory findings.[53] However, the literature is tilted toward the opinion that SDF application does not result in an adverse effect on bond strength of dentin to adhesive restorations.[56]

## Drawbacks of SDF

No adverse effect was reported with the use of SDF for 50 years in Japan.[22] One clinical trial which included over 4,000 young children worldwide did not report any mortality or systemic toxicity by using the recommended amount of SDF. One significant local adverse effect is related to aesthetics. Permanent black stains of active carious lesions are the main disadvantage of SDF application. These stains can be seen clearly, especially if the tooth treated is anterior.[58] For this reason, many patients refuse to be treated with SDF. A literature review regarding patients'/guardians' acceptance to permanent blackness of teeth after the treatment with SDF reported that 100% of parents were satisfied and accepted their children to be treated with SDF despite the aesthetic concerns.[58] Contrarily, another study reported that only 26.9% of parents admitted treating their children with SDF for anterior teeth.[58] To counter the undesirable staining effect, in 2005, a new approach was introduced. This approach suggested the application of saturated KI immediately after SDF placement. A recent study showed that at the time of SDF/KI protocol (►**Table 1**) being used, there was an insignificant color variation when used under GIC as compared with irrigation with deionized water. The KI did not adversely affect bond strength.[13]

Recently, a commercial SDF/KI agent (Riva Star; SDI, Bayswater, Australia), consisting of 30 to 35% SDF and a saturated solution of KI, was introduced for the treatment of hypersensitive dentine. Other local adverse effects include temporary stains of oral mucosa having "henna appearance" after its contact with oral mucosa. Since the dermis cannot absorb silver, the stains will disappear over ~14 days when keratocytes are shed. Permanent staining of the clothes or counters may also occur if the materials come in contact. Patients who are treated with SDF are advised not exceed

**Table 1** Recommended protocol for potassium iodide (KI) staining reversal

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| Dispense an appropriate amount of SDF into disposable medicine cup (1 drop can be applied to at least 5 teeth with moderate-size cavities). |
| Apply petroleum jelly or use a rubber dam to protect soft tissue near affected areas. |
| Dry affected tooth surfaces as much as possible with air syringe or with cotton pellets. |
| Use a microbrush saturated with SDF to paint directly onto the tooth surface. |
| Avoid cavity margins or soft tissues. |
| Allow to absorb for 1 minute, then remove excess with cotton pellets. |
| Dispense an appropriate amount of KI into a disposable medicine cup. |
| Use a microbrush saturated with KI to paint directly onto the tooth surface, like SDF application. Reaction products form immediately. |
| Restore areas with resin-modified glass ionomer or composite restoration as indicated. |

Source: Adapted from Garg et al.[55]
Abbreviation: SDF, silver diamine fluoride.

1.142 mg\L of drinking silver water. Moreover, SDF should not be used in patients allergic to silver.[41]

For stain reversal, the dosage of KI is comparable to 0.3 mL of saturated KI (1 g/mL) oral solution. When potassium iodide is applied, the reaction products are immediately formed and minute, safe amount of KI may reach the saliva. In the past, the synergistic effect of SDI and KI was investigated in the past for its impact on the permeability of demineralized dentin to *S. mutans*.[57] However, only recently, the property of potassium iodide to treat staining was investigated.[13,26,55,59] It is proposed that the discoloration inhibiting effect of potassium iodide does not adversely affect the caries inhibiting effect of SDF. The explanation suggested is there is a reaction of silver ions with iodide ions to form silver iodide. Also, the interaction of potassium iodide with carious dentin treated with SDF resulted in the formation of a white powder of tripotassium phosphate. This white powder is the major reason suggested for the black stain reversal. Another product formed is silver iodide. It is a photosensitive yellowish-white powder which can turn dark with exposure to light. The margins of restoration may still be at risk for discoloration. However, the overall staining is greatly reduced as compared with SDF alone.[55] SDF and KI combination inhibited caries, but its efficacy was lower as compared with SDF alone.[55] Therefore, the mixture should be used with careful case selection, such as anterior teeth. Another drawback is if the rubber dam isolation is not done or soft tissues are not protected with petroleum jelly, desquamative process such as ulcerative gingivitis may occur. However, these symptoms are temporary and subside within 48 hours. KI use should be restricted in pregnant and lactating women because KI may cause fetal harm, abnormal function of thyroid, and goiter.[55] Data related to the effect of SDF and potassium iodide on pulpal tissue is scarce and requires further investigation.

## Conclusion

SDF is a promising nontoxic material which can prove be a turning point concerning conservative dentistry if the patient and dental practitioners are adequately educated regarding it. Several advantages have been reported related to the use of silver diamine fluoride including the procedure being pain-free and drill-free, patient- and doctor-friendly caries control strategy, and management of dentinal hypersensitivity. However, the main drawback of SDF is the staining of carious dentin. Therefore, case selection is an essential aspect of this method. One strategy suggested to counter this drawback is the use of potassium iodide in combination with SDF. Although SDF material seems highly biocompatible material, further research is needed to evaluate the molecular and histological long-term effects of SDF on dental hard and soft tissues before it can be recommended to be used routinely.

**Conflict of Interest**
None declared.

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