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REVIEW ARTICLE

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Silver Diamine Fluoride – Review

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Abstract

Dental caries remains one of the most prevalent chronic diseases affecting children worldwide, particularly among high-risk populations. Silver diamine fluoride (SDF) has emerged as an effective, non-invasive, and cost-efficient therapeutic agent for the prevention and arrest of dental caries. SDF is an alkaline solution containing silver, fluoride, and ammonia, each contributing to its unique properties. Silver provides potent antimicrobial action by disrupting bacterial cell membranes, inhibiting metabolic processes, and reducing cariogenic biofilm formation. Fluoride promotes remineralization by forming fluorohydroxyapatite, while ammonia stabilises the solution and maintains its effectiveness. SDF has broad antimicrobial activity against cariogenic bacteria, periodontal pathogens, and fungal species, and also protects both inorganic and organic components of tooth structure. Its clinical application is simple, painless, and particularly beneficial in pediatric patients, individuals with special healthcare needs, and those with limited access to dental care. Despite disadvantages such as black staining of treated lesions and lack of restorative function, its advantages, including safety, affordability, ease of use, and effectiveness in caries arrest, make it an important tool in modern minimally invasive dentistry. This review highlights the composition, mechanism of action, clinical applications, advantages, and limitations, highlighting its significant role in caries management and prevention.

KEYWORDS

Silver Diamine Fluoride, Fluorohydroxyapatite, non-invasive

1 | INTRODUCTION

Despite being a mostly preventable disease, dental caries remains a severe oral health problem in children. Its impact on individuals and population related to pain, diminished function, and oral health-related quality of life is high, especially the disadvantaged individuals and communities.[2] In past 25 years, caries is affected by half of the Indian children and increase in caries burden is seen in children. The worse socioeconomic status are often associated with greater risk of severity of caries. Child cooperation to the treatment is another challenging aspect of caries to the dentist. So, in order to reduce the burden of caries and to avoid possible sequel associated with it, an alternative method which is cost-effective and effective in treating patients with high-risk to dental caries and with limited access to dental caries is required.[3] Silver diamine fluoride (SDF), a clear liquid that combines the antibacterial effects of silver and the remineralizing effects of fluoride, is a promising therapeutic agent for managing caries lesions in young children and those with special care needs that has only recently become available in the United States. Multiple in vitro studies document its effectiveness in reducing specific cariogenic bacteria and its remineralizing potential on enamel and dentin. Its in vivo mechanism(s) of action are a subject of ongoing research. What is currently understood is that the fluoride component strengthens the tooth structure under attack by the acid byproducts of bacterial metabolism, decreasing its solubility, but SDF may also interfere with the biofilm, killing bacteria that cause the local environmental imbalance that demineralizes dental tissues. Thus, SDF becomes one of the tools available to address caries by modifying the bacterial actions on the tissue while enhancing remineralization.[5]

2 | HISTORY

Silver compounds, especially silver nitrate, have been used in medicine to control infections for more than a century. In dentistry, reports of use of silver nitrate are well-documented for caries inhibition and, before the twentieth century, silver nitrate was firmly entrenched in the profession as a remedy for "hypersensitivity of dentin, erosion and pyorrhea, and as a sterilizing agent and caries inhibitor in deciduous as well as in permanent teeth." Howe's solution (ammoniacal silver nitrate, 1917), was reported to disinfect caries lesions and continued to be used for nearly one-half of a century as a sterilizing and disclosing agent for bacterial invasion of dentin to avoid direct pulp exposures, to detect incipient lesions, and to disclose leftover carious dentin.[5] The use of ammoniacal silver fluoride for the arrest of dental caries was pioneered by Drs Nishino and Yamaga in Japan, who developed it to combine the actions of F— and Ag+ and led to the approval of the first SDF product, Saforide (Bee Brand Medico Dental Co, Ltd, Osaka, Japan) in 1970. They described its effects for prevention and arrest of dental caries in children, prevention of secondary caries after restorations, and desensitization of hypersensitive dentin. They warned that because the agent stains the decalcified soft dentin black, its application should be confined to posterior teeth and gave specific instructions for its application.[5] Results from clinical trials conducted in many different countries on more than 3900 children have led investigators to develop recommendations for its use as a caries arrest medicament in children.[5] In 2017, the American Academy of Pediatric Dentistry published a Guideline for the "Use of Silver Diamine Fluoride for Dental Caries Management in Children and Adolescents, Including Those with Special Health Care Needs." In November 2016, the US Food and Drug Administration granted SDF a breakthrough therapy status, which facilitates clinical trials of SDF for caries arrest to be carried out in the United States. Studies are currently underway that may result in the change of its labelling in the near future.[5]

3 | COMPOSITION

Silver diamine fluoride (SDF) is a colorless liquid with an alkaline nature (pH = 8–10). The formation of diamine– silver ions is a chemically reversible yet functionally stable process under physiological conditions. The proportions of silver, fluoride, and ammonia in SDF solutions vary slightly between manufacturers. While most commercially available SDF products are formulated at 38%, lower concentrations (e.g., 10%, 12%, and 30%) are also available. The 38% SDF solution consists of 5% fluoride ions and 25% silver ions dissolved in an 8% ammonia solution. Research indicated that for the examined bottles of identical products, the average pH levels varied by 0.5% around pH = 10.0 and stayed consistent over a period of three months. The levels of silver and fluoride displayed variability, with silver concentrations between 257,000 and 285,000 ppm and fluoride ranging from 49,400 to 53,360 ppm among the different bottles. The ion concentrations measured in these investigations consistently exceeded the anticipated values in all solutions, with a range of 3.2% to 25.9% increase for silver and 3.5% to 21.4% increase for fluoride.[7]

4 | WORKING MECHANISM

Silver diamine fluoride (SDF) acts through a dual mechanism, antimicrobial action, and remineralization. This synergy enables SDF to arrest caries, prevent new lesions, and exert broad-spectrum antimicrobial and antifungal effects.

Silver ions (Ag^+): When Silver Diamine Fluoride (SDF) is applied to demineralized tooth surfaces, silver ions (Ag^+) undergo a sequence of chemical and biological interactions that contribute to both antimicrobial action and remineralization. One key reaction involves the reduction of silver ions, forming metallic silver (Ag^0), which is commonly observed as a black precipitate on the tooth surface. Chemically, Ag^+ reacts with hydroxyapatite to form metallic silver (Ag^0) and silver phosphate (Ag_3PO_4). Biologically, Silver ions (Ag^+) display potent antibacterial activity through multiple mechanisms that disrupt bacterial cell integrity and interfere with metabolic processes. Primarily, Ag^+ ions destabilize the bacterial cell envelope, leading to intracellular potassium ions (K^+) leakage and a subsequent drop in ATP levels, impairing essential cellular functions. Additionally, silver ions target key intracellular components such as proteins and nucleic acids, hindering DNA replication and protein synthesis. A further mechanism involves the generation of reactive oxygen species, which induce oxidative stress and further damage to cellular structures. A deeper insight into the specific interactions of Ag^+ and bacterial membranes shows that Ag^+ ions are known to interact directly with the inner membrane (IM) of cells, a process considered central to silver cytotoxicity. Ag^+ accumulation causes cytoplasmic membrane detachment from the cell wall in both Gram-positive and Gram-negative bacteria. Gram-positive strains required 32 times higher Ag^+ concentrations for bactericidal effects, likely due to differences in cell wall structure. Ag^+ disrupts bacterial inner membranes, particularly in Staphylococcus aureus, by binding to thiol groups in proteins and nucleic acids, impairing key metabolic functions. It also interferes with respiration, DNA replication, and cell wall synthesis and inhibits glucosyltransferases, reducing Streptococcus mutans biofilm formation in sucrose-rich environments. Additionally, the 'zombie effect' where silver-laden dead bacteria continue to exert antimicrobial effects prolongs silver's action against biofilms. Ammonia ($NH3$): Ammonia is a key component of silver diamine fluoride (SDF). It forms the diamine-silver complex [$Ag(NH_3)_2^+$], which stabilizes silver ions in solution. This stabilization increases silver compounds' solubility and contributes to SDF's alkaline pH (typically between 8 and 10). Fluoride ions (F−): Silver diamine fluoride ($Ag(NH_3)_2F$) reacts with calcium and phosphate ions in saliva to form fluoro hydroxyapatite, a highly stable, acid-resistant mineral that promotes enamel and dentin remineralization. This reaction is enhanced under alkaline conditions (pH 8–10), which favor fluorohydroxyapatite over other byproducts like silver phosphate and calcium fluoride that form in acidic environments. SDF also facilitates fluoride incorporation into apatite, enlarging crystal size in a concentration-dependent manner. Mechanism of action: Silver diamine fluoride (SDF) acts through a dual mechanism, antimicrobial action, and remineralization. This synergy enables SDF to arrest caries, prevent new lesions, and exert broad-spectrum antimicrobial and antifungal effects. Effect of SDF on oral microorganisms: Streptococcus mutans and cariogenic bacteria SDF exhibits potent antimicrobial properties, effectively inhibiting the growth of cariogenic bacteria such

TABLE 1 SDF Composition and Safety reference for a 10 kg child.

SDF Composition	UNIT DOSE 1 DROP	ion (mg/ml)	ion (mg/ml)	Safety reference
Fluoride (5%-6%)	0.5 mg/ml	2.24	5.65 - 11.3	Safer than 5% NaF varnish
Silver (24%-27%)	2.5 mg/ml	4.74mg	520mg/kg	Safety margin = 400 – fold lethal dose (Oral)
SDF Other Composition	Ammonia (7.5%-11.0%)		Deionized water (62.5%)	

as Streptococcus mutans and Actinomyces. It disrupts bacterial cell membranes and impairs metabolism by interacting with cell wall components and intracytoplasmic enzymes through silver ions. Additionally, SDF suppresses DNA replication by binding silver ions to phosphorus-containing DNA molecules. Studies have shown that SDF reduces the adherence of S. mutans to tooth surfaces and significantly decreases the count of colony-forming units (CFUs) in multi-species biofilms. Compared with silver ammonium nitrate or sodium fluoride, SDF is more effective at inhibiting the growth of cariogenic bacteria. Periodontal pathogens: SDF has also demonstrated significant antibacterial activity against major periodontal pathogens, including Aggregatibacter actinomycetemcomitans and Porphyromonas gingivalis. Its bactericidal efficacy is concentration-dependent. Interestingly, Streptococcus species, such as Streptococcus oralis, were frequently detected in biofilm samples following SDF exposure, suggesting in vitro resistance. Kern et al. (2023) further underscored the therapeutic potential of SDF by demonstrating that a single application of 38% SDF significantly reduced gingival inflammation in dogs. Candida and fungal species: SDF exhibits antifungal activity, inhibiting the synthesis of extracellular phospholipases and the transition from yeast to a hyphal form. The anti-Candida action of SDF was dose-dependent, effectively inhibiting the growth of Candida albicans on dentin from human teeth. Additionally, SDF was more effective against certain Candida species, with C. krusei and C. glabrata being more susceptible than C. albicans and C. tropicalis. Impacts on inorganic content: After the administration of SDF, a series of chemical reactions occur. Primarily, SDF interacts with hydroxyapatite, resulting in the formation of insoluble fluorapatite. Furthermore, calcium fluoride (CaF_2) formation acts as a slow-release reservoir. In demineralization conditions, SDF treatment shows reduced calcium dissolution from enamel, indicating its protective role against mineral loss. Impacts on organic content: Fluoride protects dentin collagen through two primary mechanisms: inhibiting collagenases, and stimulating remineralization which helps cover and protect the collagen. In primary teeth, fluoride treatment promoted remineralization; the arrested caries lesions exhibited smoother surfaces with fewer exposed collagen fibers, whereas active dentin lesions displayed porous, rough surfaces with disorganized and sparsely dispersed collagen fibers.[7]

5 | CASE SELECTION AND INDICATIONS

Determining which patients will benefit from Silver Diamine Fluoride involves identifying individuals at high risk for caries who have active cavitated lesions in either anterior or posterior teeth. It is particularly effective for patients presenting with behavioral or medical management challenges, as well as those with multiple lesions that may not all be treated in a single visit. Additionally, SDF serves as a vital tool for patients with lesions that are difficult to treat or those who face significant barriers to accessing regular dental care, such as individuals with intellectual or developmental disabilities. Clinically, it is indicated for arresting caries in primary teeth and serves as an interim treatment for children with special health care needs.[8] Selecting the appropriate tooth is equally critical for success. The target tooth must show no clinical signs of pulpal inflammation or reports of unsolicited and spontaneous pain. Clinicians must ensure the tooth is not suffering from pulpitis or pulpal necrosis. Ideally, radiographs should be taken to assess the depth of the caries to ensure the lesion is not encroaching on the pulp. The lesion surface must be accessible with a microbrush, though orthodontic separators may be used to help gain access to proximal surfaces. Contraindications include individuals with a known silver allergy or those with sensitive oral lesions that could be irritated by the medicament.[9]

6 | CLINICAL APPLICATION PROTOCOL

The application process begins by removing gross debris from the cavitation to allow better SDF contact with the denatured dentin. To protect the patient, a protective coating may be applied to the lips and skin to prevent a temporary henna-appearing tattoo. Isolation is achieved using cotton rolls. For the procedure itself, no more than one drop of SDF should be used for the entire appointment. After drying the lesion with a gentle flow of compressed air, the SDF is applied directly to the affected surface using a bent microsponge brush for at least one minute. In very young or difficult patients, a shorter application time may be necessary. Excess liquid should be removed with gauze or a cotton pellet to minimize systemic absorption. The area should ideally remain isolated for up to three minutes, followed by a gentle flow of air until the medicament is dry. Finally, the entire dentition may be treated with five percent sodium fluoride varnish to help prevent caries on untreated sites.[10]

7 | ADVANTAGES, DISADVANTAGES, AND ADVANCEMENTS

SDF is a safe, non-invasive, and inexpensive material that is painless to apply. It features a simple chairside 'paint-on' technique that is particularly useful for children and requires minimal personnel training. It is highly efficient for arresting caries and preventing new lesions, providing a great alternative when time and cooperation are issues. Furthermore, it does not require local anesthesia, carries no risk of infection, and has a high safety margin with no reported cases of toxicity.[11] Despite these benefits, the primary disadvantage is the permanent black staining of the treated lesions. It may also occasionally produce a metallic taste and does not restore the physical form or function of the decayed tooth. Consequently, informed consent is recommended. Advancements in the field include testing SDF in gel forms, the use of Potassium Iodide to mitigate staining, and new techniques involving light curing.[11]

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