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REVIEW

Historical background and clinical implications of silver diamine fluoride in dentistry: A narrative review

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Dental caries is a chronic, irreversible disease affecting preschool children worldwide. As the frequency of dental caries has steadily declined over the past few years, children from low socioeconomic backgrounds still have higher rates of dental caries, and still have a higher prevalence in developing countries. Though the role of fluoride in dental caries prevention has been scientifically proven, the antimicrobial effect of silver compounds to treat various infections has been postulated. However, 38% silver diamine fluoride (SDF) solution is currently used to arrest dental caries, and as an antihypersensitivity agent. The SDF solution is available in dark, amber-colored bottles and is simple, non-invasive, and easy to use by trained dentists or specialists. Although it has the disadvantage of causing black discoloration and an unpleasant metallic taste after application, studies in the literature show that it can help prevent dental caries, hypersensitivity, root caries, and remineralization. This article explains in depth the SDF: its historical background, clinical application, and efficacy in different fields of dentistry.

Keywords: remineralizing agent, silver diamine fluoride, caries prevention, topical agent, hypersensitivity

1. Introduction

Dental is a disease process that is multifactorial, dynamic, and irreversible that occurs due to an imbalance between host and ecological factors (1). The epidemiological studies confirm that early childhood caries remains a significant disease burden in both developed and developing countries, along with high unmet dental needs (2). The reasons for the unmet dental needs could be poor access to resources, financial constraints, the higher cost of dental treatment, lack of awareness, and their general health, and education opportunities (3). The traditional treatment for a carious tooth is to remove the infected, irreversible, and demineralized dentin by mechanical excavation and restore it with a restorative material (4). In young children, behavior issues routinely complicate or prevent the restorative treatment. This unmet treatment needs lead to progression of the carious lesion and pain in some cases, which has a fatalistic impact on quality of life. Arresting the carious lesion has been proposed in children with uncooperative behavior and disadvantaged low socioeconomic communities (5).

Silver diamine fluoride (SDF), a colorless liquid with a pH of 8 to 9 and the ability to remineralize minerals, is utilized as a caries arresting agent in dentinal caries lesions in children. In the late 1970s, SDF was initially used in Japan but was not that popular. However, in the beginning of the 21st century, it has gained popularity in China as a dental caries arresting agent (6, 7). It has recently become popular and available in the United States and South Asian countries. Other silver products like silver fluoride and SDF in different concentrations are commercially available in Austria, Argentina, and Brazil these days (8, 9). SDF is most commonly used in a concentration of 38% solution containing 44,800 parts per million (ppm) of fluoride. It

Abbreviations: SDF, silver diamine fluoride; SnF_2, stannous fluoride; DNA, deoxyribonucleic acid; ppm, parts per million; HA, hydroxyapatite crystals; CaF_2, calcium fluoride; CSP, calcium sodium phosphosilicate; CCP–ACP, casein phosphopeptide–amorphous calcium phosphate complexes.

is also available in 30% containing 35,400 ppm and 12% containing 14,150 ppm of fluoride, respectively (10). The caries arresting efficacy of dental caries was reported to be 65.9% by 38% SDF (11). The primary drawback of SDF is the black discoloration of dentinal carious tissue following application due to the oxidation process of silver ions, along with a few other reversible modifications such as oral tissue staining and ulceration (12). This page provides information on this intriguing substance, including how it can be used to treat and prevent dental problems in both primary and permanent teeth.

2. Historical background

Although silver compounds were used to prevent dental caries, in Japan, it was customary for women to "Ohaguro," or color their teeth black, to signify their marital status 1,000 years ago (13). Around 1,000 B.C., the first medicinal use of silver compounds was to treat various infections. In medical science, silver-based materials such as silver foil, silver nitrate, and silver sutures have been employed (14). Von Hofmann discovered silver nitrate to be a highly powerful antibacterial agent (Naegeli) (15). In 1891, Stebbins used silver amalgam and nitric acid for the first time in dentistry, and found caries inhibition in the subsequent follow-ups (16). "Howe's solution" consisting of silver nitrate was used directly on caries lesions and similar results were found by Howe et al. (17). Since then, it has been used for caries arresting solution.

3. Silver diamine fluoride in dentistry

The first time silver fluoride was applied in dentistry was in the early 1970s (18). Stannous fluoride (SnF_2) must be used as a reducing agent for applying silver fluoride, a colorless, alkaline liquid that contains active silver, and fluoride ions. SDF has been approved as a therapeutic agent by the Central Pharmaceutical Council of the Ministry of Health and Welfare, Japan dentistry (19). SDF is a stable chemical compound, not as alkaline as silver fluoride (at a pH of 8–9), and does not require a reducing agent like silver fluoride. Practitioners in Southern California used SDF in preschool children with nursing bottle caries (20). Many community projects were planned in sub-Saharan Africa, Cuba, and several African countries using SDF as a caries-arresting agent (5). During this time, SDF is used quite seldom, and there has been limited research regarding its effectiveness. SDF has been used to stop tooth cavities in various nations, including China, Japan, the United States, and South Asian nations, at a concentration of 38%.

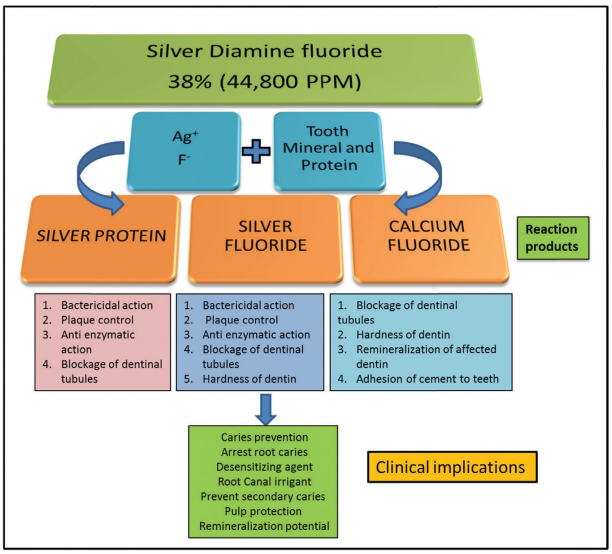

FIGURE 1 | Mechanism of action and clinical implications of SDF in dentistry.

4. Mechanism of action

According to research (Lansdown), silver interacts with sulfhydryl groups on proteins or DNA to block respiratory processes, change hydrogen bonding, affect the formation of cell walls, unwind DNA, and affect cell division at the microcellular level (21, 22). Bactericidal activity and biofilm formation inhibition are produced by these interactions (23). Shimizu and Kawagoe outline three potential modes of action (24). **Figure 1** illustrates the many therapeutic consequences of SDF.

4.1. Obturation of dentinal tubules

Gottlieb hypothesized that dentinal caries can be prevented by obturation/blockage of dentinal tubules, i.e., blocking the organic invasive pathway (25). When dentin is treated with SDF, silver, and its derivatives stop acid diffusion and microbial penetration through the dentinal tubules. Shimizu showed that the dentinal tubules were shown to have reduced permeability and increased electric resistance. He further affirmed that the dentin's surface area will shrink, and the dentin's most readily demineralized region, the peritubular zone, may become coated with silver particles in obturated dentinal tubules (26). In a recent study, Mei et al. discovered that the usage of 38% SDF protected the collagen from deterioration in demineralized dentin. The oligodynamic effect of the silver present in the dentinal tubules will restrict bacterial development and prevent demineralization of the dentin (27).

4.2. Cariostatic action of the reaction products

Shimooka discovered that SDF ($Ag(NH_3)2F$) prevents and hardens dentinal cavities by reacting with hydroxyapatite crystals (HA) ($Ca10(PO_4)6(OH)2$) found in tooth material to produce calcium fluoride (CaF_2) and insoluble silver phosphate (Ag_3PO_4) (28). CaF_2 continues to precipitate and hardens dentinal cavities by interacting with the insoluble silver phosphate crystals (Ag_3PO_4) present in tooth material (28).

4.3. Antibacterial properties through antienzymatic action

Suzuki et al. suggested that the antibacterial properties of SDF are due to *Streptococcus mutans* cariogenic strains' enzyme activity suppression and dextran-induced agglutination. We now provide two examples in this regard (29). The reaction between silver and the organic component of dentin by ionophoresis leads to increased resistance to trypsin (30). Additionally, Yanagida et al. demonstrated that collagenase and trypsin resistance in dentin protein treated with $Ag(NH_3)2F$ had risen (31).

5. Clinical application of silver diamine fluoride

5.1. Dental caries arresting agent in primary teeth of preschool children

Most of the children in this study are suffering from severe early childhood caries. The treatment of these young children involves many difficulties, like child uncooperative behavior, so the majority of them remain left untreated. Nishino et al. and Moritani et al. compared two groups receiving SDF, and without SDF, and reported less caries increment in the children treated with SDF (32, 33). In another study, SDF was used in a community-based caries control program, and results have shown that SDF effectively arrested the carious lesion in the primary teeth of preschool children (6). In a systematic review, controlled clinical trials of caries prevention in primary teeth were evaluated by Oliveira et al., and concluded that SDF was effective compared to the fluoride varnish group or the placebo group in avoiding dental cavities (34). According to a subsequent systematic study by Contreras et al. using SDF at concentrations of 30 and 38% is more successful in stopping dentinal caries in both primary and permanent dentition (35).

5.2. Prevention of pit and fissure caries

Due to structural differences, pits and fissures are more likely to develop dental cavities, and are more difficult to keep clean than smooth surfaces. Pit and fissure caries are challenging to detect, and topical fluoride treatment has been shown to be less efficient in preventing pit and fissure caries. Due to its antibacterial properties, SDF has been demonstrated to be useful in reducing pit and fissure caries of the first molar teeth (36). In a research by Nishino and Massler, it was shown that the mean caries score was considerably lower in the fissures treated with silver fluoride or SnF_2 compared to 8% in the SDF-treated group (37).

5.3. Prevention of secondary caries

Most of the restorative materials are insoluble in oral fluids and adhere to the tooth structure. There are microspaces at the junction of the cavity wall and the restorative material, so microorganisms penetrate through microleakage, which leads to secondary caries (38). SDF has been found to be used for the prevention of secondary caries. Shimizu and Kawagoe in their study found that there was no evidence of secondary caries after 26 months of follow-up in primary teeth treated with SDF (24).

5.4. Arrest root caries

Studies have shown a high prevalence of root caries in the elderly population (39–41). The various studies mentioned that application of SDF arrests the root caries and there was less increment in the new carious lesions with the addition of SDF and oral health education (42, 43).

5.5. Desensitize sensitive teeth

Gottlieb suggested that reaction products of SDF occlude the dentinal tubules, thus preventing dentin hypersensitivity and arresting dental caries (25). Various studies have shown that SDF is more effective against chemical and mechanical wear such as abrasion, erosion, and hypersensitive dentin to thermal stimulation (44–46).

5.6. Irrigation of infected root canals

Silver compounds like ammoniated silver nitrate solution have been used as an irrigating solution to disinfect root canals. Silver fluoride solution has disinfectant and protein-coagulating properties. This blocks the root canal's dentinal tubules (47). According to Hiraishi et al., 3.8% SDF is an effective antimicrobial root canal irrigant which removes the microbes from the canals and circumpulpal dentin (48).

5.7. Other applications in dentistry

The remineralizing action of SDF has been proven in the literature because of the fluoride content. When SDF, calcium sodium phosphate (CSP), and casein phosphopeptide–amorphous calcium phosphate complexes (CPP–ACP) were compared in an *in vitro* study by Vinod et al. using DIAGNOdent readings, the results revealed a statistically significant difference between baseline, post-demineralization, and post-remineralization readings. SDF demonstrated the highest levels of remineralization in the intergroup comparison, followed by CSP and CPP–ACP, respectively (49). SDF also has antifungal potency against oral *Candida* species along with antimicrobial activity in the management of severe early childhood caries (50).

6. Disadvantages of silver diamine fluoride

The main disadvantage and concern of SDF are black discoloration and metallic taste, so some parents and their children may not accept the treatment outcome. When SDF was applied to the carious dentin, insoluble yellow-colored silver phosphate was formed (51), which later turns to black when exposed to sunlight or due to the influence of reducing agents. Knight et al. suggested application of after using SDF, potassium iodide is used to remove the black discoloration. Crystals of creamy white silver iodide are created when potassium iodide combines with the remaining free silver ions. As a result, there are no longer any free silver ions that may interact with sulfur to produce black precipitates (52).

SDF also has a metallic taste, which is unacceptable to the children, and parents. Sometimes gingival and mucosal irritation can occur, which is transient in nature and the tissue affected turns white and heals within 1–2 days. Thus, use of a rubber dam or a separating medium like vaseline or cocoa butter should be used before using the SDF solution near to the gingiva (13).

Crystal et al. evaluated the parental acceptance and perception of SDF staining and observed that staining was more acceptable on posterior teeth compared to anterior teeth. Most parents preferred SDF application compared to treatment under deep sedation or general anesthesia (53). In a different research, Alshammari et al. discovered that the majority of the parents disapproved of the SDF application. The authors came to the conclusion that dentists should offer informed consent forms with unambiguous photos while treating anterior teeth showing expected staining (54).

7. Conclusion

SDF has been proven to be an effective therapeutic agent in arresting dental caries in both primary and permanent teeth. It also helps in reducing dentinal hypersensitivity, remineralizing properties, antimicrobial activity, and antifungal potency. Furthermore, SDF is a simple, easy to use, easily affordable, and widely available therapeutic agent in developing countries. Though it has the disadvantage of black staining and metallic taste, more studies would be needed to prove SDF as a material of choice in the current scenario.

Author contributions

NK and RK contributed to concept designing, searching the literature, and writing the review manuscript. Both authors contributed to the article and approved the submitted version.

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