

STUDY OF THE EFFECTIVENESS OF SILVER DIAMINE FLUORIDE (SDF)

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Abstract:

Silver diamine fluoride (SDF) is a compound that has gained wide recognition in dentistry due to its ability to effectively inhibit the caries process and exert antimicrobial action. This review article analyzes current evidence on the effectiveness of SDF in clinical practice. The paper discusses the mechanisms of action of the agent, its impact on the remineralization of dental hard tissues, as well as its antimicrobial properties and effects on the dental pulp. Special attention is given to clinical studies comparing SDF with other methods for managing initial and progressive caries in both children and adults. Potential side effects, including tooth discoloration, and strategies for their minimization are also highlighted. The review emphasizes the high potential of SDF as a non-invasive, cost-effective, and clinically significant agent in caries prevention and treatment.

Introduction

Silver diamine fluoride (SDF) is a non-invasive agent that is widely used for the treatment of dental caries [9]. As a topical solution, it contains a high concentration of fluoride and silver ions [5].

SDF has been used in dentistry for more than 50 years [24]. It was first introduced in Japan in 1969 as an effective method to arrest dental caries [25]. Since then, SDF has been extensively applied in East Asia and Latin America [26]. Health Canada approved the use of SDF in 2017 [27,28]. Later, it was introduced in the United Kingdom as a desensitizing agent and was also used off-label for caries arrest [29]. In 2014, the U.S. Food and Drug Administration (FDA) authorized the marketing of SDF in the United States as a dentin desensitizer [29]. The American Academy of Pediatric Dentistry subsequently recommended its use for caries arrest in primary teeth as part of a comprehensive caries management program [30]. In 2020, the American Dental Association supported the use of SDF for caries treatment.

Earlier methods relied on the application of silver nitrate and a reducing agent, which resulted in the precipitation of metallic silver. While this provided an antibacterial effect, it was associated with several drawbacks, including tooth discoloration, pulp irritation, the need for isolation, and the complexity of a multi-step procedure. In the

second half of the 20th century, Japanese researchers began using silver diamine fluoride, which demonstrated higher caries-arresting efficacy and fewer side effects. This compound forms a durable protective layer on the tooth surface that is impermeable to microorganisms and promotes tissue remineralization through the formation of calcium fluoride.

According to the study by J.C. Llodra et al., biannual application of SDF over three years, beginning at the age of six, resulted in a 65% reduction in caries incidence on the surfaces of first permanent molars and an 80% reduction in primary canines and molars [14]. In preschool children, annual application of the agent over a 30-month period achieved a 70–84% reduction in caries of primary incisors and canines, depending on the application technique. This efficacy exceeded that of four applications of Duraphat fluoride varnish (5% NaF), which showed only a 44–56% reduction [9].

Main Body

Mechanism of Action of Silver Diamine Fluoride (SDF)

SDF acts in a complex manner: silver suppresses bacterial growth and causes protein coagulation, sealing the dentinal tubules, while fluoride interacts with hydroxyapatite, promoting remineralization. The chemical reaction that occurs upon SDF application leads to the formation of silver phosphate, calcium fluoride, and other compounds that stabilize hard dental tissues [8,15,18].

A simplified scheme of the chemical reaction occurring when SDF ($\text{Ag}[(\text{NH}_3)_2]\text{F}$) is applied to hard dental tissues can be written as follows:



Silver ions can penetrate into the hard tissues of the tooth upon SDF application to dentin [31]. SDF mainly consists of a silver diamine-ion complex $[\text{Ag}(\text{NH}_3)_2]^+$ and fluoride ions (F^-). Silver ions are released from this complex after SDF application [32]. These silver ions react with hydroxyapatite to form silver phosphate. However, silver phosphate is unstable and quickly reverts back to silver ions [33].

Silver ions can also react with collagen in dentin, where collagen reduces the ions to metallic silver. Collagen in hard dental tissues is already exposed due to demineralization by acidic byproducts of cariogenic bacteria. The more collagen is exposed, the greater the amount of silver ions reduced to metallic silver in a shorter time. This process leads to black discoloration. However, the depth of silver penetration and tooth discoloration differed in some studies [31].

Levels of silver penetration into hard dental tissues were reported inconsistently in previous research. One study reported silver penetration depths ranging from 25 to 200 μm , while in a case report by Bimstein and Dam [35], silver penetration reached up to 1 mm into dentin. The latter study indicated that increased depth of silver penetration was associated with the proximity of the cavity to the pulp, the young age of the patient, and the enlarged diameter of dentinal tubules in this region. Another study reported that silver penetrated through the entire thickness of demineralized dentin and spread into

adjacent healthy dentin [31]. Notably, in one study, silver was detected in pulp tissue [36]. Penetration of silver into pulp tissue in this study may have been related to the type of specimens used, which were primary teeth with deep carious lesions [36]. However, this study was not included in the present review, as it focused on the effect of SDF on hard dental tissues.

Advantages of Silver Diamine Fluoride (SDF) Treatment

1. High effectiveness in caries prevention and treatment in children.

SDF demonstrates superior outcomes compared to fluoride varnishes, reducing caries incidence by up to 80% with infrequent applications [14]. Clinical data indicate that among six-year-old children who received SDF applications twice annually for three years, 77% of active carious lesions on the surfaces of primary and permanent molars and canines became inactive. In preschool children treated with SDF once annually for 2.5 years on decayed dentin of primary incisors and canines, complete arrest of disease progression was observed on all treated surfaces [11].

Interestingly, the effectiveness of SDF in arresting caries progression does not depend on whether infected tissue is removed before application. This makes SDF a particularly convenient and non-invasive treatment method [11]. According to S.P. McDonald, the greatest effect is achieved when SDF is used together with stannous fluoride, reducing caries progression to only 5% [17]. Furthermore, in a study by E.C.M. Lo et al., comparing 468 carious lesions in permanent molars of 6–7-year-old children treated with either SDF or atraumatic restorative treatment (ART), both methods showed comparable effectiveness after one year [16].

2. Safety of use on sound dentin areas.

Histological studies of pulp in primary teeth extracted due to physiological resorption, which had previously been treated with SDF followed by ART restoration with glass ionomer cement, revealed marked regenerative activity in 90.9% of cases when assessed 3–58 months after intervention.

Experimental histological studies in animals (dogs) also confirmed the absence of pathological reactions in periapical tissues when SDF was used as an antiseptic for root canal disinfection [12,18].

3. Cost-effectiveness.

SDF is cheaper than most traditional methods, requires no expensive equipment, and can be applied in field conditions, such as schools.

4. Simplicity and painlessness of the procedure.

Application is simple, painless, and suitable even for young children and anxious patients [14].

5. Long-lasting effect.

SDF continues to act over extended periods without losing effectiveness [10].

6. Reduced discoloration compared to earlier silver-based products.

7. Fewer sessions required.

Treatment with SDF often requires only a single application, whereas silver nitrate treatments usually require multiple (4–5) sessions.

Disadvantages of Silver Diamine Fluoride (SDF) Treatment

1. Tooth discoloration.

The main esthetic drawback is darkening of treated tooth surfaces. While discoloration intensity varies, in some cases it occurs in almost all patients after long-term use. In vitro studies reported that 10–20% of carious lesions treated with SDF exhibited grayish or dark staining, depending on the specific commercial product [10]. However, with long-term use (twice a year for three years) on primary teeth, discoloration rates rose to 97% [14].

Tooth staining negatively affects esthetic appearance, so it is recommended to inform parents in advance about this potential side effect. Nevertheless, according to Chu C.H. et al. [11], who studied 123 children aged 3–5 years treated with SDF on primary incisors and canines, the presence of dark, caries-arrested lesions did not increase parental dissatisfaction.

2. Metallic taste.

A slight metallic taste is sometimes reported, though it is temporary and does not cause significant discomfort [9,13].

Formation of Tertiary Dentin

SDF contributes to tertiary dentin formation by modulating the degree of irritation. Severe irritation leads to pulp necrosis, while mild or moderate irritation stimulates tertiary dentinogenesis [22]. The rate of tertiary dentin formation is directly related to the severity of pulp injury [19]. Such injury may be caused by microorganisms and their byproducts, operative procedures, or restorative materials. In the study by Korwar et al. [23], standardized cavity designs and operative methods were used to control variables resulting from surgical procedures. Their results showed that tertiary dentin formation was associated with the applied liner materials, as SDF was able to block dentinal tubules through ion deposition and its remineralizing effect.

Inflammatory Response of the Pulp to SDF Application

Mild inflammation and normal pulp architecture were observed when SDF was applied to deep cavities without pulp exposure, even in cases where the remaining dentin thickness was between 0.25 mm and 0.50 mm [23]. The dentin–pulp complex has a

protective response against external irritants, such as acids produced by oral bacteria, mechanical irritation during surgical procedures, or chemical irritants from restorative materials. In deep carious lesions, microorganisms and the byproducts of their metabolism can penetrate through dentinal tubules and irritate the pulp even without direct contact with the pulp tissue. These toxins are one of the main factors leading to reversible or irreversible pulp damage [37].

The use of SDF can block irritants from reaching the pulp because SDF contains high concentrations of both fluoride and silver ions, which can kill and suppress the growth of microorganisms in deep cavities [39]. SDF also reduces the metabolic activity of bacteria [40]. A reduction in the number of microorganisms and their byproducts may result in decreased irritation of the dental pulp. Moreover, silver deposits were found on the surface of demineralized dentin after SDF application [21]. These deposits can block dentinal tubules and prevent the penetration of microorganisms and their byproducts into the pulp [38]. Additionally, the surface became resistant to bacterial adhesion [41].

However, direct application of SDF to exposed dental pulp showed contradictory results. In most cases, severe inflammation and pulp necrosis were observed [35]. In the study by Hosoya et al. [43], more teeth with complete or partial necrosis of pulp tissue were observed in the experimental group compared to the control group. This outcome may be due to the accumulation of high concentrations of SDF in the pulp within a short observation period, which did not allow SDF to be washed out by normal pulp circulation. These findings can be explained by the toxic effect of the high concentration of silver ions in SDF. A silver solution containing high concentrations of metallic silver ions can be toxic to cells upon direct contact [42]. The results of Kim et al. [44] also confirmed that SDF is cytotoxic to pulp cells upon direct contact, even at low concentrations (0.038% or 0.0038%).

Nevertheless, in the study by Hosoya et al. [43], tertiary dentin formation was observed in one tooth after direct SDF application to the pulp at 30 days. The perforated pulp chamber was closed with newly formed tertiary dentin [43]. No convincing explanation for this outcome was provided. It was suggested that hard tissue regeneration was mainly associated with the host's immune response. However, no definitive conclusion can be drawn from this result, since it was an isolated finding based on a single tooth.

Bacteria were not detected inside the pulp chamber after indirect SDF application. Only in a case report (1 tooth) by Bimstein and Dam [30] was the presence of bacteria in the dentin–pulp complex evaluated after SDF was used as an indirect pulp-capping agent. No viable microorganisms were found in the dentin or pulp, but this finding cannot yet be generalized, as it was observed only in a single case. The strong antibacterial effect of SDF has been demonstrated by a series of laboratory studies. SDF inhibited the growth of single-species, dual-species, and multi-species cariogenic biofilms [39, 2.3], which is logical considering that the antibacterial effect of silver is well known [48].

Furthermore, dead silver-treated bacterial cells can kill live bacterial cells upon contact. This is known as the “zombie effect” [1].

SDF is mainly used in the minimally invasive technique and may not always be followed by restoration placement. This leads to the exposure of hard dental tissues in the oral cavity. The presence of a material with strong antibacterial properties, such as SDF, can destroy bacteria in the dentin–pulp complex and maintain this type of barrier against microorganisms.

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1. Фторид диамминсеребра (ФДС) – перспективный препарат для использования в стоматологии, особенно с целью профилактики и лечения кариеса. Но имеются вопросы, требующие дальнейшего изучения препаратов ФДС и, возможно, их усовершенствования.
2. Согласно ограниченной доступной литературе, прямое применение SDF вызывает некроз пульпы. Непрямое применение SDF, как правило, биосовместимо с тканью пульпы зуба с легкой воспалительной реакцией, повышенной одонтобластной активностью и усиленным формированием третичного дентина. Будущие исследования с точными количественными и качественными тестами, большим размером выборки и более длительным временем наблюдения необходимы для понимания биологической активности пульпы зуба для лечения SDF
3. Несмотря на ограниченность вышеупомянутых исследований, такие подходы и усилия должны быть признаны. Они представляют собой первые шаги на пути к определению направления для будущих исследований. Исходя из полученных данных, наличие SDF в сочетании с правильной концентрацией и надлежащим расстоянием от пульпы можно считать катализатором процесса репарации дентин-пульпового комплекса. Необходимы дальнейшие исследования *in vitro* для уточнения механизма этого действия. Кроме того, необходимы дополнительные клинические исследования с более мелкими деталями, большими выборками и различными условиями тестирования.

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