Silver diamine fluoride – an overview of the literature and current clinical techniques

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Key points

- Silver diamine fluoride (SDF) is an alkaline colourless solution, with the ability to prevent and manage dental caries.
- Several additional benefits of SDF exist in comparison to traditional fluoride solutions.
- Knowledge of the clinical procedure, contraindications and indications is key to ensure successful utilisation of SDF.

Abstract

Dental caries continues to affect the British population, despite advances in prevention and management options. There are many treatment and preventive treatment strategies to address dental caries. Silver diamine fluoride (SDF) is a colourless alkaline solution containing silver and fluoride, which forms a complex with ammonia and has proven to be effective in management of dental caries. Additional dental benefits of SDF continue to be explored and discussed in the literature. SDF is a relatively new material which can be used to reduce and crystallise dental caries in a simple non-invasive treatment modality without the use of local anaesthetic. It can thus be well tolerated by children as a treatment technique and can be quickly applied to the isolated tooth without the need for extensive excavation. Currently, SDF is classified in the UK as a desensitising agent; however, it may be reclassified as a caries treatment agent at some stage and thus provide an effective non-invasive treatment for children's tooth decay. This would prevent the multiple admissions for dental extraction under general anaesthetic, as a simpler approach can be provided. This article will evaluate and review the literature behind SDF and provide details on its use and clinical application.

Introduction

Despite continued advances in knowledge of disease progression and prevention methods, dental caries is the most common reason for hospital admission in children aged between five and nine.[1] What makes this even more concerning is that the disease is almost entirely preventable. A plethora of fluoride-based prevention systems are available at our disposal and continue to form a mainstay in the management of dental decay.[2] However, recently, the use of silver diamine fluoride (SDF) has appeared as one of the more popular and effective methods for the prevention and management of the dental disease, with a systematic review by Rosenblatt *et al.*[3] finding that SDF is more effective than fluoride varnish and may be a valuable caries-preventative intervention.

SDF, $Ag(NH_3)_2F$ (also referred to as diamine silver fluoride and silver ammonium fluoride) is a colourless alkaline solution containing silver and fluoride, which forms a complex with ammonia.[4] The ammonia ions combine with silver ions to produce a complex ion called the diamine-silver ion, and this complex is more stable than silver fluoride. SDF is not merely a simple salt of silver, ammonium and fluoride ions, but rather a mixed heavy-metal halide coordination complex.

SDF reportedly releases two to three times more fluoride than sodium fluoride, stannous fluoride or acidulated phosphate fluoride, substances commonly found in foams gels and varnishes.[3] In this paper, a clinical and evidence-based overview of SDF in dentistry will be provided.

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History

Use of silver in medicine has a long history of application. Probably the earliest medical use of silver was for water disinfection and storage. Alexander the Great (335 BC),[5] the Greeks and the Romans[6] all stored water in silver vessels to keep it fresh.

In more recent history, German obstetrician Karl Crede found that dilute solutions of silver nitrate reduced the incidence of neonatal eye infections from 10.8% to under 2%.[7] Silver nitrate for the use of burns also became popular in the nineteenth century.[8]

Use of silver in dentistry was reported as early as the 1840s, where silver nitrate was reported for its use in arresting caries.[9] In 1917, Howe[10] reported the use of an ammoniacal silver nitrate solution, referred to as 'Howe's solution', applied directly to caries lesions. Howe's solution was believed to penetrate into affected dentine, having an antibacterial effect, and was used up until the 1950s, at which time questions regarding the efficacy of the product were raised.[11]

At the end of the twentieth century and the beginning of the twenty-first century, a range of both *in vivo*[12,13,14] and *in vitro* studies[15,16,17,18] documented the effectiveness of silver fluoride compounds at arresting caries lesions. This led to the commercial use of silver fluoride compounds in Mexico, Australia and Japan.

Ammonium has since been included with the compound, resulting in the formation of SDF.

SDF mechanism of action

The anti-cariogenic mechanism of SDF is two-fold, with direct actions on bacteria and teeth.[3]

Antibacterial action

Both fluoride and silver ions contained in SDF appear to have the ability to inhibit the formation of cariogenic biofilms. An *in vitro* study by Knight *et al.*[19] demonstrated that dentine surfaces treated with SDF had significantly reduced *Streptococcus mutans* quantities, which is one of the most important pathogens associated with the initiation and progression of the caries lesion. The antimicrobial action of the SDF has also been demonstrated on multi-species cariogenic biofilms[20] and *Lactobacillus*[21] species.

High-concentration fluorides inhibit biofilm formation by binding to bacterial cellular components and influencing enzymes related to both carbohydrate metabolism and sugar uptake.[20] Silver ions' antibacterial action is threefold:[22] penetrating and destroying bacteria cell wall structures, inhibiting enzymatic activity thus influencing metabolic processes, and inhibiting the replication of bacterial DNA.

Teeth

SDF has been shown to have a remineralisation effect on dentine caries.[23] One proposed chemical reaction between SDF and hydroxyapatite of teeth involves the formation of silver phosphate and calcium fluoride, which aid in elevation of pH and formation of fluoride reservoirs.[24] The subsequent dissolution of fluoride and calcium facilitates the formation of insoluble fluorapatite. It has been demonstrated that the reaction between SDF and hydroxyapatite also leads to the formation of nanoscopic metallic silver particles attached to hydroxyapatite crystals.[23] The incorporation of silver particles into the hydroxyapatite is significant due to the antibacterial and anti-cariogenic nature of the silver mentioned previously, thus inhibiting the development of future caries on the arrested lesion.

SDF has also been shown to have an inhibitory effect on matrix metalloproteinases (MMPs)[25] and cysteine cathepsins (or cathepsins).[26] MMPs and cathepsins are proteolytic enzymes that contribute to dentine collagen degradation and caries progression. MMPs and cathepsins are also responsible for the hydrolytic degradation of collagen matrix in the dentine-adhesive interface;[27] therefore, as will be discussed later, this action of SDF may be key in the product's future use for increasing the longevity of adhesive restorations.

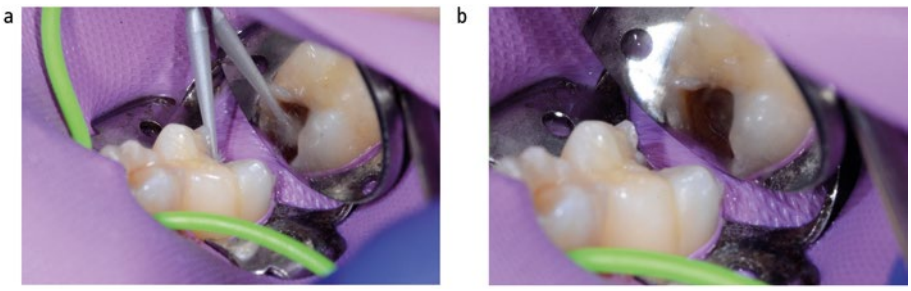

Fig. 1 An intraoral image demonstrating SDF application to a large carious lesion on the 46. The SDF is applied for three minutes before thorough washing and drying. It is common to notice the lesion darkening in colour during application

Indications and evidence for SDF

Although traditionally used for its anti-cariogenic properties, SDF has been utilised for a range of applications in the literature.

Caries arrest and caries prevention

The most common application for SDF is its use as a caries-preventative and caries-arresting agent (Figures 1a and 1b). Several randomised control trials have examined the effectiveness of SDF as both a preventative agent and as a caries-arresting agent, while also comparing the agent to alternative caries management techniques.

In 2002, Chu *et al.*[28] undertook a 3–5-year prospective controlled clinical trial comparing the use of annual application of 38% SDF (48,000 ppm F) to the use of 5% sodium fluoride (NaF) varnish (22,600 pp F). Both products were applied every three months to Chinese schoolchildren with carious primary anterior teeth. The study found that SDF's prevented fractions for caries arrest and prevention in primary teeth were >96% and >70%, respectively. In contrast, for fluoride varnish, the highest prevented fractions were 21.3% and 55.7% for caries arrest and prevention, respectively.[3] The study also found no significant benefit of caries excavation before application of SDF.

In 2005, Llodra *et al.*[29] undertook a three-year prospective controlled clinical trial examining the efficacy of applying 38% SDF solution twice a year for caries reduction in carious primary and permanent teeth. The study found that, for primary teeth, the prevented fractions for SDF were 55.6% and 78.6% for caries arrest and prevention, respectively. In permanent teeth, the prevented fractions for SDF were 100% and 63.6% for caries arrest and prevention, respectively.[3]

Braga *et al.*[30] compared the effectiveness of SDF to other non-invasive approaches (cross-tooth brushing technique [CTT] and glass-ionomer cement [GIC] fissure sealants) in arresting occlusal caries in erupting permanent first molars. The study found that, after three and six months, 10% SDF showed a significantly higher capacity than CTT and GIC for arresting caries. A general reduction in active lesions was noted in all groups. Dos Santos Jr *et al.*[31] compared caries-arresting properties of 30% SDF with those of GIC as an intermediate restorative technique (IRT). The study demonstrated that, after 12 months, SDF was 1.73 (95% CI, 1.38–2.18) times more effective in arresting caries (RR, 66.9%) than IRT (RR, 38.6%).

Duangthip *et al.*[32] examined the effect of 30% SDF applied three times with a weekly interval and compared this to three applications of 5% NaF varnish and a single 30% SDF application. The study found that SDF was significantly more effective at arresting caries than NaF. The study also found no significance between the three-time application of SDF and the single application of SDF.

Sensitivity

The use of SDF for management of dentine hypersensitivity has also been examined. In 2014, the Food & Drug Administration[33] cleared SDF for use in reducing tooth sensitivity. As such, use of SDF for caries management is actually an off-licence use.

The mechanism behind SDF and sensitivity control is that the aqueous silver and fluoride solution can produce a squamous layer over the exposed dentine, partially plugging the dentinal tubules of the exposed dentine,[34] thus reducing fluid shifts in the dentinal tubules.[35]

In terms of effectiveness, two randomised control trials have found that SDF has the potential to reduce sensitivity.[36,37] However, one of the studies[36] only enlisted 19 subjects and, as such, the reliability of the study must be questioned. A second study[37] was a multi-centre study evaluating 126 adults with sensitivity. This study found that SDF could significantly reduce sensitivity among adult patients both 24 hours and seven days post-application. Despite the promising findings, longer evaluation periods and comparison to alternate sensitivity treatments are required to gain a better understanding regarding effectiveness.

One of the issues with the use of SDF as a sensitivity agent in comparison to alternative sensitivity agents is the possible discolouration. However, the Castillo *et al.* study[37] found that, unless existing caries was present on the surface of the exposed dentine, no staining occurred.

MMP and cysteine cathepsin inhibitors

The adhesion of resin to dentine became feasible through the development of hydrophilic resins capable of infiltrating and polymerising within the collagen mesh exposed through acid decalcification of dentine, forming a hybrid layer.[38] Unfortunately, this hybrid layer degrades over time,[39] probably due to hydrolysis and degradation of both the resin and collagen. MMPs and cysteine cathepsins (CCs) in both saliva and mineralised dentine can lead to the enzymatic degradation of the composite resin adhesive hybrid layer collagenous matrix.[27] This can lead to a reduction in resin-dentine bond strength over time due to the development of microgaps between the tooth-resin interface, which are subsequently invaded by pathogens, leading to a failure of the restoration.

Research is currently being undertaken to determine ways to stabilise the dentine-adhesive hybrid layer over time. Much of this research focuses on inhibiting the actions of MMPs and CCs. Some enzyme inhibition agents currently being employed include chlorhexidine, galardin and benzalkonium chloride. As described earlier, SDF has been shown to limit activity of MMPs and CCs as well as reduce collagen degradation.

Mei *et al.*[25] examined the *in vitro* degradation of collagen by MMPs in the presence of SDF, silver nitrate ($AgNO_3$) and NaF. The study found that SDF had significantly more inhibition on MMPs than solutions of NaF and $AgNO_3$ containing equivalent concentrations of fluoride and silver ions. In 2014, Mei *et al.*[26] found that SDF significantly inhibited the activity of cathepsin B and K. Additionally, in 2013, Mei *et al.* demonstrated in two separate *in vitro* studies that SDF could significantly reduce collagen degradation.[21,40.]

While the results of these studies are promising, future research into comparing the effect of the product with other enzyme inhibition agents would be beneficial. Additionally, use of more aggressive testing methods such as thermocycling and long-term storage in water would be beneficial to examine the effect of SDF on the adhesive interface over time.

Theoretically, it is the authors' opinion that, due to SDF potentially resulting in the incorporation of a silver ion into the mineralised dentine structure,[23] a more prolonged inhibitory effect would be expected with SDF. The effect of SDF on bond strength will be discussed in detail further on.

Endodontic irrigant and inter-appointment medication

The elimination of microorganisms of the root canal in endodontic treatment is fundamental for successful treatment. This is achieved through mechanical cleaning and shaping in conjunction with irrigation with antibacterial agents. The use of an antimicrobial inter-appointment dressing further contributes to bacterial elimination within the root canal space.

In 2010, Hiraishi *et al.*[41] examined the effectiveness of a 3.8% SDF solution (a 1:10 dilution of the original 38% SDF for root canal infection). The antimicrobial effectiveness of the SDF irrigant was measured by examining quantitative reductions in *Enterococcus faecalis* biofilms. Controls of 5.25% NaOCl (sodium hypochlorite) and saline (0.9% NaCl) were used.

The study also examined the effectiveness of SDF as an inter-appointment dressing by measuring silver penetration of radicular dentine.

Findings of the study showed that *Enterococcus faecalis* was completely killed by SDF and NaOCl after exposure to these agents for 60 minutes. Silver deposits were present on 66.5% of the radicular dentine surfaces after 72-hour application of SDF as simulated inter-appointment dressings. Penetration of the silver deposits was observed at most 40 µm into dentinal tubules after smear layer removal. The presence of silver deposits in dentinal tubules suggests that it is possible for the SDF to penetrate and reduce/eliminate biofilms formed in dentinal tubules. Thus, this demonstrates that SDF may be effective as both an irrigant and inter-appointment medication.

Again, despite these promising results, further studies are required to demonstrate efficacy and safety of SDF as an irrigant and intra-canal medication. Additionally, use is likely to be limited to areas whereby staining resulting from the SDF is unlikely to be of significant concern. However, as mentioned previously, incorporation of silver particles into the dentine tubules is likely to provide a potential means of substantivity that permits the gradual release of silver and a longer-lasting antimicrobial effect than other respective irrigants and inter-appointment dressings.

Contraindications for SDF

Contraindications for use of SDF include:

- Silver allergy
- Significant desquamative gingivitis or mucositis
- Pregnancy
- Breastfeeding
- Restorations in the aesthetic zone
- Caries in the aesthetic zone
- Signs or symptoms of periapical pathology
- Radiographic signs or symptoms of periapical pathology.

Silver allergy is a complete contraindication to SDF. Use of potassium iodide (KI) for discolouration, described later, is contraindicated in pregnant women and during the first six months of breastfeeding due to concern of overloading the developing thyroid with iodide.[34]

Although some staining associated with SDF can be polished off, it may remain, especially at restorative margins. As such, patients should be aware of this and SDF not applied to patients whereby this is of major concern.

Side effects of SDF

SDF has been used in several countries for upwards of 80 years. Not a single adverse event has been reported to the Japanese authorities since they approved SDF (marketed as Saforide; Toyo Seiyaku Kasei Co. Ltd., Osaka, Japan) over 80 years ago.[4]

There are, however, some localised potential side effects of SDF that have been discussed in the literature.

Discolouration

One of the most frequently reported side effects of SDF is discolouration.[28,29,32,33] Discolouration tends to be black/dark brown (Fig. 2) and is thought to result from silver phosphate (Ag_3PO_4), which is formed when dental caries is treated with SDF. Silver phosphate readily turns black under sunlight or under the influence of reducing agent.

One method for overcoming the issue of discolouration is the application of a salt after SDF placement. The salt reacts with the remaining free silver ions, preventing the formation of silver phosphate and the resulting discolouration. One of the salts to prevent staining is KI,[42] which produces silver iodide, a creamy white reaction product (Fig. 3) that after adequate application turns colourless. However, there is no clinical data to prove the effectiveness of KI in reducing staining in the long term and, in the authors' experience, staining still occurs (however noticeably less) when KI is applied.

It has been reported that the staining/discolouration was not a concern to patients/parents.[28] From the authors' experience, this is dependent on the tooth in question. Parents are more likely to accept staining on primary teeth and teeth in the posterior quadrant.

Discolouration can be polished off or removed through more invasive measures. Occasionally, even with polishing, discolouration remains, particularly at restoration margins. Due to the metallic nature of the discolouration, dental bleaching does not remove the discolouration. It is essential that patients are warned pre-operatively about the potential for discolouration, especially around restorative margins.

Bond strength

It has been postulated that SDF reduces the bond strength to adhesive materials due to the introduction of a new interface at the tooth-restoration complex and the occlusion of dentinal tubules, thus reducing the penetration of the adhesive agents into the tubules. Interestingly, contradictory to this, some products even claim an improvement in bond strengths. Literature on SDF effects on bond strength, however, has inconclusive findings.

An *in vitro* study by Quock *et al.*[43] examined the effect of SDF (38% and 12%) on bond strength to dentine. The study found that SDF does not adversely affect the bond strength of resin composite to non-carious dentine. This finding was supported by Camacho *et al.*,[44] who found that the *in vitro* application of SDF to etched non-carious enamel before orthodontic bracket bonding does not adversely affect bond strength.

Two *in vitro* studies by Wang *et al.*[45] and Knight *et al.*[46] examined the effect of SDF with KI, respectively, on dentine. The studies found that SDF with or without KI had no effect on bond strength to GIC as long as precipitate was washed and dried off. The Knight *et al.* study demonstrated that washing and air-drying the

Fig. 2 SDF has been utilised in the restoration of the 54 and 55. Discolouration can be observed around the margin of the restoration. This type of discolouration is commonly associated with SDF application. Staining of the gingival margin, resulting from SDF, can also be observed on the 54 on the palatal surface

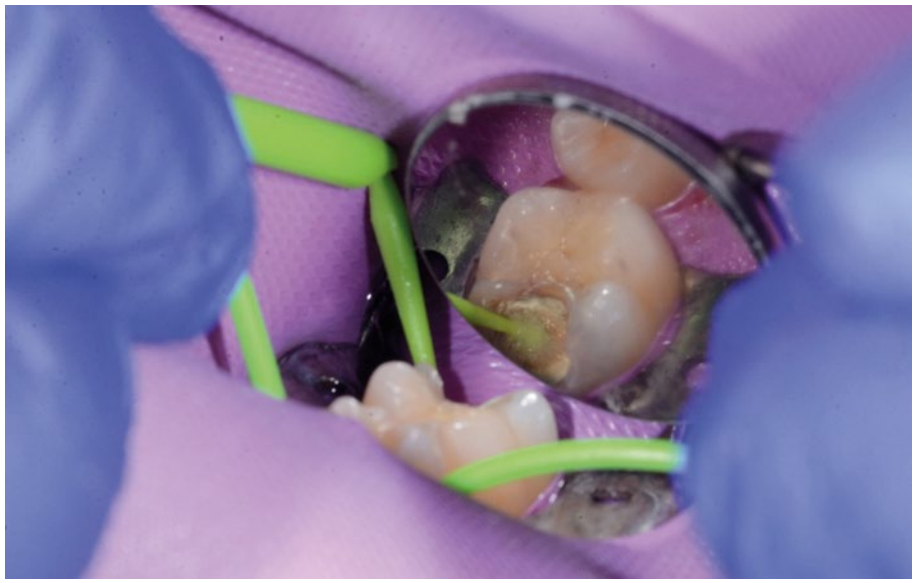

Fig. 3 Application of KI and SDF to a large carious lesion in the lower left first permanent molar. A white precipitate forms following SDF application. This becomes translucent after repeated KI application

SDF/KI precipitate nearly doubled the bond strength to GIC.

An *in vitro* study by Soeno *et al.*[47] in 2001 examined the effect of a range of desensitisers, including an ammoniated silver fluoride desensitiser, on bond strength of adhesive resin luting agents to dentine. The study found that ammoniated silver fluoride (SDF) had the potential to significantly reduce the dentine bond strength; however, bond strengths were increased when used in combination with a sodium hypochlorite conditioning agent.

An *in vitro* study by Koizumi *et al.*[48] examined the effect of SDF and KI on a range of adhesive systems' bond strength to dentine. The study found that SDF and KI have the potential to significantly reduce the bond strength of the adhesive systems to dentine. A recommendation is made that if SDF/KI is to be used, the dentine surface is to be roughened prior. The study, however, failed to rinse and air-dry the surface of the SDF as recommended by Knight *et al.*

Greenwall-Cohen *et al.*[49] examined the effective of SDF adhesive protocols on bond strength to high-viscosity GIC. The study found that no adhesive protocol made a significant difference on bond strength to GIC; however, bond strength to GIC with SDF without KI resulted in higher bond strengths than with SDF with KI. Additionally, the study found that use of polyacrylic acid conditioning agent after SDF/KI use resulted in higher bond strength.

Ultimately, with regards to SDF and bond strength, further research is still required. If SDF and KI are to be used, it is essential that the precipitate is washed and air-dried thoroughly before application of the adhesive system or material. Use of a conditioning agent or acid etch post-application of SDF/KI may further improve bond strength. Additionally, surface abrasion may improve bond strength, although there is no clinical research to demonstrate this. Finally, if an adhesive resin cement is required, more invasive measures may be required, such as partial removal of SDF-affected dentine.

An important theoretical question is raised with regards to bond strength and stability of the bond on survival of a restoration. Is high-bond strength more important than a stable adhesive interface? Additionally, will a higher bond strength or a more stable bond improve the success of a restoration? Further research into this topic will be required before a conclusive answer can be provided.

Fig. 4 SDF placed on the 85 before restoration. SDF has resulted in a white lesion on the vermilion border of the right-hand side of the lip. This usually disappears within 48 hours without treatment

Effect on dentino-pulp complex

It has been suggested that SDF should not be used in carious lesions with close proximity to the pulp,[50] due to the potential for silver ion penetration into the pulp complex. However, a study by Rossi *et al.* in 2017[51] examined the effect of SDF on the pulp complex by examining a histological study of human teeth treated with SDF and experimental studies on laboratory animals. In the *ex vivo* study of human teeth, microscopy demonstrated that SDF sealed dentinal tubules only at the site where it had been placed, with limited penetration beneath. The pulp tissue associated to treated caries showed chronic inflammatory infiltrate and formation of tertiary dentine, with no Ag precipitate. The study concluded that SDF induces minimal adverse effects to the pulp.

An *in vivo* comparison study by Korwar *et al.*[52] examined the effect of SDF and GIC as an indirect pulp-capping material. The study concluded that SDF and GIC did not induce inflammatory changes in the pulp complex and had good tertiary dentine-inducing capabilities. It must be noted that this study was only undertaken with four premolars.

A study by Gotjamanos *et al.*[53] examined the effect of silver fluoride on the dental pulps of 55 carious primary teeth, applied 3–56 months before extraction for orthodontic reasons. The study demonstrated a favourable pulp response to silver fluoride, the presence of abundant reparative dentine and a wide odontoblastic layer.

SDF, therefore, shows promising properties as an indirect pulp-capping material and for use in deep carious lesions. Its ability to arrest dentine caries could also reduce the amount of iatrogenic pulpal exposures by reducing the amount of tissue requiring removal. No literature currently examines the effect of SDF with regards to pulp exposures and direct pulp-capping treatments. Until further evidence is produced, use of SDF in this application would not be recommended.

SDF effect on the gingiva

SDF has been reported to potentially result in gingival erythema,[37] gingival inflammation, gingival bleaching and gingival pain[54] (Fig. 2). This was shown not to be significantly different to baselines, was noted as being transient (less than seven days) and was not severe. Additionally, this erythema was not accompanied by any long-term staining of the gingiva.[37]

SDF effect on mucosa and skin

Due to the high pH of SDF, mucosal or skin burns may occur post-application (Fig. 4). The burns tend to be small, mildly painful white lesions in the mucosa, which disappear after 48 hours without treatment.[29]

Moreover, SDF can stain clothes and skin of the body. Though it does not cause pain or damage, SDF skin staining cannot be easily washed away and takes around seven days to disappear. SDF clothes staining however is permanent.

Fig. 5 A lower left second primary molar presenting with a large carious lesion before isolation. No clinical or radiographic signs or symptoms of pulpal involvement were noted. This is an ideal candidate for SDF treatment

Fig. 6 Due to limited cooperation of the patient, isolation with a rubber dam could not be utilised. As such, cotton wool roll, gauze and petroleum jelly were utilised for application

Clinical technique

Preparation

SDF has the potential to stain clinical worktops and clothing. Therefore, use of a plastic-lined work surface should be implemented. Additionally, plastic bibs for patients are required.

Isolation

Several precautions need to be undertaken before application of SDF to minimise unwanted side effects. Ideally, use of complete isolation with a rubber dam (Figures 1a, 1b and 3) should be undertaken; however, this may not always be possible. Some products include a light-cured liquid dam to apply onto the mucosa of the teeth and adjacent teeth receiving treatment.

If rubber dam or liquid dam is not available, it is essential that petroleum jelly is placed onto the gingiva and cotton wool used to isolate the tooth (Figures 5, 6 and 7). Effective isolation of the teeth minimises gingival and mucosal irritation associated with the application of the SDF. Horst *et al.*[34] also believe that dryness of the tooth benefits SDF placement; however, no literature demonstrated the effect of moisture on SDF success.

Placement of a gauze in the mouth is also essential to protect the tongue and floor of the mouth. It is also recommended to place petroleum jelly around the lips and vermilion border in order to minimise the risk of SDF skin staining.

Caries removal

As described previously, no significant benefit of caries excavation before application of SDF was noted in the Chu *et al.* study.[28] It is, however, the authors' recommendation to remove soft, necrotic, infected dentine before application of SDF, in order to sufficiently reduce the bacterial load. However, this is case-dependent, and risk of iatrogenic exposure must be weighed up before caries removal.

Application

A micro brush should be fully immersed in SDF solution and applied directly to the tooth surface in question. SDF should ideally be left for one to three minutes[34] (Fig. 7); however, it must be appreciated that this may not always be possible, especially with uncooperative patients. Patients will often describe a 'metallic taste' when SDF is applied. Excess should then be appropriately removed with cotton wool or a gauze.

If KI is to be applied, then a micro brush, fully immersed in the KI, should be applied to the SDF (Fig. 8). Initially, a white precipitate will form. KI should be repeatedly applied until the precipitate turns colourless. As mentioned previously, leaving precipitate on the tooth may result in a reduction in bond strength;[46] therefore, precipitate should be rinsed away and the tooth air-dried before undertaking further restorative intervention.

If contact with the mucosa occurs, it is essential that the area be thoroughly rinsed. The burn/staining usually appears as a mixed white/black lesion, which usually resolves within one to two weeks.[4]

Further restorative treatment

As described previously, acid etchant or acid conditioning agent should be applied only after application of the SDF (with or without KI). SDF (with or without KI) should be thoroughly washed and air-dried from the tooth after application. SDF application should be restricted to dentine wherever possible to minimise SDF contamination of enamel; however, due to the method of application (micro brush), this may be difficult to undertake. Surface abrasion of the SDF dentine may also be beneficial to improve adhesive bond strength.

As described previously, if an adhesive resin cement is required, more invasive measures may be required, such as partial removal of SDF-affected dentine. Again, risk of iatrogenic exposure must be analysed on case-based decisions before excavation of dentine.

SDF concentrations

A range of SDF concentrations are available for SDF. Two prospective randomised control trials[55,56] have examined the effect of concentration on caries arrest. Both studies

Fig. 7 SDF was applied to the lower left second primary molar with a micro brush for three minutes

Fig. 8 Following application of the SDF, KI was applied to the lower left second primary molar. Notice the white precipitate forming following the application. KI was applied until the white precipitate was rendered colourless

compared 38% and 12% SDF in its ability to arrest caries. Both studies found that 38% SDF was more effective in arresting caries than 12% SDF. As such, it is recommended to utilise a higher (38%) concentration of SDF.

Frequency of application

Two randomised control trials[56,57] have compared the use of annual and six-monthly application of SDF. Both found that six-monthly SDF application is more effective at arresting caries than yearly application. As such, six-monthly application would be recommended for caries arrest with SDF.

Post-application

If fluoride varnish is to be used post-application of the SDF, the varnish must not be applied to the surfaces where SDF has been placed, as it may reduce the antibacterial action of the SDF.[58]

Conclusion

Studies and clinical cases have found that SDF has a broad application in dentistry. SDF treatment is an efficient, simple, quick and safe method of dental treatment. Despite its recent popularity in the UK, it has been used internationally for upwards of 80 years. Further research continues to be undertaken on SDF, especially with regards to the integration of the product into restorative protocols and with regards to methods for minimising side effects, especially with regards to the staining and discolouration associated with the product.

References

1. Royal College of Surgeons. The state of children's oral health in England. 2015. Available online at https://www.rcseng.ac.uk/library-and-publications/rcs-publications/docs/report-childrens-oral-health/ (accessed April 2020).
2. Public Health England. Delivering Better Oral Health: An Evidence-Based Toolkit for Prevention. 3rd ed. 2014. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/605266/Delivering_better_oral_health.pdf (accessed May 2019).
3. Rosenblatt A, Stamford T C, Niederman R. Silver diamine fluoride: a caries "silver-fluoride bullet". *J Dent Res* 2009; **88:** 116–125.
4. Chu C H, Lo E C. Promoting caries arrest in children with silver diamine fluoride: a review. *Oral Health Prev Dent* 2008; **6:** 315–321.
5. Melaiye A, Youngs W J. Silver and its application as an antimicrobial agent. *Expert Opin Ther Pat* 2005; **15:** 125–130.
6. Barillo D J, Marx D E. Silver in medicine: A brief history BC 335 to present. *Burns* 2014; DOI: 10.1016/j.burns.2014.09.009.
7. Lansdown A B. Silver in health care: antimicrobial effects and safety in use. *In* Hipler U C, Elsner P (eds) *Biofunctional Textiles and the Skin*. pp 17–34. Basel: Karger Publishers, 2006.
8. Klasen H J. A historical review of the use of silver in the treatment of burns. II. Renewed interest for silver. *Burns* 2000; **26:** 131–138.
9. Stebbins E A. What value has argenti nitras as a therapeutic agent in dentistry? *Int Dent J* 1891; **12:** 661–670.
10. Howe P R. A method of sterilizing and at the same time impregnating with a metal affected dentinal tissue. *Dent Cosmos* 1917; **59:** 891–904.
11. Peng J Y, Botelho M G, Matinlinna J P. Silver compounds used in dentistry for caries management: a review. *J Dent* 2012; **40:** 531–541.
12. Nishino M, Yoshida S, Sobue S, Kato J, Nishida M. Effect of topically applied ammoniacal silver fluoride on dental caries in children. *J Osaka Univ Dent Sch* 1969; **9:** 149–155.
13. Craig G G, Powell K R, Cooper M H. Caries progression in primary molars: 24-month results from a minimal treatment programme. *Community Dent Oral Epidemiol* 1969 **9:** 260–265.
14. McDonald S P, Sheiham A. A clinical comparison of non-traumatic methods of treating dental caries. *Int Dent J* 1994; **44:** 465–470.
15. Thibodeau E A, Handelman S L, Marquis R E. Inhibition and killing of oral bacteria by silver ions generated with low intensity direct current. *J Dent Res* 1978; **57:** 922–926.
16. Ostela I, Tenovuo J. Antibacterial activity of dental gels containing combinations of amine fluoride, stannous fluoride, and chlorhexidine against cariogenic bacteria. *Scand J Dent Res* 1990; **98:** 1–7.
17. Oppermann R V, Johansen J R. Effect of fluoride and non-fluoride salts of copper, silver and tin on the acidogenicity of dental plaque in vivo. *Scand J Dent Res* 1980; **88:** 476–480.
18. Oppermann R V, Rölla G. Effect of some polyvalent cations on the acidogenicity of dental plaque in vivo. *Caries Res* 1980; **14:** 422–427.
19. Knight G, McIntyre J, Craig G *et al.* An in vitro model to measure the effect of a silver fluoride and potassium iodide treatment on the permeability of demineralized dentine to Streptococcus mutans. *Aust Dent J* 2005; **50:** 242–245.
20. Mei M L, Li Q L, Chu C H, Lo E M, Samaranayake L P. Antibacterial effects of silver diamine fluoride on multi-species cariogenic biofilm on caries. *Ann Clin Microbiol Antimicrob* 2013; **12:** 4.
21. Mei M L, Chu C H, Low K H *et al.* Caries arresting effect of silver diamine fluoride on dentine carious lesion with *S. mutans* and L. acidophilus dual-species cariogenic biofilm. *Med Oral Patol Oral Cir Bucal* 2013; **18:** 824–831.
22. Peng J Y, Botelho M G, Matinlinna J P. Silver compounds used in dentistry for caries management: a review. *J Dent* 2012; **40:** 531–541.
23. Mei M L, Ito L, Cao Y, Li Q L, Lo E C, Chu C H. Inhibitory effect of silver diamine fluoride on dentine demineralisation and collagen degradation. *J Dent* 2013; **41:** 809–817.
24. Zhao I S, Gao S S, Hiraishi N *et al.* Mechanisms of silver diamine fluoride on arresting caries: a literature review. *Int Dent J* 2018; **68:** 67–76.

25. Mei M L, Li Q L, Chu C H, Yiu C K, Lo E C. The inhibitory effects of silver diamine fluoride at different concentrations on matrix metalloproteinases. *Dent Mat* 2012; **28:** 903–908.
26. Mei M L, Ito L, Cao Y, Li Q L, Chu C H, Lo E C. The inhibitory effects of silver diamine fluorides on cysteine cathepsins. *J Dent* 2014; **42:** 329–335.
27. Tjäderhane L, Nascimento F D, Breschi L *et al*. Optimizing dentin bond durability: control of collagen degradation by matrix metalloproteinases and cysteine cathepsins. *Dent Mat* 2013; **29:** 116–135.
28. Chu C H, Lo E C, Lin H C. Effectiveness of silver diamine fluoride and sodium fluoride varnish in arresting dentin caries in Chinese pre-school children. *J Dent Res* 2002; **81:** 767–770.
29. Llodra J C, Rodriguez A, Ferrer B, Menardia V, Ramos T, Morato M. Efficacy of silver diamine fluoride for caries reduction in primary teeth and first permanent molars of schoolchildren: 36-month clinical trial. *J Dent Res* 2005; **84:** 721–724.
30. Braga M M, Mendes F M, De Benedetto M S, Imparato J C. Effect of silver diammine fluoride on incipient caries lesions in erupting permanent first molars: a pilot study. *J Dent Child (Chic)* 2009; **76:** 28–33.
31. dos Santos Jr V E, De Vasconcelos F M, Ribeiro A G, Rosenblatt A. Paradigm shift in the effective treatment of caries in schoolchildren at risk. *Int Dent J* 2012; **62:** 47–51.
32. Duangthip D, Chu C H, Lo E C. A randomized clinical trial on arresting dentine caries in preschool children by topical fluorides – 18 month results. *J Dent* 2016; **44:** 57–63.
33. U.S. Food & Drug Administration. 510(k) Premarket Notification: Diammine Silver Fluoride Dental Hypersensitivity Varnish. 2014. Available at http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpmn/pmn.cfm?ID=K102973 (accessed March 2019).
34. Horst J A, Ellenikiotis H, Milgrom P M, UCSF Silver Caries Arrest Committee. UCSF protocol for caries arrest using silver diamine fluoride: rationale, indications, and consent. *J Calif Dent Assoc* 2016; **44:** 16.
35. Markowitz K, Pashley D H. Discovering new treatments for sensitive teeth: the long path from biology to therapy. *J Oral Rehabil* 2008; **35:** 300–315.
36. Craig G G, Knight G M, McIntyre J M. Clinical evaluation of diamine silver fluoride/potassium iodide as a dentine desensitizing agent. A pilot study. *Aust Dent J* 2012; **57:** 308–311.
37. Castillo J L, Rivera S, Aparicio T *et al*. The short-term effects of diammine silver fluoride on tooth sensitivity: a randomized controlled trial. *J Dent Res* 2011; **90:** 203–208.
38. Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. *J Biomed Mat Res* 1982; **16:** 265–273.
39. Hashimoto M, Ohno H, Kaga M, Endo K, Sano H, Oguchi H. In vivo degradation of resin-dentin bonds in humans over 1 to 3 years. *J Dent Res* 2000; **79:** 1385–1391.
40. Mei M L, Ito L, Cao Y, Li Q L, Lo E C, Chu C H. Inhibitory effect of silver diamine fluoride on dentine demineralisation and collagen degradation. *J Dent* 2013; **41:** 809–817.
41. Hiraishi N, Yiu C K, King N M, Tagami J, Tay F R. Antimicrobial efficacy of 3.8% silver diamine fluoride and its effect on root dentin. *J Endod* 2010; **36:** 1026–1029.
42. Knight G M, McIntyre J M, Craig G G, Mulyani. Ion uptake into demineralized dentine from glass ionomer cement following pretreatment with silver fluoride and potassium iodide. *Aust Dent J* 2006; **51:** 237–241.
43. Quock R L, Barros J A, Yang S W, Patel S A. Effect of silver diamine fluoride on microtensile bond strength to dentin. *Oper Dent* 2012; **37:** 610–616.
44. Camacho K J, English J D, Jacob H B *et al*. Silver diamine fluoride and bond strength to enamel in vitro: A pilot study. *Am J Dent* 2018; **31:** 317–319.
45. Wang A S, Botelho M G, Tsoi J K, Matinlinna J P. Effects of silver diammine fluoride on microtensile bond strength of GIC to dentine. *Int J Adhes Adhes* 2016; **70:** 196–203.
46. Knight G M, McIntyre J M. The effect of silver fluoride and potassium iodide on the bond strength of auto cure glass ionomer cement to dentine. *Aust Dent J* 2006; **51:** 42–45.
47. Soeno K, Taira Y, Matsumura H, Atsuta M. Effect of desensitizers on bond strength of adhesive luting agents to dentin. *J Oral Rehabil* 2001; **28:** 1122–1128.
48. Koizumi H, Hamama H H, Burrow M F. Effect of a silver diamine fluoride and potassium iodide-based desensitizing and cavity cleaning agent on bond strength to dentine. *Int J Adhes Adhes* 2016; **68:** 54–61.
49. Greenwall-Cohen J, Francois P, Dursen E, Le-Geoff S, Pierre-Attal J, Greenwall L H. The influence of silver diamine fluoride adhesive protocols on shear bond strength of high-viscosity glass ionomer cement to dentine. Abstract number 2357. ConsEuro, Berlin. 2019.
50. Hu S, Meyer B, Duggal M. A silver renaissance in dentistry. *Eur Arch Paediatr Dent* 2018; **19:** 221–227.
51. Rossi G, Squassi A, Mandalunis P, Kaplan A. Effect of silver diamine fluoride (SDF) on the dentin-pulp complex: ex vivo histological analysis on human primary teeth and rat molars. *Acta Odontol Latinoam* 2017; **30:** 5–12.
52. Korwar A, Sharma S, Logani A, Shah N. Pulp response to high fluoride releasing glass ionomer, silver diamine fluoride, and calcium hydroxide used for indirect pulp treatment: An in-vivo comparative study. *Contemp Clin Dent* 2015; **6:** 288.
53. Gotjamanos T. Pulp response in primary teeth with deep residual caries treated with silver fluoride and glass ionomer cement ('atraumatic'technique). *Aust Dent J* 1996; **41:** 328–334.
54. Duangthip D, Fung M H, Wong M C, Chu C H, Lo E C. Adverse effects of silver diamine fluoride treatment among preschool children. *J Dent Res* 2018; **97:** 395–401.
55. Yee R, Holmgren C, Mulder J, Lama D, Walker D, van Palenstein Helderman W. Efficacy of silver diamine fluoride for arresting caries treatment. *J Dent Res* 2009; **88:** 644–647.
56. Fung M H, Duangthip D, Wong M C, Lo E C, Chu C H. Randomized clinical trial of 12% and 38% silver diamine fluoride treatment. *J Dent Res* 2018; **97:** 171–178.
57. Zhi Q H, Lo E C M, Lin H C. Randomized clinical trial on effectiveness of silver diamine fluoride and glass ionomer in arresting dentine caries in preschool children. *J Dent* 2012; **40:** 962–967.
58. Ollie Y Y, Zhao I S, Mei M L, Lo E C, Chu C H. Caries-arresting effects of silver diamine fluoride and sodium fluoride on dentine caries lesions. *J Dent* 2018; **78:** 65–71.