Minimally Invasive Techniques Used for Caries Management in Dentistry. A Review

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Objective: *Minimally invasive techniques that use silver compounds and glass ionomer cement are suggested for caries management due to their effectiveness, simplicity, and low cost. The aim of this review is to examine the evidence supporting the use of silver compounds and glass ionomer cement in dentistry.* ***Study design:*** *Literature was searched using PubMed, Elsevier, EBSCO, Google scholar, AAPD and UABC's database from 1958 to 2018 with the keywords: "Silver nitrate", "silver diamine fluoride", and "glass ionomer cement". The selected studies were then fully read to prove their relevance for this review.* ***Results:*** *The use of glass ionomer cement and silver compounds were shown to be effective in arresting caries. These compounds reduce cariogenic microorganisms. Their chemical properties inhibit bacterial growth while promoting remineralization. They are simpler and less time consuming than conventional restorations. They also cause less discomfort and anxiety to patients. Silver compounds were shown to stain teeth and may burn the cornea if used in high concentration. These disadvantages limit the use of silver compounds to posterior teeth and require caution when handling.* ***Conclusions:*** *Minimally invasive therapies are easy to apply, non-invasive and affordable. Further studies should be done to provide more evidence of these techniques for caries management.*

Keywords: Atraumatic Restorative Treatment (ART), glass ionomer cement (GIC), silver nitrate (SN), silver diamine fluoride (SDF), remineralization, inhibition of bacterial growth.

INTRODUCTION

Although people's dental knowledge has improved and dental treatments techniques have advanced in the past decades, international data on caries epidemiology confirms that dental caries continues to be a prevalent and severe disease that is found in both developing and developed countries around the world.[1-3] Even though dental caries does not jeopardize life, it brings considerable consequences like pain, infections, and tooth loss if not treated on time, as well as esthetic and functional consequences.[4, 5]

Dietary sugars, poor oral hygiene, poor parental education, adverse socioeconomic conditions, low family income, and regular medications are important factors of high-risk causing dental caries.[1] Treatment of dental caries in a general population is often either unavailable or unaffordable, especially for child populations. Moreover, cooperation from children during dental treatment is usually very challenging, requiring advanced skills of clinicians in addition to the high cost of general anesthesia or sedation for patient management. Some clinicians have suggested the implementation of minimally invasive techniques for caries management in dentistry.[1,3]

Traditionally, treatment of tooth decay consists of less conservative therapies, which implies greater destruction of healthy dental tissue in order to increase the restorative material's mechanical retention. Minimally invasive treatments have been proposed as an alternative therapy, which has evolved in with the development of

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new biomaterials. Minimally invasive treatments have been used in primary teeth with cavitated lesions in order to maintain pulp vitality, enable space conservation, and allow the natural process of exfoliation and tooth replacement without the administration of local anesthesia.[2,6,7]

Among these minimally invasive strategies, the use of atraumatic restorative treatment with glass ionomer cement (ART), silver nitrate (SN), and silver diamine fluoride (SDF) have been proposed for caries management in dentistry. Even though these materials have been used for decades in countries like Japan, China, and Australia, silver compounds (SN and SDF) and glass ionomer cements have not been commonly used in the U.S. for caries management. The aim of this literature review was to compare the effectiveness of these minimally invasive techniques in caries management. The advantages of these techniques, including cost and clinical advantage, were also evaluated. This literature review was conducted to illustrate the importance of minimally invasive techniques in caries managements for American populations, especially child populations, hoping to help incorporate these techniques into the standard of care in the U.S.

MATERIALS AND METHOD

To explore minimally invasive techniques used for caries management, we followed the protocol below:

We searched in database of PubMed, Elsevier, EBSCO, Google scholar, AAPD and UABC's metasearch for relevant studies published from 1958 to 2018. This search strategy employed the following keywords: "SDF", "SN", "Silver nitrate", "silver nitrate in dentistry", "silver diamine fluoride", "silver compounds", "silver compounds in dentistry", "ART", "atraumatic restorative treatment", "minimally invasive techniques", "glass ionomer cement", "silver nitrate and silver diamine fluoride", "minimally intervention in dentistry," and "silver nitrate & fluoride varnish."

We included all type of studies in this literature review such as case reports, *in vitro* & *in vivo* articles, clinical trials, literature reviews, and statistical analysis. For data extraction, three reviewers searched for relevant studies by evaluating the titles and the abstracts. The selected studies were then fully read to determine their relevance for this review. Data extraction waas performed for the studies included. Base on the description of the protocol, this literature review is not classified as a meta-analysis.

RESULTS

There were 214 articles found in the databases, but only 60 eligible articles were identified for this review [Table 1]. Among the eligible articles, there were 14 clinical trials, 10 in-vitro, two in-vivo, one in-vitro/in-vivo studies, 25 reviews and meta-analyses, two case reports, three statistical analyses, two guidelines, and one presentation. The review included diverse studies that were conducted in Brazil (five studies), Australia (three studies), China (nine studies), the U.S. (six studies), Argentina (one study), Thailand (two studies), Colombia (one study), South Africa (one study), Ireland (one study), the U.K. (two studies), and Nepal (one study). Most of the studies included in this review were written in English. With the studies written in Spanish, a researcher who is bi-lingual in both English and Spanish was in charge of reviewing these studies. Studies written in language other than Spanish and English were excluded.

Table 1: Eligible articles for the current review

No.	Author	Year of publish	Material used	Study design	Country
1	AAPD	2018	SDF	Review	
2	Brito AL et al	2017	ART	Clinical trial	Brazil
3	Freitas MCC et al	2018	ART	Clinical trial	Brazil
4	Chu et al	2008	SDF	Review	
5	Bagramian et al	2009	Dental caries	Review	
6	Bresciani et al	2005	ART	In vivo	Brazil
7	Ferreira et al	2012	Minimally invasive	Review	
8	Arrow P et al	2015	ART	Clinical trial	Australia
9	Van't Hof et al	2006	ART	Review	
10	Ladewig NM et al	2017	ART	Clinical trial	Brazil
11	Raggio et al	2013	ART	Review	
12	Hansen RN et al	2017	SN	Statistal analysis	USA
13	Zhao IS et al	2017	SN	In vitro	China
14	Mickenautsch et al	2007	ART	Clinical trial	South Africa
15	Gao SS et al	2018	SN	Review	
16	AAPD	2017	SDF	Review	
17	Gold J	2017	SDF	Review	
18	Devji	2018	SDF/ART	Review	
19	Simon et al	2015	ART	Review	
20	Tonmukay-akul et al	2017	ART	Statiscal analysis	Australia
21	da Mata et al	2014	ART	Clinical trial	Ireland
22	Crystal YO et al	2017	SDF	Statistal analyses	USA
23	Maragaliano P et al	2016	SDF	Guideline	
24	Gao et al	2016	SDF	Review	
25	Tomar et al	2017	SDF	Presentation	
26	Gao SS et al	2016	SDF	Review	
27	Brooke MO et al	2018	SDF	Review	
28	AAPD	2017	SDF	Guideline	
29	Duangthip D et al	2018	SDF	Clinical trial	China
30	Peng JJY et al	2012	Silver Compounds	Review	
31	Milgrom P et al	2018	SDF	Clinical trial	USA

No.	Author	Year of publish	Material used	Study design	Country
32	Vanegas S et al	2014	SDF	In vitro	Colombia
33	Mabangkhru et al	2020	SDF	Clinical trial	Thailand
34	Rojas F	2008	Fluoride	Review	
35	Chu CH et al	2008	SDF	In vitro	China
36	Pettar M et al	2011	Minimal intervention	Review	
37	Aida KL et al	2017	ART	In vitro/in vivo	Brazil
38	Silvestry NR et al	2007	Silver Compounds	Review	
39	Wahlberg V	1982	Neonatal care	Review	
40	Moir J et al	2012	SN	Case report	UK
41	Klein U et al	1999	SN/SDF/SF/ Sn+F	In vitro	USA
42	Duffin S	2012	Caries Manage-ment	Case study	USA
43	Rai M et al	2009	Silver nanoparti-cles	Review	
44	James PMC et al	1954	SN	Clinical trial	UK
45	Knight GM et al	2009	SDF	In vitro	Australia
46	Youravong N et al	2011	SN/SDF	In vitro	Thailand
47	Mei ML et al	2013	SDF	In vitro	China
48	Rosenblatt AA et al	2009	SDF	Review	
49	Horst JA et al	2016	SDF	Review	
50	Yee R et al	2009	SDF	Clinical trial	Nepal
51	Chu CH et al	2010	Fluoride	Review	
52	Zhao IS et al	2018	SDF	Review	
53	Gao SS et al	2017	SN/SDF	Clinical trial	China
54	Chou R et al	2014	SN	Review	
55	Hyde EJ	1973	SDF/SN	In vivo	USA
56	Molina GF et al	2013	GIC/ART	In vitro	Argentina
57	Mei ML et al	2012	SDF	In vitro	China
58	Liu BY et al	2012	SDF	In vitro	China
59	Chu CH et al	2002	SDF/FV	Clinical trial	China
60	Zhi QH et al	2012	SDF/GIC	Clinical trial	China

Atraumatic Restorative Treatment (ART)

Atraumatic Restorative Treatment (ART) is a minimally invasive technique that includes preventive measures, sealing as well as cavity filling. The restoration technique consists of removing soft and demineralized dentin using only manual instruments followed by a restoration with a glass ionomer cement, leaving aside the use of hand pieces, burs and local anesthesia.[8] ART is considered to be a valuable approach in treating dental caries for people living in under-served areas of the world where resources and facilities are limited. This technique was initially created around 1985.[8]

When it was first introduced, the indication of ART was reserved for teeth with cavitated caries lesions that, with no other treatment available, would cause tooth extraction in the less privileged communities in developing countries. Since this treatment had a successful response, through high-quality restorations, it led to questioning if ART could bring benefits not only to less privileged communities but as a minimally invasive technique that can be used in all kinds of population. Many studies have shown that ART is an appropriate approach for caries management and is comparable to conventional restorations.[9-13] A study showed that 97.3% of the primary teeth treated with ART were successful and had no caries present on a cavo-surface margin or around glass ionomer restorations.[11] It was shown that ART restorations on single surfaces of primary and permanent teeth using a high-viscosity glass ionomer had high survival rates.[13] There were few studies comparing ART restorations with conventional restorations. The reasons for this small number of studies could be that the studies with negative findings were often considered to have non-significant results and therefore could be rejected for publication. A meta-analysis review was conducted to compare the survival rate between ART and conventional restorations using three eligible articles from 126 articles.[14] It was concluded that survival rate of ART using high-viscous glass ionomer cement was similar to those of conventional amalgam and composite resin restorations in occlusal-proximal cavities.[14] As ART is considered to be a universal approach, regardless of the patients economic or social situation, ART can be used as a alternative treatment in caries management for general populations of children and adults.

Conventional restorations using composite resin are still one of the most common treatments used in dental clinics. Despite the advantage that composite resins give us such as aesthetics, preservation of dental structure and abrasion wear rate similar to that of natural primary teeth, all composite resins have polymerization shrinkage. This factor compromises marginal integrity and restoration longevity. In addition, to take full advantage of the properties of composite resin, it is absolutely necessary to use isolation with rubber dam, making the conventional technique time consuming and more traumatic for pediatric patients.[15]

An alternative to the conventional restorations is ART. This technique is an effective method to prevent and control carious lesion development due to the cariostatic effect of the silver component. Since it only requires hand instrument, ART was thought to have a potential in reducing dental anxiety and increasing patient's compliance, especially in children. A clinical trial was conducted in South Africa to evaluate the effects of ART on dental anxiety in children by assessing their anxiety level immediately after receiving ART or conventional treatment (which included administration of anesthesia and drilling of teeth) using verified surveys.[16] It showed

that the level of anxiety in children received ART was significantly lower than that of the children received conventional restorations.[16] Very few studies compared the effects of ART and conventional treatment on dental anxiety. A meta-analysis review failed to show any difference in dental anxiety between ART and conventional treatment by using three eligible studies from 416 studies retrieved from literature search.[17] ART also represents a minor economical cost. An Irish study showed that the average cost for ART restoration was lower than the average cost of conventional resin restoration in elderly adults.[18] Similar study in Western Australia also showed that ART was a cost-effective treatment when compared to conventional treatment as ART approach resulted in fewer specialist referral and lower total cost when treating dental caries in children.[19]

The correct execution of ART changes the balance of the oral microbiota, causing a reduction of cariogenic microorganisms. This change is an important factor because children affected by caries have high counts of cariogenic bacteria in saliva, such as mutant streptococci, lactobacilli, and other species such as candida albicans.[20]

The material of choice for ART is high-viscosity glass ionomer cement (GIC), which provides biocompatibility. Fluoride release helps promote remineralization and chemical adhesion to the tooth surface. ART has a thermal expansion similar to natural teeth and can be placed in a single increment.[15] This last quality gives us a huge advantage in reducing working time in dental chair.

Comparison Between Conventional Restorative Techniques And Art

Conventional restorative techniques require the use of a dental hand piece, bur, isolation with rubber dam, and the use of anesthesia. On the other hand, ART requires manual instruments and restorative materials that are more biologically friendly. ART reduces the risk for caries due to the release of fluoride ions, which leads to minimally invasive preparations and lower costs (including overhead as well as direct costs). Moreover, ART technique can reduce dental anxiety mostly in pediatric patients. All these qualities are important factors in low-income countries, where electricity is intermittent and people have difficulties accessing dental care. In general, many vulnerable populations could benefit from the ART approach.[8]

Requirements for the ART technique include:[15]

- Maintaining relative isolation of the operatory field with cotton rolls and gauze.
- Removing caries with hand excavators according to the size of the carious cavity.
- Removing infected dentin from the dentin–enamel junction and leaving some of the affected dentin that could be re-mineralized with glass ionomer.
- Cleaning the cavity by rinsing cavity walls with water.
- Restoring with GIC: In case of an occlusal-proximal cavity, use an adapted matrix strip with a wooden wedge to maintain it in place. This techinque provides appropriate contour and contact point to the restoration.
- Checking the occlusion with articulating paper. Look for any high points. If necessary, a handpiece can be used.
- Giving the patient instructions not to eat solid food for one hour.

Silver Compounds Through History

The use of silver in dentistry dates back to 659 A.D. in China. It was used for its material properties and for the long-known antimicrobial effects. Silver has been accepted as an antimicrobial material for thousands of years.[21, 22] In the 1800s, silver (Ag) was used in dentistry and medicine for its anti-caries, antimicrobial and anti-rheumatic properties. In the 1900s, silver compounds were popular for treating tetanus and rheumatism. Some clinicians attempted using silver to treat colds and gonorrhea before antibiotics were invented.[23, 24] Physicians used silver nitrate to chemically cauterize umbilical granulomas and warts. In the late 19th century, silver nitrate was used to treat venereal diseases. A solution of 1% silver nitrate as eye drops for newborn babies could protect their eyes from the transmission of gonorrhea from mothers during birth.[21, 25] After antibiotics were discovered, health professionals reported the superior effect of antibiotics compared to silver compounds due to their higher efficacy in treating infections. The successful clinical outcome of antibiotics reduced the clinical and research interests in silver compounds.[21, 22]

In dentistry, silver compounds were used early in the 1840s, when silver nitrate was used for reducing the incidence of caries in the primary dentition.[21, 22] Later, it was used as a caries- preventing agent for permanent molars.[22, 26, 27] In the 1960s, it was advocated to combine silver with fluoride as an anticaries agent for a combined beneficial effect.[22, 27] More recently, a new silver compound called silver diamine fluoride was developed that has both the cariostatic effect of silver ion and remineralizing effect of fluoride.

A. Silver Nitrate (Sn) + 5% Fluoride Varnish (Naf) For Caries Management

The use of silver nitrate (SN), whose chemical formula is $AgNO_3$, was reported to be the first silver compound used for arresting caries in the 1840s.[21] In 1917, Howe proposed a simple procedure to generate metallic silver, which was later known as Howe's ammoniacal silver nitrate solution ($AgNH_3NO_3$).[23] Silver nitrate was then adopted for caries management.[23] It was reported that silver nitrate could arrest dental caries on both permanent and primary teeth.[23] Metallic silver within Howe's solution was believed to penetrate into affected dentin and have an antibacterial effect. However, Howe's solution was only used up to the 1950s. Doubts of its clinical efficacy and possible adverse effects were mentioned by several studies concluding that it could penetrate vital and non-vital dentine; it was also said to have a self-limiting and localized effect on the pulp.[23] Silver nitrate can be toxic if ingested; however, silver nitrate in very low concentrations is used in dentistry. For example, the commonly used 25% SN contains 0.25 grams of silver nitrate in a 1 milliliter solution, which is equivalent to 20 drops.[21] Since each patient often needs only one to two drops during the treatment, the level of silver nitrate exposed to patient is extremely low. Countries, such as Japan, China, and Australia, have used silver nitrate in dentistry for decades. As silver nitrate can penetrate into vital and non-vital dentin, it is limited to teeth that have no pulpal infection and abscesses to prevent inflammatory response. Today, silver is again favored as an antimicrobial agent due to its low toxicity and bacterial resistance.[22]

Caries can progress and demineralize enamel and dentine that usually leads to pulpal infection. Yet, its progression can be

minimized through remineralization. Sodium fluoride promotes remineralization and silver nitrate has a profound antimicrobial effect.[21] A laboratory study investigated the use of silver nitrate solution on artificial caries lesions in a microbial biofilm model.[27] The results showed that caries progression (lesion depth) was significantly lower with silver nitrate application when compared with no treatment. Another study showed that silver nitrate inhibited the growth of all tested oral bacteria.[28] Silver nitrate was thus suggested to have strong antibacterial action.

Other studies have suggested that the combined application of silver nitrate solution followed by sodium fluoride varnish can be used to arrest dental caries.[21] Duffin proposed the use of ions from 25% SN solution followed by 5% NaF varnish application as a non-invasive procedure to treat caries in children.[29] The results showed that almost all caries lesions were arrested after treatment. Radiographic examination showed the formation of secondary dentin. Subsequent restorations could be done without the need for local anesthesia, which also suggested that secondary dentine was formed. The clinical follow up showed that almost all (98%) of carious lesions remained arrested for up to four years after treatment.[29] An in-vitro study also confirmed that the caries-arresting effect of a 25% SN solution followed by 5% NaF varnish application enhanced the remineralization process of artificial caries-affected dentine and inhibited the degradation of dentin's collagen.[30] A study using scanning electron microscopy showed that the teeth that received 25% SN + 5% NaF had no dentine collagen exposed, with smaller mean lesion depth, and lower hydroxyproline released from dentine when compared to the control non-treated teeth.[30] The application of silver nitrated followed by fluoride vanish was shown to be an effective approach in caries management. Moreover, the treatment protocol is simple, non-invasive, and low-cost. It was reported that the SN only costed about $32 for one 8-mL bottle (~$4.00/mL).[31] This makes silver nitrate a potential strategy for treating dental caries in young children, elderly populations, and people with special needs in the low-income communities.[21]

To apply the combined technique of silver nitrate and fluoride varnish, assure that the patient is not allergic to silver. It is recommended to take radiographs before the treatment to make sure there is not a compromised pulp and the tooth is not abscessed. A microbrush can be used to apply tiny amounts of the silver nitrate into the affected tooth structure, followed by the application of sodium fluoride varnish as a separate treatment at the same appointment. This technique promotes remineralization of damaged tooth surfaces and treats unaffected tooth surfaces. The teeth can then be restored for cosmetic reasons, as needed.

B. Silver Diamine Fluoride (Sdf) For Caries Management

Silver products such as silver nitrate (SN) and silver diamine fluoride (SDF) have been used in Japan for over 40 years to arrest caries in primary and permanent teeth. In the past decade, many other countries, such as Australia and China, have been using SDF with similar success.[32, 33] SDF was recently introduced in the United States, but it wasn't until 2014 that it was cleared for use in the U.S. by the Food and Drug Administration.[33] SDF is a practical and affordable treatment for arresting the progression of carious lesions in primary and permanent teeth.[34] According to a presentation by Association of State and Territorial Dental Directors, the average cost for one 8 mL bottle of SDF is $149 or ~$18.63/mL.[35]

SDF has been used internationally for treating dentinal hypersensitivity and caries lesions. It is a cost effective, minimally invasive, and is a clinically simple treatment option for most of patients. Due to its advantages (non-invasive and easily performed), it can be a promising strategy to manage dental caries in very young children and those with special needs. This product is colorless and odorless. Although it looks like water, it can stain skin, clothing, countertops, flooring, and instruments. SDF is commonly used at a high concentration [38% (44,800 ppm fluoride)] and is effective in arresting caries among children.[36-38] This concentration is still relatively small since a patient only needs one or two drops for the treatment. SDF is also available in the U.S. market as it was approved by the FDA in 2014.[33] A meta-analysis review showed an overall percentage of active caries on primary teeth became arrested was: 86% after 6 months of receiving 38% SDF treatment, 81% after 12 months, 78% after 18 months, 65% after 24 months, and 71% after 30 months or beyond.[37] The patients who may benefit from SDF include those with high-caries risk, behavioral or medical management challenges, multiple teeth with cavitated lesions, and those with difficulty accessing dental care.[39]

In its 38% concentration, SDF is composed of 25% silver ions and 5% fluoride ions dissolved in 8% amine ($2NH_3$) that is similar in structure to silver nitrate (SN) followed by fluoride varnish (NaF). SDF's biochemical interaction with tooth structure and cariogenic bacteria is also similar to SN. Both help strengthen the crystalline structure of the tooth by forming fluorapatite and use silver ion to decrease bacterial deoxyribonucleic acid (DNA) and proteins.[40] It is hypothesized that the caries-arresting ability of SDF is a combined effect of inhibiting cariogenic biofilm, preserving collagen from degradation and increasing the hardness of dentine.[41] In-vitro studies have demonstrated that SDF reduces demineralization and has antimicrobial action on cariogenic bacteria.[42] Silver ions in SDF could inhibit the growth of cariogenic oral bacteria by denaturalizing enzymes that would breakdown collagenous dentin.[28] Streptococcus mutant, a primary pathogen in dental caries, was shown to be less able to form a biofilm on teeth treated with silver fluoride.[43] The fluoride of SDF promotes deposition of fluorapatite, which is more resistant to acidic degradation than normal tooth structure.[33]

It is theorized that SDF reacts with hydroxyapatite in an alkaline environment to form calcium fluoride (CaF_2) and silver phosphate as major reaction products. CaF_2 provides the formation of fluorapatite, which is less soluble than hydroxyapatite in an acidic environment.[33] Silver and fluoride ions can penetrate approximately 25 microns into enamel and 50 to 200 microns into dentine. In fact, SDF has arrested lesions of 150 microns depth according to some studies.[40]

Systematic reviews have reported that silver compounds are useful in caries management to prevent and arrest caries lesions in primary and permanent dentition. Many studies have highlighted the black dental stains that appear after SDF application as one of its disadvantages.[23, 44] More recent studies[45] have demonstrated its effectiveness. A study on 375 preschoolers demonstrated that annual application of SDF was more effective at arresting caries than application of 5% sodium fluoride every three months;[46] another study of 976 Nepalese schoolchildren demonstrated that a single application of SDF was effective in arresting caries after six, 12 and 24 months. [47]

The technique used for SDF application can be modified to meet the clinical needs of individual patients. A suggested SDF protocol for patients with behavioral challenges is to dry, apply and protect. Clinicians are advised to check in one to three weeks post-application to see if caries have been arrested. If the lesion is not arrested, SDF should be reapplied. If arrested, the agent should be reapplied every three to six months.[45]

Application Technique for Silver Nitrate & Silver Diamine Fluoride [42]

- Isolate areas to be treated with cotton rolls. Air-drying prior to application is thought to improve effectiveness.
- Remove debris from cavitation. Carious dentin removal is not necessary. When removal is done, it may reduce proportion of arrested caries lesions that become black, so it may be considered for aesthetic purposes.
- Dry lesion with compressed air.
- Dip a brush into SDF or SN solution and apply directly only on tooth surface.
- Allow 1-3 minutes for the silver diamine fluoride to react with the caries lesion.
- Apply gentle flow of compressed air until SDF or SN is dry.
- Remove any excess material with the same cotton used to isolate. This routine minimizes systemic absorption.

C. Disadvantages and Safety Issues on Using Silver Compounds in Dentistry

Studies confirmed that silver compounds were effective to different approaches already mentioned, specifically their capability to arrest dental caries.[21, 28, 38, 42, 43] However, excess of silver is reported to accumulate in skin, liver, kidneys, spleen, corneas, gingiva, mucous membranes, and nails. In exposed parts of body subjected to light, prolonged exposure to large amounts of silver may lead to irreversible pigmentation of the skin or the eyes. However, very little data reported the possible toxic effects of using silver compounds. Traditionally, it has been thought that silver ions have low cell toxicity. There are few known reports of silver allergy.[23, 48]

The most evident disadvantage of using silver compounds such as silver nitrate and silver diamine fluoride in dentistry is that the caries lesions will be permanently stained black.[21, 23] This discoloration is caused by the oxidation of ionized silver into metallic silver;[23] this outcome limits the clinical use of silver compounds in aesthetically demanding patients. For the treatment of primary tooth that will exfoliate, the discoloration is not a long-term concern. Additionally, when applying this material, rubber dam or vaseline is recommended to avoid accidental contact with skin, gingiva, mucous tissue, and lips.[23] To address the esthetic issue, some clinicians have suggested placing a tooth-colored material such as glass ionomer cement on the stained and arrested caries lesion.[21]

It is very important to inform and to explain to the patient these disadvantages before treatment to avoid dissatisfaction. A survey in New York, USA showed that staining on children's posterior teeth was more acceptable to parents than staining on anterior teeth after caries treatment with silver compounds.[49] The survey also showed that parental acceptance increased in children who had more difficulties with receiving treatment. Parental acceptance of the treatment was related to socioeconomic status. Parents with a lower education level had higher acceptance and their acceptance level did not vary much as children's difficulty with receiving treatment increased.[49]

A temporary henna-appearing stain appears when SN or SDF solution comes into contact with skin. The skin pigmentation will disappear within 7 to 14 days, if the silver does not penetrate into the dermis.[3, 21, 23]

In addition, unintentional placement of a high concentration of silver nitrate to the cornea might lead to blindness due to the fact that it can burn the cornea.[24] Therefore, patient and the operator must wear protective eye glasses. The solution should be always kept in small quantities. It is thus required to pay attention when handling silver solution during its application.

Nevertheless, exposure to a small amount of the solution will not produce immediate or even any side effects other than staining of the skin. Complications and side effects can become more noticeable with repeated exposures. The toxicity of SN and SDF is related to the dosage; however, the dosage used for treating dental caries is extremely small.

DISCUSSION

Dental caries is a disease caused by bacterial infection, with patients at different degrees of risk, rather than just a lesion. Although most schools have taught the surgical mode of restoring the damage from caries in the past decades, the contemporary caries-management philosophy has changed from the traditional approach to a minimally invasive therapy, which includes the use of fluoride and antimicrobial agents.[50] Instead of just focusing on restorative treatment, dentists should also focus in the bacterial infection to develop an individual strategy to treat the bacterial component of caries, so that it can prevent further infection. Amelioration of oral hygiene and change of diet decrease the risk for dental caries. In addition, dentists should aim to re-mineralize rather than to remove the caries (demineralized tissue). Remineralization can be facilitated with the use of fluoride agents.[21, 50]

Fluoride is used in various forms to prevent and arrest caries; however, the combined effects of silver and fluorides have been shown to be more efficient in arresting caries progression and preventing the development of new caries. [44] For example, semi-annual application of 38% SDF was shown to be more effective than semi-annual application of 5% NaF in arresting carious dentine lesions. [51] Similarly, annual application of 38% SDF was more effective than every three-month application of 5% NaF. [46] It was concluded that SDF was an effective, efficient, equitable, and safe caries-preventive agent that seems to meet the standards of the U.S. Institute of Medicine and the Millennium Goals of the World Health Organization.[52]

The solution of 25% silver nitrate ($AgNO_3$) followed by 5% NaF varnish that Duffin proposed to arrest caries is accepted by most countries and their corresponding authorities such as the US Food and Drug Administration (FDA). One laboratory study has suggested that 25% SN solution and 5% NaF varnish may be as effective as 38% SDF in arresting dentin caries.[30] Also, a 12-month randomized clinical trial showed no difference between 38% SDF and 25% SN solution followed by a 5% NaF varnish in arresting dentin caries among preschool children.[53]

Treatments using 38% SDF and 5% SN followed by 5% NaF have been shown to be an effective prevention method. They both can reduce the incidence of caries in non-affected teeth more extensively than the sodium fluoride varnishes alone, which is endorsed by the U.S. Preventive Services Task Force.[31, 54]

Focusing on the restorative and surgical treatment procedures, a study reported that the average costs for the children treated with silver nitrate followed by fluoride varnish were marked lower than those treated conventionally.[31] The results are consistent with a recent case report suggesting fewer children need extensive invasive treatment such as in-hospital restoration when treated with SN/FV.[29] Available literature suggests that biannual treatment with SN/FV or SDF may be sufficient to arrest over 90% of caries lesions, while typically children at high risk are treated with fluoride varnish four times per year.[31, 55]

Minimally invasive dentistry can be applied for the treatment of deeper carious lesions by using the atraumatic restorative treatment approach, which removes selectively infected carious tissue, leaving caries-affected dentin for therapeutic remineralization. Atraumatic restorative treatments are considered to have a combined technique-material effect. They arrest caries and induce dental remineralization by utilizing the potential of glass ionomer cements. A study showed 83% of dentine caries were arrested after 24 months of receiving annual application of glass ionomer cement.[56]

Glass ionomer cements, due to their high fluoride release and tooth color, are being used for a wide range of applications in dentistry. The use of a restorative glass-ionomer with optimal mechanical properties is, therefore, very important. Several studies have assessed the mechanical properties of glass-ionomers currently used for ART procedures.[57] Studies have showed that ART using high-viscosity glass ionomer cement had relatively high survival rate.[13, 24] The Atraumatic Restorative Treatment (ART) approach was first suggested to treat enamel and dentine carious lesions in patients with disabilities. However, it is now used for treating dental caries in young children, elderly populations and people with special needs.[21, 29]

Studies have found that the treatment of SDF can increase the mineral density of enamel lesions and the microhardness of dentin lesions and preserve dentin collagen from degradation in demineralized dentin.[58-60] However, SDF is not available in certain countries. It is possible to get these results using 25% SN + 5% NaF varnish, which are already available worldwide.[30] The concentrations of silver and fluoride are lower in 25% SN + 5% NaF varnish than in 38% SDF. The same trend is found in the cost of treatment. Therefore, 25% SN followed by 5% NaF varnish could be more favorable for use in young children when considering the availability worldwide and cost effectiveness.[30]

Studies have reported that using SDF was better than glass ionomer cement or fluoride varnish in arresting caries in primary teeth.[46, 56] Caries removal is not necessary before the application of silver compounds and their applications does not require sophisticated instruments or techniques. They are cost-effective agent to manage dental caries. The application is painless and simple and can be used for general population.[1]

Silver compounds have been used in dentistry for more than a century. Several studies have proved the effectiveness of silver nitrate + fluoride varnish as well as the silver diamine fluoride for caries management. Although the black staining is inevitable and most parents perceive it as aesthetically unacceptable, many of them accept the treatment to avoid their children going under conventional treatment even with sedation or general anesthesia.

CONCLUSIONS

In conclusion, studies have suggested that the use of minimally invasive techniques such as ART, silver nitrate followed by fluoride varnish, and silver diamine fluoride are effective for caries management. They offer a cost-effective treatment for dental caries and they can help improve oral health in the U.S. and worldwide.

This literature review substantiates that these therapies are non-invasive, painless, available, affordable, and easy to apply. They pose minimal risk to patients and don't require caries removal. The application of these techniques is an alternative strategy to conventional dental caries treatment among children, elderly people, patients with special needs, and the general population. Further studies should be done to provide more evidence of these techniques for caries management.

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