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Review Article

Effect of light curing on the efficacy of silver diamine fluoride: A systematic review

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الملخص

أهداف البحث: مقارنة أداء فلوريد ثنائي أمين الفضة المعالج بالضوء مع فلوريد ثنائي أمين الفضة غير المعالج بالضوء من حيث الخصائص المختلفة.

طريقة البحث: بعد استرجاع الأوراق البحثية (حتى أبريل 2023) من قواعد البيانات الإلكترونية ("بابميد" و "سكوبس" و "ساينس دايركت") باستخدام العوامل المنطقية، تم البحث يدويا في قوائم الاقتباسات الخاصة بالأوراق المضمنة. كانت جميع المقالات المضمنة عبارة عن دراسات أصلية نصية كاملة أجريت باللغة الإنجليزية والتي قيمت تأثير فلوريد ثنائي أمين الفضة المعالج بالضوء وقارنته بفلوريد ثنائي أمين الفضة وحده. تم تقييم خطر التحيز في الدراسات المختبرية على مواد طب الأسنان باستخدام القائمة المرجعية المعدلة للمعايير الموحدة لتجارب إعداد التقارير.

النتائج: تم تضمين ست دراسات في المجموع للتحليل النوعي بعد البحث اليدوي الشامل والبحث في قاعدة البيانات الإلكترونية. وكانت خمس دراسات عبارة عن دراسات في المختبر وواحدة كانت دراسة خارج الجسم الحي. قارنت كل دراسة فلوريد ثنائي أمين الفضة المعالج بالضوء مقابل فلوريد ثنائي أمين الفضة غير المعالج بالضوء من حيث الخصائص المختلفة مثل عمق الاختراق، وترسيب أيونات الفضة، وصلابة العاج، وتشكل السطح، والخصائص المضادة للبكتيريا. تم تصنيف غالبية الدراسات (6/4) على أنها ذات جودة منخفضة وتحيز عالي المخاطر، في حين تم الحكم على الدراستين المتبقيتين بأنها ذات جودة عالية وتحيز منخفض المخاطر.

الاستنتاجات: في حدود هذا البحث، أظهر فلوريد ثنائي أمين الفضة المعالج بالضوء أنه طريقة فعالة لتعزيز خصائص فلوريد ثنائي أمين الفضة بالمقارنة مع فلوريد ثنائي أمين الفضة غير المعالج بالضوء. لا تزال الدراسات المستقبلية عالية الجودة ضرورية للتحقق من هذه النتائج، وخاصة التجارب السريرية العشوائية. يمكن أن يكون استخدام المعالجة الضوئية بفلوريد ثنائي أمين الفضة بمثابة استراتيجية مفيدة تعزز الاستخدام السريري لفلوريد ثنائي أمين الفضة. إن مراجعة المقارنة بين الخصائص المختلفة لفلوريد ثنائي أمين الفضة المعالج بالضوء وفلوريد ثنائي أمين الفضة غير المعالج بالضوء ستساعد الأطباء على تعزيز استخدامه السريري وقبول المريض.

الكلمات المفتاحية: المعالج بالضوء؛ فلوريد ثنائي ديامين الفضة؛ تسوس الأسنان؛ صحة الأسنان؛ مراجعة منهجية

Abstract

Objective: This study was aimed at comparing the performance of light-cured (LC) silver diamine fluoride (SDF) to non-LC SDF in dental applications, in terms of various properties.

Methods: Articles published until April 2023 were retrieved from electronic databases (PubMed, Scopus and Science Direct) according to Boolean operators, and the reference lists of the included articles were manually searched. The included articles were all full-text, original studies in English that assessed the effects of LC SDF compared with SDF alone. The risk of bias in the in vitro studies on dental materials was evaluated with the modified Consolidated Standards of Reporting Trials (CONSORT) checklist.

Results: Six studies (five in vitro and one ex vivo) were included in qualitative analysis after a comprehensive

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manual search and electronic database search. Every study compared LC SDF versus non-LC SDF in terms of properties such as penetration depth, silver ion precipitation, dentine hardness, surface morphology and antibacterial characteristics. Four studies were categorised as low quality with a high risk of bias, whereas the remaining two studies were considered high quality with a low risk of bias.

Conclusion: In this investigation, LC SDF, compared with non-LC SDF, was found to be an efficacious approach for enhancing SDF properties. Future high-quality studies, particularly randomised clinical trials, remain necessary to verify these findings.

Clinical significance: The use of light curing with SDF can be a beneficial strategy that enhances SDF's clinical use. This review comparing various properties of LC SDF and non-LC SDF may help clinicians enhance clinical use and patient acceptance of LC SDF.

Keywords: Dental caries; Dental health; Light curing; Silver diamine fluoride; Systematic review

Introduction

Silver diamine fluoride ($Ag(NH_3)2F$ or SDF), a topical medication approved by the Food and Drug Administration, is used off-label to stop the growth of bacteria and active tooth caries.[1–4] This colourless photosensitive silver compound solution has a pH of 9–10, with 253,900 ppm of silver ions and 44,800 ppm of fluoride ions.[5,6] This medication has four basic methods of action. First, the fluoride component stops demineralisation and increases remineralisation, thus strengthening tooth structure.[7–10] Second, the silver component functions as an antibacterial agent, killing bacteria and preventing new biofilm growth.[11,12] SDF procedures are useful because of their ability to manage caries infections, ease of use, affordability, low clinician training requirements, and minimally invasive nature.[11]

SDF has been used since 1970 in Australia, Japan, China and Argentina, despite not being authorised in the United States (U.S.).[13] The Food and Drug Administration awarded SDF a "breakthrough therapy designation" for arresting dental cavities, and the first product was approved in August 2014 as a dentinal hypersensitivity treatment for adults, although the product is used off-label to treat caries in the U.S.[11] Numerous clinical studies have documented the utility of SDF as an early caries control agent in paediatric populations.[14–18] In the United States, more than 88% of postgraduate paediatric dental school directors agree that SDF is advantageous for individuals with high caries risk, particularly young, non-cooperative children, and patients with behavioural disorders, logistical issues or special healthcare needs. Fourteen children with poor diets, low socioeconomic status, and a DMFT >1 were patients with high caries risk.[19]

Horst et al.[11] have identified five indications for SDF therapy: (1) high risk of caries; (2) medical or behavioural management treatment challenges; (3) multiple caries that cannot be managed in a single visit; (4) lack of access to dental health care; and (5) challenging dental carious lesions. SDF application may lessen the need for standard restorations, and decrease the financial burden on patients receiving cancer treatment and those with salivary dysfunction.[11]

Despite efforts to standardise procedures for applying SDF, additional research is required to identify the application method yielding optimal results.[11] According to anecdotal reports, SDF's ability to stop caries can be enhanced by light curing in clinical settings. However, no study has tested this hypothesis.

According to Suzuki et al., the silver and fluoride ions present in SDF can infiltrate to a depth of approximately 25 μm in enamel.[20] Chu et al. have noted that silver ions penetrate undamaged, healthy dentin by 50–200 μm.[21] Recently, Li et al.[22] have shown that extracted carious primary incisors have penetration depths of 744 ± 448.9 μm. This penetration depth increase of 10-fold was unexpected. The deep lesions in that study were found to have caries that had spread to the pulp.[22] Moreover, Fung et al. have found higher caries arrest rates in the anterior teeth than the posterior teeth.[23] According to Crystal et al., anterior teeth exposed to natural light may lead to shorter SDF soaking times and more active silver precipitation.[24]

Although an umbrella review on the effectiveness of SDF in treating carious lesions has been published,[25] no systematic review has compared the effects of light cured (LC) and non-LC SDF. Consequently, the objective of this systematic review was to investigate the effects of dental application of LC versus non-LC SDF on SDF penetration potential, dentine hardness, silver ion precipitation and antimicrobial activity.

Materials and Methods

Research question

We sought to answer the following research question according to the PICO framework: what is the effectiveness of LC SDF versus non-LC SDF, on the basis of various properties?

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) revised standards.[26]

Eligibility criteria

Inclusion criteria

1. Study designs: All original research studies, regardless of their design
2. Substrate: Studies using human/bovine teeth (with natural/artificially induced caries) and hydroxyapatite discs
3. Intervention: All studies applying SDF combined with light curing
4. Comparator: All studies applying SDF without light curing
5. Outcomes: All studies reporting outcomes including surface morphology, mean mineral density difference, antibacterial properties, SDF penetration depth, dentine hardness, and silver and fluoride ion precipitation after the application of LC SDF and non-LC SDF

Exclusion criteria

Studies that did not use LC SDF, and those that did not compare LC SDF with non-LC SDF, were excluded from the review. Similarly, systematic reviews, literature reviews, case series, case reports, editorials, short communications, conference proceedings and studies in languages other than English were excluded. The PRISMA flowchart (Figure 1) illustrates the study selection, screening, inclusion and exclusion processes.[26]

Literature search

Free text keywords and Boolean operators were used to comprehensively search the PubMed (National Library of Medicine), Scopus (Elsevier) and ScienceDirect (Elsevier) databases to find relevant articles (Supplementary file). The free text keywords used were as follows: *(silver diamine fluoride OR silver diamine fluoride OR diamine silver fluoride OR SDF OR silver fluoride OR Riva Star OR Cariestop OR Saforide OR Advantage Arrest) AND (light curing OR light cured OR light-curing OR light-cured OR dental curing light OR light curing technique)*.

No search restrictions were used, and the only items included were those published until 11 April 2023. EndNote was used to store articles (Clarivate Analytics, EndNote 20, 2023). After duplicates were eliminated, initial screening was conducted on the articles' titles and abstracts. The full text of each screened article was then obtained and subjected to screening on the basis of PRISMA standards.[26] A manual search of the references of the screened studies was also performed to identify additional eligible studies.

Literature screening

Two reviewers evaluated the study titles and abstracts for screening and evaluation of the eligibility criteria. A third referee settled any disputes. Full-text versions of the studies were retrieved and examined to ensure that additional eligible studies were not overlooked in the review procedure. Cohen's kappa score was used to evaluate agreement between reviewers.[27]

Data extraction and quality assessment

A modified Excel spreadsheet was used to retrieve the data from the included articles. Table 1 provides a list of the studies excluded on the basis of eligibility criteria. Two independent assessors using the modified Consolidated Standards of Reporting Trials (CONSORT) checklist for reporting in vitro studies on dental materials evaluated the risk of bias and quality of the evidence in the included studies.[28] Again, the third referee arbitrated any disputes.

Results

Study characteristics

The first search yielded 132 documents from all electronic databases. After removal of duplicates ($n = 4$) in EndNote 20 software, the remaining 128 studies were examined (titles and abstracts), and 19 studies remained after excluding 109 studies. Of these, the full texts of 18 studies were retrievable, and their suitability for inclusion in this systematic review was thoroughly examined; one study whose full text could not be obtained was excluded. Six articles were considered for analysis after retrieval of an additional study through a manual search.[29–34] Sixteen studies were excluded for a variety of reasons[35–50] after electronic and manual searches (Table 1). Table 2 demonstrates the main characteristics of the studies included in this systematic review, and Table 3 shows the data collected from the studies and the key conclusions. After screening of the titles/abstracts and of the full-text, the inter-agreement score (k) between authors was determined to be 0.83 and 0.89, respectively, thus indicating significant, nearly total agreement. The included studies were heterogeneous, thus precluding meta-analysis.

Synthesis of the results

Study design and randomisation

Of the six studies, five were in vitro studies,[29,31–34] and one was an ex vivo study.[30] Four[29,30,33,34] of the six studies used randomisation, whereas two studies[31,32] did not.

Tooth type and substrate

No considerable interstudy differences were identified in the tooth type and substrate in this systematic review. Among the selected articles, five used extracted human teeth,[29–31,33,34] whereas one used hydroxyapatite discs[32] for analysis. Regarding dentition type, four[29,30,33,34] of five studies used deciduous teeth, and one[31] used permanent teeth. Regarding tooth type, three studies[29,33,34] used molars, one study used maxillary incisors,[30] and one study[31] did not report the tooth type used. Furthermore,

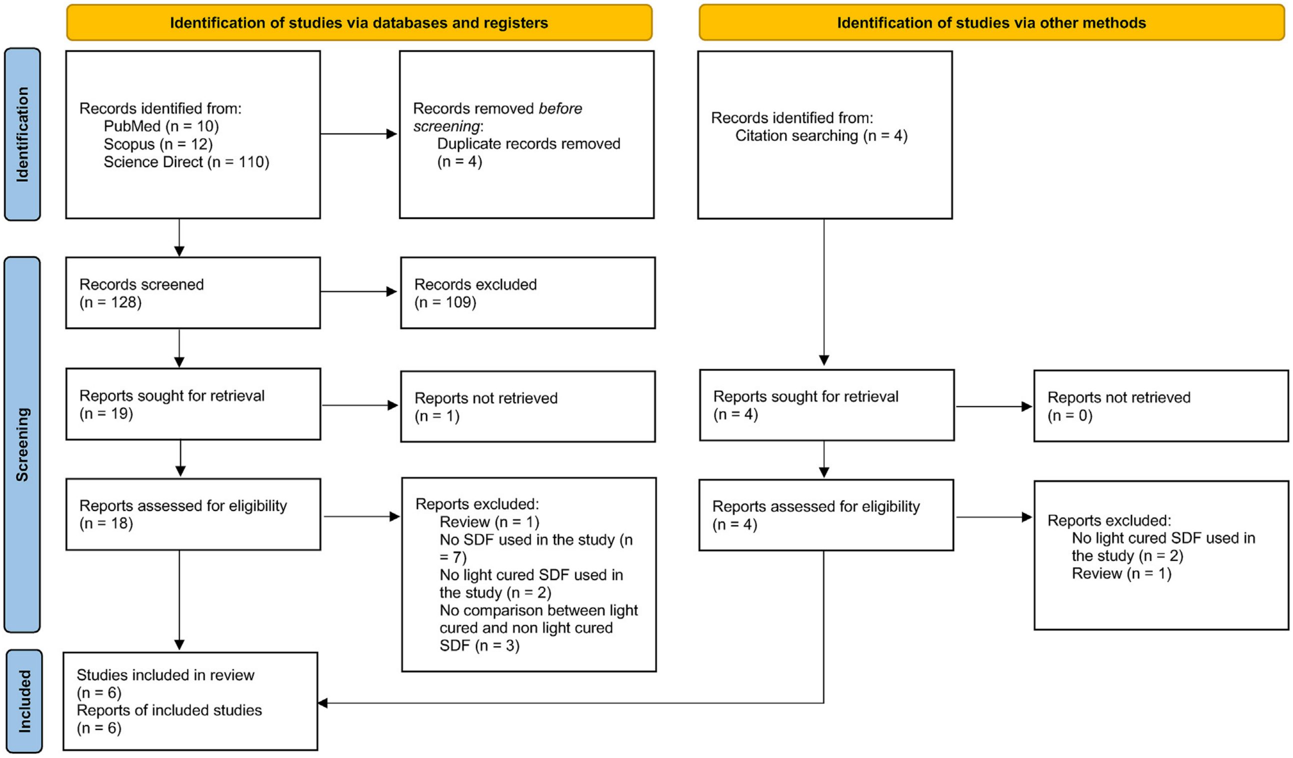

Figure 1: Flowchart illustrating the review process.

Table 1: Studies excluded on the basis of eligibility criteria and justifications for their exclusion.

Author/year	Reason for exclusion
Dunne et al. (1996)[35]	No SDF used in the study
Frazier et al. (1996)[36]	
Hattab and Amin (2001)[37]	
Pashley et al. (2002)[38]	
Herzlieb et al. (2012)[39]	
Gutiérrez et al. (2017)[40]	
Yang et al. (2021)[41]	
Alrahlah et al. (2020)[42]	No LC SDF used in the study
Nguyen et al. (2017)[43]	
Wang et al. (2016)[44]	
Lou et al. (2011)[45]	
Burgess and Vaghela (2018)[46]	Review article
Kilpatrick (1993)[47]	
Al-Qahtani (2021)[48]	No comparison between LC and non-LC SDF
Alshahrani (2020)[49]	
Markham et al. (2020)[50]	

LC, light cured; SDF, silver diamine fluoride.

all studies on extracted human teeth[29–31,33,34] used dentine as a substrate.

Caries type and specimen dimensions

The types of caries/protocols used in the eligible studies for caries induction did not significantly differ. Among the included studies, five studies used teeth with natural caries,[29–31,33,34] whereas one study used a zone of inhibition test with no caries induction.[32]

All studies reported the specimen dimensions, except for Sayed et al.[31]

Quality assessment of the included studies

According to the modified CONSORT checklist[28] most (4/6) included studies were classified as having low quality and a high risk of bias.[29–32] The remaining two studies were found to have a low risk of bias and to be of high quality.[33,34] A 25-item checklist is included in the CONSORT statement. The purpose of the CONSORT statement is to describe the planning, analysis and interpretation of a clinical trial, as well as other investigations such as in vitro experiments, thus aiding in the standardisation of findings

Table 2: General features of the included articles.

Author/year	Country	Study design	Randomisation
Karnowakul et al. (2023)[33]	Thailand	In vitro	Yes
Wilson et al. (2022)[32]	United States	In vitro	No
Chanratchakool et al. (2022)[29]	Thailand	In vitro	Yes
Toopchi et al. (2021)[30]	United States	Ex vivo	Yes
Hassan et al. (2021)[34]	KSA	In vitro	Yes
Sayed et al. (2021)[31]	Japan	In vitro	No

Table 3: Data extracted from the included publications and key conclusions.

Author/year	Sample type/ substrate	Caries type/specimen dimensions	Sample size and grouping	Measured outcome and equipment used	Reported outcomes
Karnowakul et al. (2023)[33]	Extracted human primary molars/ dentine	Natural caries/ 1 × 1 × 0.9 cm (W × L × H)	Total: 40 1: SDF for 10 s (10) 2: SDF for 60 s (10) 3: SDF for 10 s + LC for 20 s (10) 4: SDF for 60 s + LC for 20 s (10)	mMDD (digital subtraction radiographic analysis) Surface morphology and elemental profile (SEM and EDS)	10 SDF + LC and 60 SDF + LC groups had considerably greater mMDD levels than the non-LC groups. The mMDD was much higher in the 60 SDF + LC group than the 10 SDF group, but was nearly equivalent between the 10 SDF + LC group and 60 SDF group. According to SEM, the mineral content layers in the 10 SDF + LC and 60 SDF + LC groups were denser than those in the 10 SDF and 60 SDF groups. Application time was shorter with LC-enhanced SDF remineralisation than the traditional approach.
Wilson et al. (2022)[32]	HA discs/NA	No caries (zone of inhibition tests)/0.5 inch diameter	Total: 4 1: HA discs (2) 2: HA discs + LC for 20 s	Antibacterial activity (Kirby−Bauer zone of inhibition) assessed with a scale and digitally captured with a Canon PowerShot camera	In both single and multiple microbial cultures, no appreciable differences were observed between experimental groups. Although SDF + LC might have particular characteristics, these characteristics are not associated with antibacterial activity.
Chanratchakool et al. (2022)[29]	Extracted human primary molars/ dentine	Natural caries/3 × 3 × 2 mm^3	Total: 20 1: DW (negative control) (5) 2: SDF for 10 s (5) 3: SDF for 10 s + LC for 20 s (5) 4: SDF for 1 min (5)	Antibacterial activity (measured as CFU/mL; bacterial colonies counted)	No change was observed in the bacterial counts persisting on the samples after 1 min exposure to 10 SDF, 10 SDF + LC and SDF. All three groups had considerably lower bacterial counts than observed with DW treatment. Shortening the application time of SDF with or without LC did not result in different antibacterial effects from the standard 1min application.
Toopchi et al. (2021)[30]	Extracted human primary maxillary incisors/dentine	Natural caries/whole teeth	Total: 16 1: SDF (8) 2: SDF + LC for 40 s (8)	Penetration depth of SDF (stereomicroscopy) Dentine hardness (Vickers hardness test performed with a microhardness	SDF penetration into sound dentine and beyond cavities was evident in both groups. Without LC SDF, the penetration depth into sound dentine was 70 µm

				indenter machine) Silver and fluoride ion precipitation (SEM and EDS)	deeper. Silver precipitation in infected dentine was approximately 2.6 times greater with LC SDF than non-LC SDF. The hardness of diseased dentine increased by 26% with LC. LC SDF makes the infected dentine harder, because greater silver ion precipitation occurs in the infected dentine, and less SDF permeates healthy dentine.
Hassan et al. (2021)[34]	Extracted human primary molars/ dentine	Natural caries/whole teeth	Total: 30 1: SDF + laser for 10 s (10) 2: SDF + LC for 40 s (10) 3: SDF (10)	Dentine hardness (Vickers hardness test performed with a microhardness indenter machine)	The surface hardness of sound dentine beneath the caries was noticeably higher in the laser + SDF group than the other two groups (LC + SDF and SDF only). In comparison to SDF alone, SDF + LC led to a substantial difference in measured microhardness.
Sayed et al. (2021)[31]	Extracted human permanent teeth/ dentine	Natural caries/NR	Total: 40 1: Control (10) 2: CC (10) 3: SDF (10) 4: SDF + LC for 10 s (10)	Depth of discolouration (light microscopy observation) Dentine hardness (Vickers hardness test performed with a microhardness indenter machine) Surface morphology and elemental profile (SEM and EDS)	In the SDF-treated group, black-stained regions extended down from the surface of the lesion. SDF + LC demonstrated a deep, black stain that was restricted to the dentine lesions' surface, was carious and showed no further penetration. Microhardness for different dentine depths showed that from depths of 200−1200, 1800 and 2000 μm, SDF with LC and SDF alone significantly differed. Microhardness for 1200, 1400 and 1600 μm dentine depth showed an insignificant difference between SDF + LC and SDF. On the surface, both SDF groups had many crystal forms with high silver peaks on the EDS, thus indicating the formation of silver compounds.

DW, distilled water; EDS, energy dispersive x-ray spectroscopy; HA, hydroxyapatite; LC, light cured; mMDD, mean mineral density difference; NA, not available; NR, not reported; SDF, silver diamine fluoride; SEM, scanning electron microscopy.

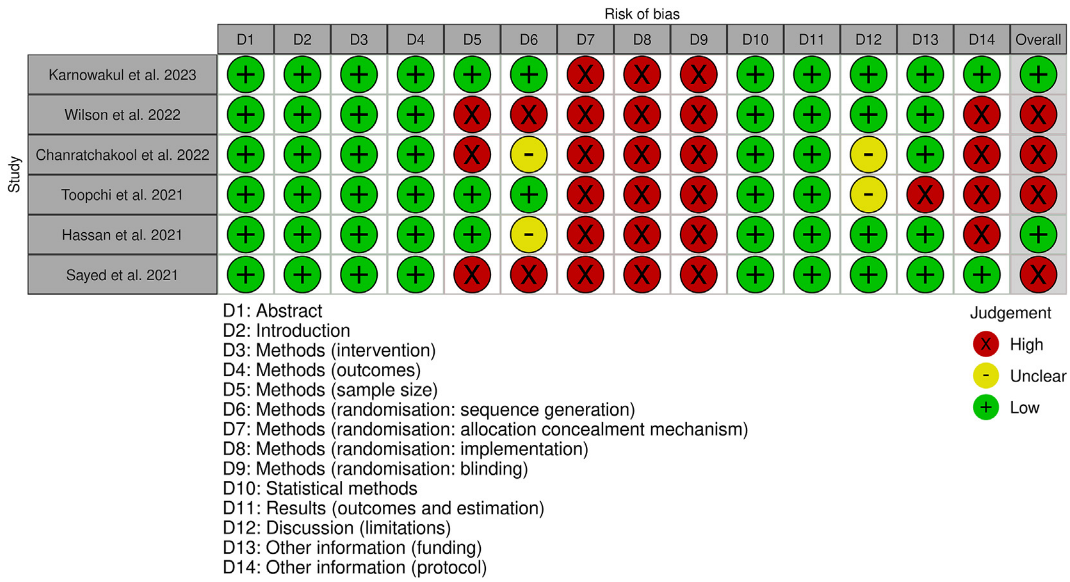

Figure 2: Risk of bias using modified CONSORT checklist.

from clinical trials and other research studies. Figure 2 displays the included studies' characteristics and the modified CONSORT checklist.

Discussion

In numerous trials, SDF has been shown to be beneficial in halting and limiting the progression of caries in deciduous teeth. Novel techniques for applying LC SDF have received substantial interest because of their potential to alter the depth of SDF penetration[30]. Additionally, recent studies have shown that this method might be able to alter the hardness of the dentine surface below and above the treated caries[31,34]. Nonetheless, a thorough analysis of LC SDF compared with non-LC SDF was lacking.

Karnowakul et al.,[33] in a study on the remineralisation effects of LC and non-LC SDF use on natural dentine caries in deciduous posterior dentition, have observed that light curing is the sole variable associated with lesion remineralisation and increased silver ion precipitation after SDF administration. These findings suggest that light increases SDF's remineralisation effectiveness. When silver particles are subjected to light, their spherical structure frequently transforms into plate-like square, triangular or hexagonal shapes. Similarly to the non-LC groups, the LC groups with SDF displayed dentine surface lesions with more square-shaped particles. This finding is consistent with the substantial amounts of silver in the elemental profile and strongly supports that the particles were made of silver. The radiopacity caused by silver, as opposed to amalgam restoration, was not entirely visible in the post-treatment radiographs. Further research is necessary to determine how fluoride and silver concentrations affect mineral gain. Thus, LC SDF treatment causes less SDF penetration into sound dentine and increases silver ion precipitation in diseased dentine. Demineralisation occurs in bacteria-rich, infected dentine, in agreement with findings from Mei et al.,[51] who have observed mineral deposition 150 m below the surfaces of dentine caries in deciduous anterior teeth treated with non-LC SDF. The silver penetration depth of sound dentine has not been found to differ between LC and non-LC specimens, according to Lau et al.[52] However, that study used various burs or laser ablation techniques to prepare the specimens. Additionally, neither pH cycling nor caries lesions were used in that study.

Wilson et al.,[32] in a study of the antimicrobial properties of LC and non-LC SDF, have discovered that light curing does not considerably modify this biomaterial's efficacy. Moreover, SDF has been found to impede the growth of Gram-positive saccharolytic bacteria and polymicrobial (mixed) cultures.[53,54] SDF's antimicrobial characteristics have been identified. SDF's antibacterial characteristics are widely known and substantially support the efficacy of this treatment[55,56]; moreover, light curing does not appear to significantly affect these characteristics. Although available data do not indicate that light curing improves or potentiates antibacterial characteristics, the finding that it does not modulate this feature may be a noteworthy result. Light curing has been found to increase the depth of SDF penetration into dentine and to increase dentine hardness. These results demonstrate that, contrary to expectations, light curing does not appreciably affect or impair the antibacterial characteristics of SDF in vitro. Instead, it might have additional beneficial effects that could improve treatment results, such as increasing the depth of dentine penetration in vivo.

Silver ions have a major role in SDF's antibacterial activity. The antibacterial action of silver compounds may be diminished because light exposure accelerates the precipitation of silver ions from SDF.[6] However, Chanratchakool et al.[29] have observed no differences in the antibacterial efficiency of SDF with versus without light curing. The different solubility of various silver compounds (silver chloride, silver phosphate and silver oxide) may explain this finding.[6] Silver ions may be released after some ions partially dissolve in water. The emitted silver ions may have antimicrobial effects against surface bacteria. However, the antibacterial action of SDF against bacteria in dentinal tubules could not be demonstrated by Chanratchakool et al.[29] Because the dentine samples used in that study[29] were taken from affected dentine of various teeth, an outlier value was obtained during the SDF application for 10 s with LC group. Consequently, each surface may have a different pattern, thus impairing *Streptococcus mutans* (*S. mutans*) adherence. An alternative approach may be to develop artificial caries on sound dentine to produce caries with equal depths and surfaces.

S. mutans has been used to test SDF's antibacterial effectiveness, because this bacterium is associated with dental caries, particularly in young children.[57] However, a range of bacteria species contribute to the development of tooth caries. Further clinical investigations are necessary to properly assess the bactericidal effects of LC SDF in the oral cavity.

Hassan et al.[34] have observed significantly different microhardness measurements between SDF + LC and SDF alone. Toopchi et al. have reported a similar outcome,[30] and have claimed that the light reduction of SDF and subsequent formation of the tenacious, insoluble, opaque black substance known as silver sulphide is responsible for the increase in hardness. Toopchi et al.[30] have observed a higher level of silver deposition in dentine and have claimed that the light-induced reduction of SDF, which decreases the penetration depth and keeps most of the silver at the surface, leads to better silver surface deposition.

According to Toopchi et al.,[30] adding a second stage of dental light curing of SDF for 40 s after application decreases the SDF penetration depth in healthy dentine and increases the hardness of infected dentine. The authors have concluded that dental light curing increases the silver ion precipitation in the diseased dentin layer of carious lesions. The diseased dentine layer absorbs more light than other deeper layers. Natural light acts as a catalyst in silver solution reduction, thus producing silver ions and nanoparticles, according to Babaahmadi et al.[58] The increased precipitation of silver ions in the diseased dentine layer of carious lesions may be explained by dental light curing functioning as an initiating agent enabling rapid reduction and shorter SDF penetration times. Silver ions in the sound and affected dentine layers have not been found to significantly differ across the experimental groups. Thus, only the surface layer of the infected dentine is significantly penetrated by the dental curing laser, whereas the deeper layers of the carious lesion remain unaffected. The curing light's ability to penetrate deeply may be hampered by the dark colour of affected dentine.

This review has several limitations, including that meta-analysis (quantitative analysis) could not be conducted, because of the heterogeneity in study settings, methods, outcomes assessed and types of teeth used among the included studies. Furthermore, the availability of only five in vitro studies together with the lack of randomised clinical trials on this subject may raise concerns regarding the external validity of the findings and the consequently increased risk of bias. Therefore, randomised clinical trials are warranted to resolve this issue and validate the findings of this study. Moreover, only six studies were identified in our exhaustive literature search, thus suggesting a scarcity of research on this topic. In addition, most included studies (4/6) were classified as having a high risk of bias and low quality. Hence, care should be taken while inferring the findings of this review. To address these limitations, future research should include more ex vivo and clinical trials with larger sample sizes, standardised methods, and exploration of additional properties such as long-term stability, cytotoxicity, bond strength, aesthetic effects and fluoride release, to provide a comprehensive evaluation of the effectiveness of LC SDF compared with non-LC SDF in dental applications.

Conclusion

Compared with non-LC SDF, LC SDF was demonstrated to be a successful strategy for enhancing the qualities of SDF in this study. However, to confirm these findings, additional high-quality research, particularly randomised clinical trials, is needed.

Source of funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

Because this is a systematic review, no ethical approval was required.

Authors contributions

Conceptualisation, A.B. and T.A.; Data curation, M.S.S.; Methodology, M.S.S. and Af.Al.; Software, M.S.S.; Writing—original draft, M.S.S.; Writing—review & editing, Ai.Al. and S.A. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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