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Success rate of silver nano-particles in comparison to silver diamine fluoride in management of deep carious lesions: a randomized controlled clinical trial

Taxa de sucesso de nanopartículas de prata em comparação ao fluoreto de diamina de prata no manejo de lesões cariosas profundas: um estudo clínico controlado randomizado

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ABSTRACT

Objective: Evaluate the effectiveness of nanosilver fluoride in comparison to silver diamine fluoride in management of deep carious lesions. **Material and Methods:** This double-blinded randomized controlled clinical trial included thirty-six patients with deep carious mandibular molars. Patients were recruited form the outpatient clinic of Suez canal university, Egypt and randomly allocated into three groups, Nanosilver fluoride group, Silver diamine fluoride group and control group. For all groups, teeth were isolated by rubber dam. Access was done followed by partial caries removal. Silver diamine fluoride or Nanosilver fluoride were applied, and all teeth were restored with composite resin restorative. Patients were recalled after 3 and 6 months to follow-up the pulp vitality. R-statistical analysis software for Windows, version 4.1.1, was used to conduct the statistical analysis **Results:** At 3 month, for all groups, all teeth were successful. After 6 months, for silver diamine fluoride group, a single case failed. Regarding the nanosilver fluoride, all cases were successful. For the control group, two cases failed. No statistically significant difference was found between the tested groups. **Conclusion:** Application of 5% Nanosilver to fluoride varnish has similar clinical efficacy as silver diamine fluoride in arresting the dentin caries progression.

KEYWORDS

Dental caries; Dental pulp disease; Nanoparticles; Pulp capping; Silver diamine fluoride.

RESUMO

Objetivo: Avaliar a eficácia de fluoreto de nanoprata em comparação ao fluoreto de diamina de prata no manejo de lesões profundas de cárie. **Material e Métodos:** Este estudo clínico controlado randomizado duplo-cego incluiu trinta e seis pacientes com lesões de cárie profunda em molares inferiores. Os pacientes foram recrutados no ambulatório da Universidade do Canal de Suez, no Egito, e alocados aleatoriamente em três grupos de tratamento: fluoreto de nanoprata, fluoreto de diamina de prata e grupo controle. Para todos os grupos, os dentes foram submetidos ao isolamento absoluto. O acesso à lesão foi feito seguido pela remoção parcial de tecido cariado. Tanto o fluoreto de diamina quanto fluoreto de nanoprata foram aplicados, e todos os dentes foram restaurados com resina composta. Os pacientes foram avaliados após 3 e 6 meses para o acompanhamento da vitalidade pulpar. O software estatístico R-statistical para Windows, versão 4.1.1, foi usado para as análises. **Resultados:** Em 3 meses, para todos os grupos, todos os dentes apresentaram sucesso no tratamento. Após 6 meses, para o grupo que utilizou o fluoreto de diamina de prata um único caso falhou. Em relação ao fluoreto de nanoprata, todos os casos apresentaram sucesso. Para o grupo controle, dois casos falharam. Não houve diferença estatística entre os grupos testados. **Conclusão:** A aplicação de verniz de fluoreto de nanoprata a 5% tem eficácia clínica semelhante ao fluoreto de diamina de prata na interrupção da progressão de cárie no tecido dentinário.

PALAVRAS-CHAVE

Cárie; Doença da polpa dentária; Nanopartículas; Capeamento pulpar; Fluoreto de diamina de prata.

INTRODUCTION

The standard treatment protocols for caries lesions include completely removing all infected tissue before restoring the tooth. This method for treating deep lesions increases the danger of pulp exposure, which frequently necessitates endodontic therapy [1]. Deep carious lesions are defined as cases showing radiographic evidence of caries reaching the inner third or inner quarter of dentine with a risk of pulp exposure [2]. For the treatment of teeth with reversible pulp irritation that are asymptomatic, conservative procedures of carious dentin removal have been devised in order to stop pulp exposure and the complications that follow [3]. Stepwise excavation (SW) is a two-step process that involves completely excavating diseased tissue. However, the SW approach has significant drawbacks associated with cavity reopening, such as the possibility of pulp exposure during the final excavation or when reentering the cavity. A different course of treatment has been suggested because of the second intervention's lack of evidence and the drawbacks of the SW approach. In this method, partial dentin removal and placement of restorative material are carried out in a single procedure [4]. Many fluoride-based therapeutic materials were introduced and assessed for their effects on arresting dental caries [5]. Owing to its efficiency in stopping the advancement of dental cavities, Silver diamine fluoride (SDF), a topical fluoride preparation based on metal ions, has recently received more attention. It was reported that 38% SDF had a clinical efficacy of about 65.9% in halting the advancement of dentinal caries. The main disadvantage of SDF is the heavy dark tissue discoloration caused by the oxidation of the ionic silver used in its composition, coupled with ulceration and painful oral tissue staining. However, SDF-related soft tissue stains are typically reversible [6].

Among the most effective antibacterial agents is silver nanoparticles (AgNPs), whose effectiveness against cariogenic bacteria like *S.mutans* has been demonstrated in-vitro. AgNPs are utilized in dental materials because of nano silver's enhanced anti-viral and anti-fungal properties[7]. Despite the well established ability of nano silver fluoride and SDF in halting the carious process [8], the available data in literature was limited to primary teeth, invitro studies and case reports [8,9]. According to a recent non-randomized case series, Silverfluoride demonstrated the capacity to protect the pulp in 277 permanent teeth with very deep decay [10]. Furthermore, although partial caries removal is currently the recommended approach to preserve pulp vitality, still the majority of dentists practice the complete carious tissue removal to hard dentin [2,11]. Thus by comparing the two current cariostatic agents presented in this study, there will be an a expansion on the current understanding in terms of efficacy, cost and clinical decision making. Consequently, this research was done to assess and contrast the promising cariostatic properties of NSF to that of SDF. The null hypothesis is that there is no difference in clinical efficacy between NSF and SDF in arresting deep carious lesion.

MATERIALS AND METHODS

Study design

This study was a double blinded randomized controlled three arm study with allocation ratio 1:1:1. The patients and outcome assessors were blinded to the study groups. The Suez Canal University Faculty of Dentistry's Research Ethical Committee (226/2019) granted its approval for this randomized clinical research. Patients were recruited from the outpatient clinic of the department of conservative dentistry, Suez canal university, Ismailia Egypt. Follow up was carried out for 6 months. The study's protocol was submitted into the US National Institutes of Health protocol registry (ClinicalTrials.gov NCT05231330). This study was reported based on the Consolidated Standards of Reporting Trials (CONSORT). Informed consent was obtained from all individual participants included in the study.

Sample size calculation

Using power analysis, the total sample size for a Chi-square test comparing three groups was calculated. The minimum estimated sample size was 30 individuals, and the effect size (w) was 0.75 utilizing alpha levels of 0.05 (5%) and beta levels of 0.10 (10%), i.e., power = 90%. The number of subjects was increased to 36, with 12 subjects per group, to account for a 20% dropout rate.

Criteria of patient selection

Inclusion criteria included Cooperative patients between 18-50 years old having vital lower first and second molars with class I primary

deep carious lesions with no widening in the periodontal ligaments, pain, mobility or sensitivity to percussion. Medically unfit patients, women who were pregnant, and those with allergies to any restorative materials, including anesthetics, were among the exclusion criteria. Retained deciduous teeth and teeth with previous restorations were also excluded.

Randomization and allocation

A random sequence was created with the use of an online tool by a coinvestigator[12]. The randomization table was then printed and kept with the co-investigator. The operator provided opaque envelopes with folded, numbered papers for the patients to drag. Patients were unaware of their treatment group. The study groups remained anonymous at end of study during assessment by the statistician. All participants signed a written informed consent.

Grouping of patients

Thirty-six patients were evenly distributed by random among three groups based on the tested material:

- Silver Nanoparticles group (A1), (n=12): conservative caries management (selective caries removal to soft dentin) was carried out to deep carious teeth followed by application of NSF (Nano silver particles in fluoride solution).
- SDF group (A2), (n=12): conservative caries management (selective caries removal to soft dentin) was carried out to deep carious teeth followed by application of SDF.
- Control group (A3), (n=12): conservative caries management (selective caries removal to soft dentin) was carried out to deep carious teeth with no additional intervention.

Intervention

AgNPs synthesis in powder form

25ml of clear silver nitrate solution was added drop wise to the freshly prepared aqueous solution of Sodium Borohydride (NaBH4) at 60°C for 30 minutes in a dark environment. The solution was stirred to ensure homogeneity. The pH of the mixture was then adjusted to 11 while raising the temperature to 90°C and continuous stirring for 30 minutes. The resulted silver nanoparticles suspension was exposed to simultaneous coating with Polyvinylpyrrolidone in the early stage of formation. It was allowed to cool at room temperature. Besides the tiny amount produced, the dispersion medium was freeze dried also and affected the degree of nanosilver powder purity. Therefore, the nanoparticles suspension was subjected to centrifugation followed by drying at 50°C to produce dark greyish powder with uniquely fine particles that representing nano-silver powder [13].

Characterization of silver nanoparticles

In order to identify the distinctive optical characteristics of silver nanoparticles, the generated silver nanoparticles were examined with the aid of ultraviolet-visible absorption spectroscopy. The size and form of the silver nanoparticle were assessed using a transmission electron microscope (TEM). Once a drop of the solution has been applied on a copper grid that has carbon coating and allowed to dry in the air, samples were then subjected to TEM analysis. A Gatan (DualVision 600t CCD) camera was used to capture images, and Gatan was used to analyse the captured images (Digital Micrograph Version 3.11.1.)

Preparation of 5% silver nanoparticles in fluoride varnish (NSF)

In a brown light-proof bottle, 10 ml of 22,600 ppm slow release sodium fluoride varnish (FLUORITOPTM-SR)3 was combined with 0.5 grammes of silver nanoparticle powder and vigorously stirred by vortex at low speed for 30 seconds to achieve uniform dispersion of the particles.

Diagnostic procedures

A comprehensive medical and dental history was documented. A diagnostic chart was filled out with the patient's demographic information, tooth count, and number of affected surfaces. Digital periapical and bitewing radiographs (EzSensor Classic, Vatec, Korea) were taken for each tooth by the same X-ray machine (Xgenus®, De Götzen, Italy) utilising uniform exposure conditions (70 kvp, 3.5 mAs, and 0.2 s). A cold test was performed using EndoIce (Hygenic Endo-Ice, Coltene Whaledent, Cuyahoga Falls, OH) and electric pulp tester (Denjoy DY310, Denjoy, Henan, China). Scaling and polishing were done to remove any present dental plaque or calculus eliminating any biofilms harboring bacteria on the teeth surface.

Single tooth isolation was performed for simple occlusal lesions. Access through the cavitated enamel was obtained, when necessary, using a high-speed handpiece and a sterile high-speed bur (#245 bur, Meisinger GmbH, Germany) with copious water spray rotating at speed ranging from 380,000-450,000 rpm. Following the guidelines published by the International Caries Consensus Collaboration (ICCC), selective caries removal to soft dentine strategy was performed using hardness criteria. Total caries removal to hard dentine was performed for the peripheral walls of the cavity using a sterile tungsten carbide bur (#245 bur, 0.8 mm in diameter and 1.6 mm in length Meisinger GmbH, Germany) and a low-speed large round bur (HM 71, size 4, Meisinger GmbH, Germany) operated at 10000-12000 RPM. The dentino-enamel junction (DEJ) and cavosurface margins were inspected carefully and made sure to be clean. For the pulpal floor soft dentine was removed until the level at which would put the pulp at risk of exposXure.

For the NSF group (A1) The cavity was rinsed with copious water spray to remove any debris then a gently compressed air flow was done to dry the cavity followed by bending and dipping the micro brush into NSF solution and applying pressure to the plastic dappen dish's side to squeeze out extra liquid before application over the remaining discolored soft dentin. Excess material was removed with gauze followed by application of a gently compressed air flow until the medicament was dry and left for 2 minutes for complete dryness. Selective etching of the enamel was carried out in accordance with the manufacturer's instructions using a 35% phosphoric acid gel for 15 seconds, followed by a 15-second water rinse and a 5-second gentle air-drying period. Using a disposable applicator brush, a single coating of universal bond was applied to the prepared cavity and rubbed for 20 seconds. For about 5 seconds, a gently stream of air passed over until it stopped moving and the solvent had evaporated. According to the manufacturer's recommendations, photo activation was carried out for 10 seconds using the Elipar S10 light curing system (3M ESPE in St. Paul, Minnesota, USA) at an intensity of 1200 mW/cm2. Composite resin restorative was used to restore the cavities, the material was placed in increments of 2 mm following the anatomic layering technique and then light curing was done for 40 seconds. After checking the occlusion, one-step polishing tips and/or cups (Dimanto ®, Voco Gmbh, Germany) and a low-speed contra-angle handpiece (NAC-EC, NSK, Japan) with water coolant and low pressure were used for final polishing.

For SDF group (A2) The cavity was rinsed with copious water spray, a gentle flow of compressed air was done to dry the cavity followed by application of SDF with a microbrush according to manufacture instruction directly to the carious tooth surface. Excess SDF was removed with gauze followed by application of a gently compressed air flow until medicament is dry and left for as long as three minutes. Etching, bonding and composite application was done as mentioned previously.

For the control group (A3) The cavity was rinsed with ample spray of water, then a gently compressed air flow was done to dry the cavity. Etching, bonding and composite application was done as mentioned previously. Postoperative instructions and oral hygiene recommendations for the follow-up period were given to all patients. Patients were instructed to contact the primary investigator if there were any symptoms of pain or complains regarding the restoration.

Outcomes

The patients were contacted three and six months later to evaluate the results. The outcome of this study was the success/ failure of the tooth expressed as a binary variable. Success requires positive response to sensitivity pulp testing, absence of spontaneous pain, sensitivity to percussion, sinus/ fistula/swelling and radiographic abnormalities as follows [14]:

1. Vitality pulp testing: Cold pulp testing and electric pulp testing were performed to confirm pulp vitality. The patient notified the operator when he/she felt pain and when the pain subsided. The length of the response was recorded and compared to a control tooth.
2. Spontaneous pain: post-operative pain was assessed as presence / absence.
3. Sensitivity to percussion: light tapping of the occlusal surface using mirror handle and patients were asked to report presence/ absence of pain. Test was also carried out for adjacent and contralateral teeth.
4. Sinus/fistula/swelling: using visual inspection and tactile sensation, recorded as presence/ absence.

5. Radiographic abnormalities: Indicating presence of periapical radiolucency, widening of lamina dura, internal and external root resorption. Periapical radiolucency was considered in case of widening twice the width of the periodontal ligament space and absence of lamina dura and was recorded as a binary outcome as presence or absence. If one of these tests indicated the presence of an irreversible pulpitis or pulp necrosis the tooth was considered as failure. Patients who reported treating the tooth in another healthcare facility were recorded as failure.

Statistical analysis

Using the chi-square test for the effect of material comparison, categorical data were presented as frequency and percentage values. Using the Shapiro-Wilk test, the mean and standard deviation values of the supplied numerical data were examined for normality. One-way ANOVA was used to analyze parametric data. For all tests, the significance level was set at p 0.05. R statistical analysis software for Windows, version 4.1.1, was used to conduct the statistical analysis.

RESULTS

The study was conducted on 36 cases that were equally and randomly allocated to one of the three studied groups. Consort 2010 flow chart for the trial design is presented in Figure 1. There were 5(41.7%) males in the control group and 7(58.3%) females, in SDF group there was 8(66.7%) males and 4(33.3%) females, while in silver nanoparticles group there was 7(58.3%) males and 5(41.7%) females. The mean age of the cases in the control group was (32.50±11.55) years, in SDF it was (28.42±10.47) years, while in silver nanoparticles group it was (31.25±13.30) years. There was no significant difference between groups regarding sex distribution (p=0.589) and age (p=0.690).

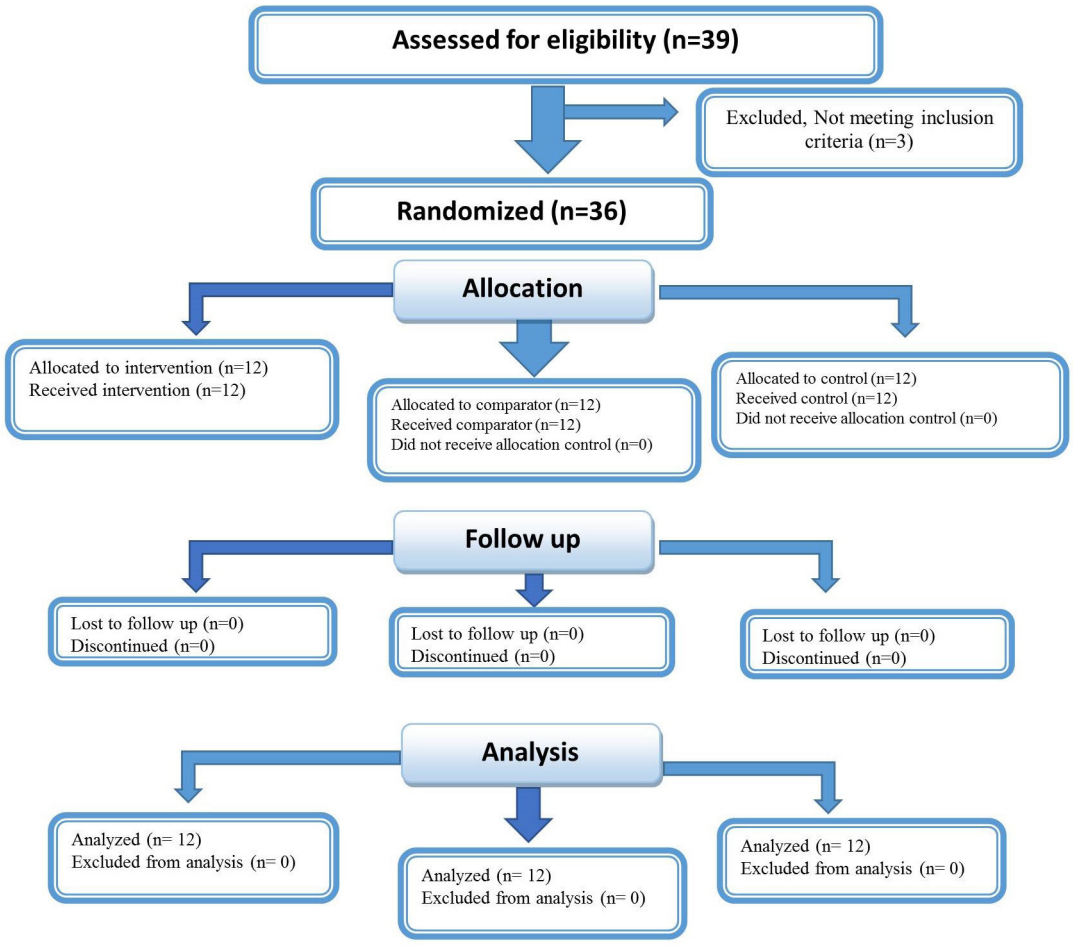

Figure 1 - Consort 2010 flow chart for the trial design.

Regarding teeth vitality, after three months, all cases of all groups were positive. After 6 months only one case in the control group was negative while other cases were positive and the difference between groups was not statistically significant (p=0.358). For spontaneous pain, after 3 months, all cases were free from spontaneous pain. After 6 months, one case in the control and one in SDF groups suffered spontaneous pain, while all cases of silver nanoparticles group were free and there was a non-significant difference between groups (p = 0.589).

Regarding the sensitivity to percussion, after 3 months, all cases were free from sensitivity to percussion. After 6 months, 2 cases in the control group and one case in SDF group had sensitivity to percussion while all the cases of the silver nanoparticles group were free but there was no significant difference between groups.

For both intervals, all cases in all groups were free from presence of sinus/swelling/fistula. While for the radiographic abnormalities, after 3 months, all cases in all groups were free. After 6 months, one case in the control group had radiographic abnormalities with no significant difference between groups (p=0.358) (Table I).

Overall success rate

After 3 months, all cases were successful in all groups. After 6 months, 2 cases failed in the control group and a single case failed in SDF, while all cases of silver nanoparticles were successful. No significant difference between the materials was found (p=0.336) (Table II, Figure 2).

Table I - Frequency and percentage values for assessed patient symptoms

Parameter		Control	SDF	Silver nanoparticles	p-value
Vitality					
Negative	**n (%)**	1 (8.3%)	0 (0.0%)	0 (0.0%)	**NS 0.358**
Positive	**n (%)**	11 (91.7%)	12(100.0%)	12 (100.0%)	
Spontaneous pain					
Absent	**n (%)**	11 (91.7%)	11 (91.7%)	12 (100.0%)	**NS 0.589**
Present	**n (%)**	1 (8.3%)	1 (8.3%)	0 (0.0%)	
Sinus/fistula/swelling					
Absent	**n (%)**	12 (100.0%)	12 (100.0%)	12 (100.0%)	**NS**
Present	**n (%)**	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Sensitivity to percussion					
Absent	**n (%)**	10 (83.3%)	11 (91.7%)	12 (100.0%)	**NS 0.336**
Present	**n (%)**	2 (16.7%)	1 (8.3%)	0 (0.0%)	
Radiographic abnormalities					
Absent	**n (%)**	11 (91.7%)	12 (100.0%)	12 (100.0%)	**NS 0.358**
Present	**n (%)**	1 (8.3%)	0 (0.0%)	0 (0.0%)	

Significant (p ≤ 0.05), ns; non-significant (p>0.05). [Chi-square test x^2].

Table II - Frequency and percentage values for outcome status for different materials

Time	Parameter		Control	SDF	Silver nanoparticles	p-value
3 months	**Failure**	**N (%)**	0 (0.0%)	0 (0.0%)	0 (0.0%)	**NS**
	Success	**N (%)**	12 (100.0%)	12(100.0%)	12 (100.0%)	
6 months	**Failure**	**N (%)**	2 (16.7%)	1 (8.3%)	0 (0.0%)	**NS 0.336**
	Success	**N (%)**	10 (83.3%)	11 (91.7%)	12 (100.0%)	

Significant (p ≤ 0.05), ns; non-significant (p>0.05). [Chi-square test x^2].

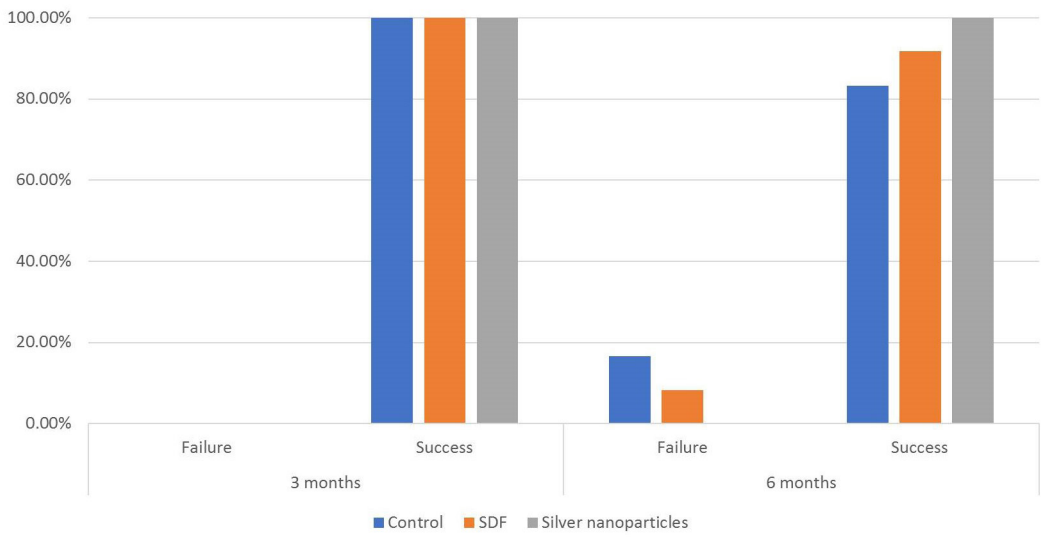

Figure 2 - Bar chart showing success percentage values for outcome status for different groups.

DISCUSSION

This study was designed to evaluate the success rate of silver nanoparticles in comparison to SDF in managing deep carious permanent teeth. SDF has been reported as a successful caries arresting agent for up to 10 years [15]. In the current study, the concentration of SDF was 38%. SDF is available in solutions with 10%, 30%, and 38% silver content, although the 38% solution appears to be the most efficient at inhibiting caries and fostering remineralization [16]. Silver compounds transform into metallic silver, which causes carious tissue to become darkly stained. SDF precipitates as a black precipitate on the surface of carious dentin as a result of the reaction between unreacted silver ions and the partially denatured collagen. Because of the oxidative qualities of the ionic silver used in the formulation, extra unreacted silver ions continue to precipitate as silver sulphide capping, which results in staining [17].

Silver nanoparticles have drawn attention in the recent years in medical fields. For gram-negative bacteria, tiny spherical silver nanoparticles can enter the bacterial matrix and disrupt vital cell functions including DNA replication [18]. NSF was the experimental prepared material in the current study for managing deep carious lesions. The benefits of using NSF over SDF were the fact that it did not turn the dental tissue black, and did not produce oxides when it interacted with oxygen in the media [19]. The experimental prepared material was composed of nanosilver for its antimicrobial effect and fluoride to enhance remineralization. And also, to prepare a material similar in composition to the ready-made SDF but in nanoscale hoping to improve its cariostatic effect and reducing the drawbacks of black staining caused by silver in its molecular form and without ammonia to avoid the bad taste.

The characterization of materials containing AgNPs is a crucial step in their development. UV-visible spectroscopy, which has been demonstrated to be a useful and significant method for the characterization of metal nanoparticles, was used to characterise the produced AgNPs. The UV absorption spectral test were carried out to monitor the reduction of silver ions to AgNPs and confirm their formation [20]. TEM was used to visualize the particle size and shape [21]. Weight dilution method described by Haghgoo et al. (2014) [13] was adopted in the preparation of 5% NSF and this concentration was used as it is the minimum nano silver concentration to kill and inhibit growth of cariogenic microorganisms such as *S.mutans and S.Salivarius* [5].

In the current study, teeth were selected according to pre-defined clinical and radiographical criteria which ensured to great extent the absence of irreversible changes in the dental pulp complex [22]. Only molars with class I primary deep carious lesions were included in the current study. This was done to decrease the variables as much as possible as the number of surfaces in a dental restoration has shown to be of different influence in different type of studies. In addition to their easier radiographical interpretation [23]. No dyes were utilized during

the caries removal process since they can lessen visual and tactile subjective perceptions, moreover, dyes are less specific to caries, causing excessive removal of perfectly healthy tooth structure, and raising the risk of mechanical pulp exposures [24].

For enhanced mechanical strength, wear resistance, and improved aesthetics, an impervious restoration is mandatory [25]. Additionally, dental pulp healing is directly correlated to the ability of both the interim and definitive restorative material to create a biological seal, along the entire interface, against both long-term and short-term microleakage, rather than being solely dependent on the purported stimulatory effect of a particular type of medication [26]. Therefore, in the current study, all treated teeth in all groups were restored with a light cured composite resin to avoid bacterial leakage.

Radiographic follow up was performed using digital radiography, in order that the information from radiographic images would be collected more easily and in a more objective way, thus improving the performance of the diagnostic process, in addition to minimize the patient radiation. Paralleling technique was used since it ensures image reproducibility which is an important requisite for standardization [4]. It has been known that management of deep carious lesions success or failure is dependent upon accurate diagnosis at the time of treatment. Considering the fact that more clinical failures usually occur within the first-time interval (3- 6 months), it is believable that improper diagnosis may contribute to these failures. Hence, in the present study the follow up visit were after 3 and 6 months [14,27,28].

The results of the current study showed that, after 3 months, all cases were successful in all groups. After 6 months, for the control group, 2 cases failed with no significant difference between intervals. For SDF group, a single case failed with no significant difference between intervals. For NSF group, all cases were successful. Regarding the NSF success rate in the current study all cases were successful after 3 and 6 months. These results come in accordance with Santos et al. (2014) [30], who found that at five months, the NSF group had 72.7% cases with arrested decay, and the control group had 27.4% that might be attributed to the synergism of the components of its formulation (AgNPs and fluoride) and the small size of the NSF nanoparticles increasing the contact surface area. Butrón Téllez Girón et al. (2020) [31] also found that teeth treated with silver nanoparticles added to fluoride varnish seemed to have enhanced dental structure. They attributed this to the fact that the added silver nanoparticles are more effective in the dental remineralization thus not only halting progression of the carious process but also reverting it [30].

The clinical and radiographic success rate at the end of the 6-month follow-up period in the current study was 100% in NSF group, 91.7% in SDF group and 83.3% in control group although no significant difference was found among the three groups. This result was in accordance with that of Tirupathi et al. (2019) [18] who compared the success rate of 5% NSF and 38% SDF [18]. Higher success rate for NSF was observed with no significant differences between the 2 groups during their 6 months follow-up. This might be attributed to the fact that NSF is a better inhibitor of S. mutans biofilm formation than SDF. As these nanoparticles would easily enter the polysaccharide matrix inside the cell, they could prevent biofilm formation and maturation by inhibiting the creation of exopolysaccharides [15]. The nano-sized particles of NSF are significantly smaller than SDF, hence the inhibition of the bacteria with silver was stronger. As a result, even low quantities of silver could significantly minimize the adverse effects of NSF while having powerful antibacterial properties.

Regarding the success rate of SDF in this study, after 3 months, all cases were successful while a single case failed after 6 months (spontaneous pain and sensitivity to percussion) with no significant difference between intervals, which come in accordance with Divyashree R. (2021) who reported that SDF seems to be a good indirect pulp therapy (IPT) material as it fulfils the criteria for IPT procedure such as good biological seal and maintenance of the pulp vitality and there was no statistically significant difference between the clinical success rates of SDF when used after 3 and 6 months [31]. They hypothesized that both silver ions and fluoride ions are involved in the mechanism of action, with fluoride ions acting primarily on tooth structure and silver ions acting primarily on cariogenic bacteria. Santos et al. (2014) [32] compared the effectiveness of SDF with temporary restorations in the arrest of caries and they found that 38% SDF was 1.73 times more effective in stopping caries than an interim restorative approach after

6 and 12 months. SDF acts as a fluoride reservoir for acid attacks by pathogenic organisms by providing an alkaline environment that makes CaF2 less soluble.

As for the success rate of the control group in this study, after 3 months, all cases were successful while 2 cases failed after 6 months with no significant difference between intervals (p=0.500). The results of the control group in this study come in accordance with a plethora of studies that proved that if severely damaged dentin is removed and a good interfacial seal is created, the dentin-pulp complex's healing and self-repair processes can occur without the use of a mineralization inducer [33-35]. In the current study, the good clinical and radiographic success reported with PCR group could be attributed to the correct diagnosis and utilization of a well-sealed coronal restoration to stabilize any remaining carious dentine while reducing the availability of exogenous nutrients thus preventing microleakage.

This study did have some limitations, first, even though the trial was carried out by a single consistent operator who used the same clinical judgement regarding degree of caries removal, application of materials, and evaluating proximity to pulp tissue, the investigator was not blinded to the study groups due to noteworthy differences in the materials used. Along with being a single center study, this might affect the generalizability of the study findings. Another limitation was the relatively small sample size and short follow up period, which adds another burden on the external validity of the study. Further clinical trials with larger sample size and longer observations periods are needed to provide a broader and more relevant viewpoint regarding the long-term biological effects of these materials on the dental pulp.

CONCLUSION

Under the limits of the present study, it could be concluded that Application of 5% Nanosilver to fluoride varnish has same clinical efficacy as SDF in preventing the progression of dentinal caries without causing undesirable tooth staining. However, further clinical randomized trials with different shapes, sizes and concentrations of Silver nanoparticles.

Author's Contributions

KHAA: Conceptualization, Methodology, Validation, Investigation, Formal Analysis, Data Curation, Writing – Original Draft Preparation. MIR: Conceptualization, Validation, Writing – Review & Editing, Supervision. AFAE: Conceptualization, Validation, Writing – Review & Editing, Supervision.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

All procedures performed in the study were in accordance with the ethical standards of the institutional research committee of Cairo university and with 1964 Helsinki declaration and its later amendments.

REFERENCES

1. Pal S, Tak YK, Song JM. Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli. Appl Environ Microbiol. 2007;73(6):1712-20. http://dx.doi.org/10.1128/AEM.02218-06. PMid:17261510.
2. Duncan HF, Galler KM, Tomson PL, Simon S, El-Karim I, Kundzina R, et al. European Society of Endodontology position statement: management of deep caries and the exposed pulp. Int Endod J. 2019;52(7):923-34. http://dx.doi.org/10.1111/iej.13080. PMid:30664240.
3. Ricketts D, Lamont T, Innes NPT, Kidd E, Clarkson JE. Operative caries management in adults and children. Cochrane Database Syst Rev. 2019;7(7):CD003808. http://dx.doi.org/10.1002/14651858.CD003808.pub4. PMid:31339555.
4. Stafuzza TC, Vitor LLR, Rios D, Silva TC, Machado MAAM, Oliveira TM. Clinical and radiographic success of selective caries removal to firm dentin in primary teeth: 18-month follow-up. Case Rep Dent. 2018;2018:9213681. http://dx.doi.org/10.1155/2018/9213681. PMid:29796320.
5. Soekanto SA, Marpaung LJ, Ushohwah H, Djais A, Darwita RR. Efficacy of propolis fluoride and nano silver fluoride for inhibition of streptococcus mutans and enterococcus faecalis biofilm formation. Int J Appl Pharm. 2017;9(Spe 2):51-4.
6. Sayed M, Nikaido T, Abdou A, Burrow MF, Tagami J. Potential use of silver diammine fluoride in detection of carious dentin. Dent Mater J. 2021;40(3):820-6. http://dx.doi.org/10.4012/dmj.2020-308. PMid:33775985.
7. Yin IX, Zhao IS, Mei ML, Li Q, Yu OY, Chu CH. Use of silver nanomaterials for caries prevention: a concise review. Int J Nanomedicine. 2020;15:3181-91. http://dx.doi.org/10.2147/IJN.S253833. PMid:32440117.
8. Rady MA, Elbehery SM, Eldesouky G, Elbaz G, Mahfouz S. Clinical evaluation of the efficacy of silver diamine fluoride in arresting active dentin caries in primary molars. Dent Sci

Update. 2021;2(2):197-203. http://dx.doi.org/10.21608/dsu.2021.77947.1070.

9. Mungur A, Chen H, Shahid S, Baysan A. A systematic review on the effect of silver diamine fluoride for management of dental caries in permanent teeth. Clin Exp Dent Res. 2023;9(2):375-87. http://dx.doi.org/10.1002/cre2.716. PMid:36823765.
10. Griffith M. Treating deep caries in 277 adult teeth with silver fluoride. J Calif Dent Assoc. 2021;49(1):13-7. http://dx.doi.org/10.1080/19424396.2021.12222658.
11. Schwendicke F, Stangvaltaite L, Holmgren C, Maltz M, Finet M, Elhennawy K, et al. Dentists' attitudes and behaviour regarding deep carious lesion management: a multi-national survey. Clin Oral Investig. 2017;21(1):191-8. http://dx.doi.org/10.1007/s00784-016-1776-5. PMid:26971353.
12. https://www.randomizer.at/. Accessed 10 September 2020.
13. Haghgoo R, Saderi H, Eskandari M, Haghshenas H, Rezvani MB. Evaluation of the antimicrobial effect of conventional and nanosilver-containing varnishes on oral Streptococci. J Dent (Shiraz). 2014;15(2):57-62. PMid:24883341.
14. Corralo DJ, Maltz M. Clinical and ultrastructural effects of different liners/restorative materials on deep carious dentin: a randomized clinical trial. Caries Res. 2013;47(3):243-50. http://dx.doi.org/10.1159/000345648. PMid:23343804.
15 Mei ML, Zhao IS, Ito L, Lo ECM, Chu CH. Prevention of secondary caries by silver diamine fluoride. Int Dent J. 2016;66(2):71-7. http://dx.doi.org/10.1111/idj.12207. PMid:26689611.
16. Duangthip D, Wong MCM, Chu CH, Lo ECM. Caries arrest by topical fluorides in preschool children: 30-month results. J Dent. 2018;70:74-9. http://dx.doi.org/10.1016/j.jdent.2017.12.013. PMid:29289726.
17. Akyildiz M, Sönmez IS. Comparison of remineralising potential of nano silver fluoride, silver diamine fluoride and sodium fluoride varnish on artificial caries: an in vitro study. Oral Health Prev Dent. 2019;17(5):469-77. PMid:31268047.
18. Tirupathi S, Svsg N, Rajasekhar S, Nuvvula S. Comparative cariostatic efficacy of a novel nano-silver fluoride varnish with 38% silver diamine fluoride varnish a double-blind randomized clinical trial. J Clin Exp Dent. 2019;11(2):e105-12. http://dx.doi.org/10.4317/jced.54995. PMid:30805113.
19. Brignardello-Petersen R. Although silver diamine fluoride arrested caries sooner than fluoride varnish, the overall proportion of arrested caries was not importantly different after 30 months. J Am Dent Assoc. 2018;149(8):e117. http://dx.doi.org/10.1016/j.adaj.2018.02.007. PMid:29625697.
20. Gurunathan S, Han JW, Kwon DN, Kim JH. Enhanced antibacterial and anti-biofilm activities of silver nanoparticles against Gram-negative and Gram-positive bacteria. Nanoscale Res Lett. 2014;9(1):373. http://dx.doi.org/10.1186/1556-276X-9-373. PMid:25136281.
21. Corrêa JM, Mori M, Sanches HL, Cruz AD, Poiate E, Poiate IAVP. Silver nanoparticles in dental biomaterials. Int J Biomater. 2015;2015:485275. http://dx.doi.org/10.1155/2015/485275. PMid:25667594.
22. Ricucci D, Loghin S, Siqueira JFJ Jr. Correlation between clinical and histologic pulp diagnoses. J Endod. 2014;40(12):1932-9. http://dx.doi.org/10.1016/j.joen.2014.08.010. PMid:25312886.
23. Khokhar M, Tewari S. Outcomes of partial and complete caries excavation in permanent teeth: a 18 month clinical study. Contemp Clin Dent. 2018;9(3):468-73. http://dx.doi.org/10.4103/ccd.ccd_344_18. PMid:30166846.
24. Croft K, Kervanto-Seppälä S, Stangvaltaite L, Kerosuo E. Management of deep carious lesions and pulps exposed during carious tissue removal in adults: a questionnaire study among dentists in Finland. Clin Oral Investig. 2019;23(3):1271-80. http://dx.doi.org/10.1007/s00784-018-2556-1. PMid:29987635.
25. Favaro JC, Peixoto YCTM, Geha O, Dias FA, Guiraldo RD, Lopes MB, et al. Can silver diamine fluoride or silver nanoparticle-based anticaries agents to affect enamel bond strength? Restor Dent Endod. 2021;46(1):e7. http://dx.doi.org/10.5395/rde.2021.46.e7. PMid:33680896.
26. Pratiwi AR, Meidyawati R, Djauharie N. The effect of MTA application on the affected dentine remineralization after partial caries excavation (in vivo). J Phys Conf Ser. 2017;884(1):012119. http://dx.doi.org/10.1088/1742-6596/884/1/012119.
27. Martins DAS, Moreira KMS, Pereira MSS. Partial removal of carious in primary teeth: a systematic review of the literature. Oral Health Dent Manag. 2018;17(1):1-5.
28. Maltz M, Garcia R, Jardim JJ, De Paula LM, Yamaguti PM, Moura MS, et al. Randomized trial of partial vs. stepwise caries removal: 3-year follow-up. J Dent Res. 2012;91(11):1026-31. http://dx.doi.org/10.1177/0022034512460403. PMid:22983407.
29. Santos VE Jr, Vasconcelos A Fo, Targino AGR, Flores MAP, Galembeck A, Caldas AF Jr, et al. A new "silver-bullet" to treat caries in children - nano silver fluoride: a randomised clinical trial. J Dent. 2014;42(8):945-51. http://dx.doi.org/10.1016/j.jdent.2014.05.017. PMid:24930870.
30. Butrón Téllez Girón C, Hernández Sierra JF, DeAlba-Montero I, Urbano Peña MDLA, Ruiz F. Therapeutic use of silver nanoparticles in the prevention and arrest of dental caries. Bioinorg Chem Appl. 2020;2020:8882930. http://dx.doi.org/10.1155/2020/8882930. PMid:32855631.
31. Divyashree R. Effectiveness of silver diamine fluoride when used as an indirect pulp therapy (IPT) material- a clinical and radiological assessment. Int J Appl Dent Sci. 2021;7(2):466-78. http://dx.doi.org/10.22271/oral.2021.v7.i2g.1255.
32. Santos, V. E., Targino, A. G. R., Flores, M. A. P., Pessoa, H. de L. F., Galembeck, A., & Rosenblatt, A. (2014). Antimicrobial activity of silver nanoparticles in treating dental caries. Revista Da Faculdade De Odontologia - UPF, 18(3). https://doi.org/10.5335/rfo.v18i3.3568
33. Sharma S, Logani A, Shah N. Comparative efficacy of photo-activated disinfection and calcium hydroxide for disinfection of remaining carious dentin in deep cavities: a clinical study. Restor Dent Endod. 2014;39(3):195-200. http://dx.doi.org/10.5395/rde.2014.39.3.195. PMid:25110643.
34. Franzon R, Opdam NJ, Guimarães LF, Demarco FF, Casagrande L, Haas AN, et al. Randomized controlled clinical trial of the 24-months survival of composite resin restorations after one-step incomplete and complete excavation on primary teeth. J Dent. 2015;43(10):1235-41. http://dx.doi.org/10.1016/j.jdent.2015.07.011. PMid:26231301.
35. Singh S, Mittal S, Tewari S. Effect of different liners on pulpal outcome after partial caries removal: a preliminary 12 months randomised controlled trial. Caries Res. 2019;53(5):547-54. http://dx.doi.org/10.1159/000499131. PMid:31096259.

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