ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
June 2025 • Vol. 38

Color Masking Effect of Different Fluoride Releasing Restorations Combined with Potassium Iodide or an Opaquer on Discoloration Produced Following Silver Diamine Fluoride Application in Primary Molars: An In-Vitro Study

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Aim: The present study aims to evaluate and compare the ability of different fluoride-releasing restorative materials combined with either potassium iodide (KI) or an opaquer to mask the discoloration produced subsequent to silver diamine fluoride (SDF) and to assess their color change over time.

Materials and methods: Fifty-four carious primary molars were collected and randomly divided into three main groups according to the tested material [Glass Ionomer (Group A), Giomer (Group B), and Zirconomer (Group C)]. Each group was further subdivided according to the addition of either SDF only (control), SDF+Potassium iodide (intervention 1), or SDF+Opaquer (intervention 2). Color assessments using a spectrophotometer were performed after restoration placement, after 24 hours, and after 1 week.

Results: The intragroup comparison revealed a significant change in color (ΔE value) in all groups between the 24-hour and 1-week time intervals. Group A demonstrated the greatest amount of discoloration at all periods compared to groups B and C. KI and opaquer significantly reduced the SDF discoloration ($p<0.001$) under the different restorations. Group A had the greatest (ΔE) value, followed by Group B, while Group C had the lowest value. Values of various materials were found to be significantly different from one another ($p<0.001$) in post hoc pairwise comparisons.

Conclusion: The use of KI or opaquer following the SDF application is preferable over SDF alone for masking the black staining. Additionally, zirconia-reinforced glass ionomer may be able to mask SDF-produced discoloration more effectively than both giomer and glass ionomer.

Keywords: Silver diamine fluoride, Potassium iodide, Glass Ionomer, Giomer, Zirconomer

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Introduction

Untreated dental caries is one of the main global public health problems. The delivery of caries treatment has seen a shift in emphasis in recent years, with a focus on minimum intervention dentistry (MID) and preventative techniques that aim to intercept oral disorders early on. One of the MID protocols pertinent to caries control is the use of silver diamine fluoride (SDF), and systematic studies have verified its usefulness in arresting dental caries in children and adults.[1]

However, one major drawback of SDF that leads to aesthetic issues is black staining. As it was shown by Saad et al., [2] that sdf deposits on the side-walls of dentin tubules of sound dentin and inside the open tubules in case of demineralized dentin thus causing staining. Furthermore, while SDF therapy is a non-invasive procedure that leaves teeth unfilled, it cannot restore tooth structure or masticatory function, even though it can stop a lesion from spreading.[33]

Potassium iodide (KI) saturated solution was suggested to alleviate the staining properties of SDF and has been described as a promising approach to solving the discoloration problem. However, some studies reported that the KI effect on color change was only temporary as darkening of the SDF-treated teeth still occurred, showing color changes over time.[4]

In recent years, a novel approach to caries intervention and management using SDF and ART in combination, known as the silver-modified atraumatic restorative technique (SMART), has been developed. By stopping carious lesions and repairing the tooth without the danger of aerosols, this method gives children a temporary substitute for regular restorative procedures.[5]

A variety of restorative materials, such as glass ionomer, have been suggested to conceal the black color of SDF and restore the lesions following SDF.[6]

Glass ionomer is a water-based restorative material that significantly reduces recurrent decay at the margins and adjacent surfaces. Fluoride ions released over an extended period aid in remineralization. These ions can be replenished by ions from external sources, such as fluoride toothpaste, once they are released from the GIC.[5]

New classes of glass ionomer restorative materials with improved properties have been developed as a result of the search for better materials. Examples of these classes include resin-modified glass ionomer and zirconia-reinforced glass ionomer (Zirconomer Improved, Shofu Inc., Japan), which was given the name "White Amalgam" because of its exceptional strength and extended durability. It also has an acceptable amount of translucency that resembles the shade of natural teeth and the ability to release fluoride.[6,7]

"Giomer" is a new class of bioactive materials. The surface pre-reacted glass (SPRG) particle serves as the foundation for their composition. This particle shields the structure's core from damaging moisture effects and permits the discharge of fluoride and other ions. In addition, it has good mechanical stability, encouraging clinical behavior, and the capacity to promote remineralization while inhibiting demineralization and cariogenic microorganisms.[8]

Recently, Shofu company introduced a specially designed light-cure fluoride-releasing opaquer to mask intense discolorations. Opaquers are resins with a high pigment content containing metal oxides that are accountable for opacification. The use of opaquers prior to the application of the restorations allows for the masking of the substrate with less removal of tooth structure.[9]

The recent notable rise in requests for tooth-colored restorations has been attributed to advancements in dental materials and

patients' desire for aesthetic restorations. With the growing interest in SDF use in recent years, applying SDF prior to tooth-colored restorations may hasten unfavorable color changes. Consequently, it is pertinent and important to pay attention to variations in the color of restorative materials bonded to SDF-treated teeth.[1]

The present study aims to evaluate and compare the ability of different fluoride-releasing restorative materials combined with either potassium iodide (KI) or an opaquer to mask the discoloration produced following silver diamine fluoride (SDF) and to assess their color change over time.

Materials and methods

Study design and setting

The current investigation was an in vitro study conducted at Cairo University's Faculty of Dentistry's Pediatric Dentistry Department in Egypt. The CRIS Guidelines, a checklist for reporting in vitro experiments, were adhered to in the methodology.

Ethical approval

The research protocol was approved by the Research Ethics Committee, Faculty of Dentistry, Cairo University, for working on extracted human teeth with approval number (65-7-24). Every experimental procedure complied with the Declaration of Helsinki's recommendations for the use of human subjects in medical research. Prior to the extraction of the teeth, the child and his legal guardian gave their verbal and written informed consent.

Study size

In order to conduct a 2-sided statistical test of the null hypothesis—that is, that there is no difference in the masking capability of various fluoride-releasing restorative materials on SDF, a power analysis was constructed to have sufficient power.

Based on the findings of Kamble *et al.,* 2021 [10], with an alpha (α) level of 0.05 (5%), a beta (β) level of 0.2 (20%), power=80%, and an effect size (d) of 0.3338, the estimated sample size (n) was a total of (54) samples, or (6) samples for each group. A calculation of the sample size was done using G*Power 3.1.9.4.

Sample collection

A total of 54 extracted primary molars having occlusal decay that extend to the dentin were collected from the outpatient clinic at the Department of Pediatric Dentistry. The extracted teeth were collected from children of both sexes between 4 and 7 years of age with no previous history of systemic diseases, with the following inclusion criteria: extracted first primary molars with occlusal or proximal caries extending to more than half the crown and resorption rate less than 2/3 root length. Exclusion criteria involved extracted first primary molars with root caries or developmental defects.[10,11]

The selected teeth were subjected to scaling, and the plaque was thoroughly cleaned. The teeth were then mounted in acrylic resin cylinders and stored in distilled water in clean containers at room temperature to prevent dehydration. The same operator performed all teeth preparations.

Sample grouping and randomization:

The collected teeth were randomly divided into three main groups according to the tested material [Glass Ionomer (Group A), Giomer (Group B), and Zirconomer (Group C)]. Each group was further divided according to the addition of either SDF only (control), potassium iodide (intervention 1), or opaquer (intervention 2) as follows:

Group A (Glass Ionomer)
• Group A0: Silver diamine fluoride (SDF) + Glass Ionomer
• Group A1: Silver diamine fluoride (SDF) + Potassium iodide (KI) + Glass Ionomer
• Group A2: Silver diamine fluoride (SDF) + Opaquer + Glass Ionomer
Group B (Giomer)
• Group B0: Silver diamine fluoride (SDF) + Giomer
• Group B1: Silver diamine fluoride (SDF) + Potassium iodide (KI) + Giomer
• Group B2: Silver diamine fluoride (SDF) + Opaquer +Giomer
Group C (Zirconomer)
• Group C0: Silver diamine fluoride (SDF) + Giomer
• Group C1: Silver diamine fluoride (SDF) + Potassium iodide (KI) + Zirconomer
• Group C2: Silver diamine fluoride (SDF) + Opaquer + Zirconomer
- Each group consisted of 6 teeth that were randomly assigned using a computer-generated random sequence.
- The outcome assessor and the statistician were blinded; however, the operator was not.

Teeth preparation

- Excavation of carious lesion was carried out, and SDF was applied to the cavities using a micro-brush according to the manufacturer's instructions. One drop of SDF (Riva Star, SDI GmbH, Germany) was applied to all specimens for 1 minute, and then the specimens were rinsed with water for another 30 seconds and dried with air.
-In groups A1, B1, and C1, a saturated KI solution was immediately applied after application of SDF according to the manufacturer's instructions until the white precipitate appeared.
-In groups A2, B2, and C2, opaquer (Beautifil opaquer, Shofu Inc., Japan) was applied after application of SDF according to the manufacturer's instructions. The opaquer consisting of Bis-GMA, TEGDMA, S-PRG filler based on fluoroboroaluminosilicate glass, Polymerization initiator, Pigments and others. Beautibond universal (Shofu Inc., Japan) was applied to the cavity, left undisturbed for 10 seconds, then air-dried for 3 seconds, then light cured for 10 seconds. Beautifil opaquer then applied as thinly as possible (0.5 mm or less) and light cured for 20 seconds.
- The final restoration was added according to the to the allocated group:
In group A: Glass ionomer (Nova Glass, Imicryl, Turkey) was mixed according to the manufacturer's instructions and applied to the cavity after conditioning using polyacrylic acid.
In group B: Giomer (SPRG-containing restoration): Beautibond universal (Shofu Inc., Japan) was applied to the cavity, left undisturbed for 10 seconds, then air-dried for 3 seconds, then light cured for 10 seconds. The giomer restoration (Beautifil II LS, Shofu Inc., Japan) was applied incrementally, followed by light curing for 20 seconds.
In group C: The cavity was rinsed with water then air-dried, then Zirconomer Improved (Shofu Inc., Japan) was mixed according to the manufacturer's instructions and applied in the cavity.
-The color was recorded for all specimens directly after applying the tested materials as the baseline reading.

Color measurement

- Color was recorded by a digital spectrophotometer (Cary 5000, Agilent, USA). Before the measurement of the specimens' color, the device was calibrated based on the manufacturer's instructions.
-Three readings were recorded for each specimen as follows: t0 = baseline directly after application of the tested material, t1 =after 24 hours, and t2 = after one week. The readings were taken on the occlusal surface of the restoration; mid-occlusal, mesio-occlusal, and disto-occlusal.

-The L*, a*, and b* values (L* = lightness, + a* = red, − a* = green, + b* =yellow, − b* = blue) were measured to calculate ΔL, Δa, and Δb. Then, the degree of the color change (ΔE) was assessed using the following equation:

$$\Delta E = \sqrt{(L1 - L2)^2 + (a1 - a2)^2 + (b1 - b2)^2}$$

Outcomes

The present study aims to evaluate and compare the ability of different fluoride-releasing restorative materials combined with potassium iodide (KI) or an opaquer to mask the discoloration produced following silver diamine fluoride (SDF) and to assess their color change over time.

Statistical analysis

The IBM SPSS Statistics (22.0) software program for Microsoft Windows was used to do statistical analysis. The values of the mean and standard deviation (SD) were utilized to display numerical data. They underwent the Shapiro-Wilk test to determine their normalcy. A one-way ANOVA and Tukey's post hoc test were used to statistically examine the comparison of the various groups at various time intervals. For every test, the significance level was set at $p \leq 0.05$. The color change in each group at different time intervals was compared using the t-test.

Results

1. Intragroup color change [(ΔE) values] between 24 hours and 1 week time intervals

The intragroup comparison revealed a significant change in (ΔE) value in each subgroup between the 24-hour and 1-week time intervals. In the 3 groups, the greatest color change was noted in groups A0, B0, and C0 (using SDF only). Mean values with standard deviation for color changes (ΔE) of the restorations of all subgroups at different time intervals are presented in Table 1.

Table 1: Mean values with standard deviation for color changes (ΔE) of the restorations of all subgroups at different time intervals.

ΔE	Glass ionomer			Giomer			Zirconomer		
	SDF	SDF+KI	SDF+OP	SDF	SDF+KI	SDF+OP	SDF	SDF+KI	SDF+OP
After 24 hours	5.89 (±0.17)	3.47 (±0.18)	2.27 (±0.18)	4.83 (±0.18)	2.74 (±0.14)	1.59 (±0.14)	4.35 (±0.16)	2.52 (±0.07)	1.39 (±0.13)
After one week	11.74 (±0.33)	5.88 (±0.23	4.57 (±0.23)	9.65 (±0.25)	4.75 (±0.20)	3.94 (±0.22)	6.54 (±0.21)	4.09 (±0.18)	3.12 (±0.20)
P value	2.43E-05	1.03E-04	3.66E-06	2.53E-06	6.06E-04	1.06E-04	6.25E-06	1.10E-04	2.45E-05

2. Comparison of the effect of using either KI or opaquer in masking SDF discoloration in each group at different time intervals (KI and opaquer effect)

On comparing the masking potential of KI and the opaquer in group A (Glass ionomer) at different time intervals, it was seen that group A0 (SDF) showed the greatest amount of discoloration at different time intervals, followed by group A1(SDF+ KI), while the least discoloration was seen in group A2 (SDF+ opaquer). A statistical significance was noted in (ΔE) values between the different subgroups.

In group B (Giomer), similarly, at different time intervals, it was noted that group B0 (SDF) showed the greatest amount of discoloration, followed by group B1(SDF+ KI). In contrast, the least discoloration was seen in group B2 (SDF+ opaquer). A statistical significance was noted in (ΔE) values between the different subgroups.

Likewise, group C (Zirconomer) results also showed the greatest amount of discoloration in group C0 (SDF), followed by group C1(SDF+ KI). In contrast, the least discoloration was seen in group C2 (SDF+ opaquer) at different time intervals. A significance was noted in (ΔE) values between the various subgroups.

3. Comparison of the effect of different restorations in masking SDF discoloration at different time intervals

After 24 hours and one week, using SDF only, group A (Glass ionomer) showed the highest (ΔE) value, followed by group B (Giomer), while the lowest value was found in group C (Zirconomer). Values of different materials were found to be significantly different from one another ($p<0.001$) in post hoc pairwise comparisons.

Using KI under different restorations, after 24 hours and one week, it was seen that the highest (ΔE) value was found in group A (Glass ionomer), followed by group B (Giomer), while the lowest value was found in group C (Zirconomer). Post hoc pairwise comparisons showed values of different materials to be significantly different from each other ($p<0.001$).

Similarly, when opaquer was used under different restorations, after 24 hours and one week, group A (Glass ionomer), followed by group B (Giomer), while the lowest value was found in group C (Zirconomer). Values of various materials were found to be significantly different from one another ($p<0.001$) in post hoc pairwise comparisons.

Discussion

SDF is a safe and efficient treatment that doesn't have any immediate systemic side effects. However, its biggest drawback is the black coloring of carious lesions, which is caused by silver compounds forming on carious tooth surfaces, comprising esthetics. The broad usage of SDF may be hampered by this black staining.[1]

Unfavorable tooth discoloration from SDF has been masked up with a variety of materials (such as KI), indicating that carious lesion discoloration can be hidden without diminishing the caries-arresting action. Following SDF treatment, several restorative materials have also been employed to restore cavitated teeth (with or without KI).[11]

Applying potassium iodide (KI) right after SDF assists in decreasing the staining risk by binding it with ionized silver. The interaction between silver iodide and SDF results in the formation of a creamy white precipitate. Nevertheless, some research suggests that it could not be useful in preventing staining or that it only partially prevents it, only reducing it to varying degrees.[12]

Opaquers are resins with a high pigment content that is opaque due to the presence of metal oxides. These metal oxides, which are often aluminum or titanium oxide, increase the opacity of the resin by enhancing light absorption and scattering.[13] To the best of the authors' knowledge, no previous study used opaquer under restorations to mask the discoloration produced by SDF.

In the current work, glass ionomer restorations and two of its different modifications (Giomer and Zirconomer) were used combined with either KI or an opaquer to mask the discoloration produced by SDF. In each group, a control subgroup was available (SDF alone under restoration). Control groups play various crucial roles in any experimental design and are a necessary part of all investigations, whether in vitro or in vivo. Most significantly, they assist in comprehending the impact of factors that you are unable to eliminate from your experiment completely and, as a result, incorporate them into your research of the effects of treatment.[14]

In this investigation, a computer-generated random sequence table was used for randomization. Randomization preserves a certain level of sample blinding while balancing known and unknown factors and eliminating bias. It also allows the application of probability theory, which states that the likelihood of a difference in outcome across groups is due to chance.[15]

Since the operator could clearly see the color shift brought on by SDF, blinding them was not viable. Furthermore, the new materials were immediately discernible from one another with the naked eye due to their distinct compositions and colors. The various restorative material compositions make them immediately distinguishable from one another.[11,6]

A spectrophotometer built on the CIE L*a*b* system was employed in this investigation to gauge color changes. It was found that spectrophotometers and the CIE L*a*b* color coding system were suitable instruments for objectively detecting color shifts that are invisible to the human eye. The numeric data collected from the afflicted areas of the lesion and sound allowed for an effective study of the color changes.[16]

One of the most crucial clinical factors in aesthetic dentistry for determining the durability of the treatment is the color stability of tooth-colored dental restorations.[16] In this study, a significant increase in (ΔE) value in all groups between the 24 hours and 1 week was noted. In contradiction, (Kamble et al., 2021) [10] reported significant discoloration reduction using (SDF+KI) over time and attributed this to the small number of free silver ions, as most of them had previously reacted with KI.

According to (Staxrud et al., 2023)[17],the release of silver was maximum after 24 h for all treatment groups, with a major drop after this point. In this study, in all groups, the use of SDF alone showed the highest discoloration compared to the use of SDF and KI. This can be attributed to the effect of KI in preventing the formation of silver oxide and subsequently reducing black staining by reacting with excess silver ions.[1]

A creamy white precipitate of silver iodide crystals occurs on the surface of teeth when a saturated solution of KI interacts with SDF. This prevents discoloration by removing free silver ions from SDF from forming black precipitates on the teeth.[10] Similar findings were reported by (Kamble et al., 2021; Raafat et al., 2022).[10,6]

In the current study, under different restorations, the use of an opaquer showed the least discoloration, indicating a better masking effect in comparison to the use of SDF only or in addition to KI. This could be attributed to the effect of metal oxides in opaquers, which accomplish increased opacity by rising absorption and scattering light within the resin.[13] Also, the impact of KI may be temporary, possibly due to the high photosensitivity of the silver iodide produced.[1]

Regarding the comparison of the effect of different restorations in masking SDF discoloration at different time intervals, this study showed that irrespective of using SDF alone or in combination with either KI or opaquer, the highest (ΔE) value was found in group A (Glass ionomer), followed by group B (Giomer). In contrast, the lowest value was found in group C (Zirconomer).

According to (Hamdy et al., 2021) [11] glass ionomer had a good masking effect on the color change brought on by the application of SDF. However, the notable variations in the color change after aging suggested that GI was unable to effectively conceal the color change caused by SDF after aging.

Moreover, (Raafat et al., 2022)[6] found a statistically significant difference between the various glass ionomer restorations applied after SDF alone. The zirconia-reinforced glass ionomer had the lowest DE value, indicating a good masking effect, and the highest DE value for (RMGI), suggesting a poor masking effect, followed by (GI). They explained this by pointing out that (RMGI) has resin translucent material that reflects the underlying SDF's discoloration more readily than zirconia-reinforced glass ionomer, which is thought to

be a more opaque material than (RMGI) and which only partially assisted in masking the SDF's application-induced discoloration.

However, (Alsagob et al., 2022)[18] reported that composite resin and glass ionomer restorations were similar regarding discoloration when used after SDF.

These results contradicted those of (Goswami and Singh, 2024)[19] who evaluated the masking properties of GIC and giomer following the restoration of carious teeth treated with SDF and discovered a statistical shift with GIC, which produced a superior masking effect.

This study may be a valuable addition to SDF research, considering the use of novel combinations of KI and opaquer with different GI alternatives to mask the color changes produced by SDF. However, the in-vitro nature of this study requires caution when interpreting the results in-vivo conditions. Environmental factors and intraoral circumstances that could affect the usage of SDF were not replicated in this investigation. Furthermore, in-vitro experiments may rank the materials or methods rather than revealing the true mechanism of color stability.

Conclusions

Given the limitations of this study, it can be concluded that the use of KI or opaquer following SDF application is advantageous over SDF alone in terms of masking the black staining. Also, using zirconia-reinforced glass ionomer may have a better masking effect over giomer and glass ionomer on discoloration produced by SDF. Further long-term in-vitro and clinical studies on the color stability and masking effects on SDF of different materials over time are required.

Funding

The authors express that this research was not funded.

Data availability

The datasets used during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The current study was approved by the Faculty of Dentistry at Cairo University's Ethics Committee of Scientific Research with approval number (65-7-24).

Competing interests

The authors declare no competing interests.

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