



## Effect of 38% Silver Diamine Fluoride on the Discoloration of Sound Primary and Permanent Enamel: A Spectrophotometric Study

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### Research Article

#### History

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### ABSTRACT

**Objectives:** Silver diamine fluoride (SDF) is widely recognized as an effective, minimally invasive agent for caries management. Despite its cariostatic and preventive benefits, the main drawback is the dark discoloration of dental hard tissues. This in vitro study aimed to evaluate the discoloration potential of 38% SDF on sound enamel surfaces of primary and permanent teeth, and to assess the mitigating effects of potassium iodide (KI) and post-treatment rinsing.

**Materials and Methods:** A total of 120 extracted molars (primary and permanent, n = 60 each) with intact enamel were randomly allocated into eight groups (n = 15) according to treatment protocol: SDF without rinsing, SDF with rinsing, SDF + KI without rinsing, and SDF + KI with rinsing. Color measurements (CIE Lab\* system) were recorded using a spectrophotometer at baseline, immediately after application, 24 hours, 72 hours, and 1 week. Color change ( $\Delta E$ ) values were calculated, with  $\Delta E \geq 3.7$  considered clinically perceptible. Statistical analysis was performed with significance set at  $p < 0.05$ .

**Results:** SDF without rinsing produced the greatest discoloration in both dentition types ( $p < 0.001$ ), with  $\Delta E$  values exceeding the perceptibility threshold at all time points. The combination of SDF + KI followed by rinsing resulted in the lowest  $\Delta E$  values, remaining below clinical significance during early intervals. Groups treated with KI alone or rinsing alone exhibited intermediate levels of staining, without significant differences between them ( $p > 0.05$ ). Permanent teeth generally showed more pronounced darkening than primary teeth.

**Conclusions:** Within the limitations of this in vitro study, 38% SDF caused clinically perceptible discoloration on sound enamel of both primary and permanent teeth, especially without rinsing. The adjunctive use of KI with immediate rinsing effectively minimized staining. Clinicians should exercise caution when applying SDF to esthetically sensitive areas, and inform patients or caregivers of potential discoloration risks.

**Keywords:** Permanent dentition, potassium iodide, primary dentition, silver diamine fluoride, tooth discoloration

## 38% Gümüş Diamin Florürün Sağlam Süt ve Daimi Diş Minesi Üzerindeki Renklenme Etkisinin Değerlendirilmesi: Spektrofotometrik In Vitro Çalışma

### Araştırma Makalesi

#### Süreç

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### ÖZ

**Amaç:** Gümüş diamin florür (SDF), çürük yönetiminde etkili, minimal invaziv bir ajan olarak yaygın şekilde kullanılmaktadır. Ancak, sahip olduğu avantajlarına karşın en önemli dezavantajı sert dokularda oluşturduğu koyu renklenmedir. SDF'nin sağlam mine dokusunda renklenmeye neden olma potansiyeline ilişkin kanıtlar sınırlı olup, özellikle süt ve daimi dişler arasında karşılaştırmalı veriler yetersizdir. Bu çalışmanın amacı, %38 SDF'nin sağlam süt ve daimi diş minesindeki renklenme potansiyelini karşılaştırmalı olarak değerlendirmek ve takiben potasyum iyodür (KI) uygulamanın ve durulamanın olası azaltıcı etkisini araştırmaktır.

**Gereç ve Yöntemler:** Klinik olarak sağlam mineye sahip toplam 120 çekilmiş molar diş (60 süt, 60 daimi) rastgele sekiz gruba (n = 15) ayrıldı: SDF (durulamasız), SDF (durulamalı), SDF + KI (durulamasız) ve SDF + KI (durulamalı). Renk ölçümleri CIE Lab\* sistemi kullanılarak spektrofotometre ile başlangıçta, uygulamadan hemen sonra, 24 saat, 72 saat ve 1 hafta sonra gerçekleştirildi. Renk değişimi ( $\Delta E$ ) değerleri hesaplandı ve  $\Delta E \geq 3,7$  klinik olarak fark edilebilir eşik olarak kabul edildi. Tüm analizlerde istatistiksel anlamlılık düzeyi  $p < 0,05$  olarak belirlendi.

**Bulgular:** SDF'nin durulama yapılmadan uygulandığı gruplarda, her iki diş tipinde de en yüksek renklenme değerleri elde edildi ( $p < 0,001$ ) ve tüm zaman noktalarında  $\Delta E$  değerleri klinik fark edilebilir eşik üzerinde seyretti. SDF + KI uygulamasını takiben yapılan durulama, en düşük  $\Delta E$  değerlerini oluşturdu ve özellikle erken dönem ölçümlerinde klinik açıdan fark edilebilirlik eşikinin altında kaldı. Yalnızca KI uygulanan veya yalnızca durulama yapılan gruplarda ise orta düzeyde renklenme gerçekleşti ve bu iki grup arasında anlamlı bir fark gözlenmedi ( $p > 0,05$ ). Renklenme, daimi dişlerde süt dişlerine kıyasla daha belirgin bulundu.

**Sonuçlar:** %38 SDF hem süt hem de daimi dişlerde sağlam mine üzerinde klinik olarak fark edilebilir renklenmeye neden olmuştur. Klinik uygulamalarda, özellikle estetiğin ön planda olduğu bölgelerde SDF kullanımında dikkatli olunmalı ve potansiyel renklenme riski konusunda hasta ve ebeveynler ayrıntılı şekilde bilgilendirilmelidir.

**Anahtar Kelimeler:** Daimi dişler, diş renklenmesi, gümüş diamin florür, potasyum iyodür, süt dişleri

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## Introduction

Silver diamine fluoride (SDF) has emerged as a cost-effective, minimally invasive, and clinically straightforward agent in modern caries management. Its global public health importance has been formally recognized, with the World Health Organization (WHO) including SDF in its Essential Medicines List.<sup>1</sup> In the United States, both the American Dental Association (ADA) and the American Academy of Pediatric Dentistry (AAPD) recommend the clinical use of 38% SDF for arresting active, cavitated carious lesions in primary dentition.<sup>2,3</sup> Beyond caries arrest, SDF has demonstrated effectiveness in caries prevention protocols and in managing dentin hypersensitivity.<sup>4-6</sup> It has also been successfully used to prevent pit and fissure caries, inhibit secondary caries, and promote remineralization in hypomineralized teeth, offering a non-invasive and economical alternative to conventional treatments.<sup>7-12</sup>

Despite these advantages, the principal aesthetic limitation of SDF is the characteristic dark staining of dental hard tissues due to silver precipitation, which can affect patient and caregiver acceptance.<sup>13,14</sup> This discoloration primarily results from the formation of yellow, sparingly soluble silver phosphate ( $\text{Ag}_3\text{PO}_4$ ), which undergoes gradual photochemical and thermochemical reduction to black metallic silver when exposed to light and elevated temperatures.<sup>15</sup> The process can begin within two minutes of application, intensify over the next several hours, and reach its peak within 12 hours.<sup>16,17</sup>

To address this drawback, potassium iodide (KI) has been proposed as an adjunctive agent. Iodide ions ( $\text{I}^-$ ) react with unbound silver ions to form a creamy white silver iodide precipitate, potentially reducing  $\text{Ag}_3\text{PO}_4$  formation and subsequent darkening.<sup>18</sup> While conventional understanding suggests SDF selectively binds to demineralized or carious tissues without significantly affecting sound structures,<sup>13</sup> several studies have reported perceptible discoloration in both demineralized and clinically sound dentin.<sup>18,19</sup> Although staining intensity on sound dentin is generally lower than on carious surfaces, it remains a clinically relevant concern.<sup>19</sup>

However, data on the staining potential of SDF for sound enamel remain limited and sometimes contradictory, particularly when comparing primary and permanent teeth. Furthermore, the combined effects of KI application and post-treatment rinsing on discoloration prevention have not been comprehensively evaluated. Comparing primary and permanent teeth is clinically relevant because structural and compositional differences may influence their susceptibility to SDF-related discoloration. Therefore, this *in vitro* study aimed to compare the discoloration effects of 38% SDF on sound enamel in primary and permanent teeth and to assess the potential mitigating role of KI and rinsing protocols. The null hypothesis was that SDF, with or without KI and rinsing, would not cause statistically significant color changes in sound enamel of either primary or permanent

teeth, nor would there be significant differences between these tooth types.

## Materials and Methods

This *in vitro* study was conducted with the approval of the Scientific Research Ethics Committee of the University of Lokman Hekim (Approval No: 2025/009). All procedures adhered to the ethical principles outlined in the Declaration of Helsinki.

The sample size was determined using G\*Power software (version 3.1.9.6) based on the effect size reported in a previous study,<sup>20</sup> with a statistical power of 0.80 and a significance level ( $\alpha$ ) of 0.05. The minimum required sample size was calculated to be 80 teeth, with 10 specimens assigned to each group. Accordingly, a total of 120 extracted primary and permanent molars—obtained for reasons unrelated to the present study—were included. Written informed consent was obtained from all participants and/or their legal guardians after providing detailed information about the study procedures and objectives.

Both primary and permanent molars with clinically intact enamel—free from caries, restorations, or developmental defects—and exhibiting similar morphological characteristics were selected to ensure sample standardization. All specimens were examined under 3.0× magnification using dental loupes (Zumax, Suzhou, China) to identify any cracks, fractures, restorations, or severe discoloration. Primary teeth were either naturally exfoliated or extracted for clinical reasons, while permanent molars were collected following extractions performed for orthodontic or periodontal indications. After collection, residual soft tissue and debris were removed using a periodontal curette. All teeth were subsequently stored in distilled water containing 0.1% thymol at room temperature until the experimental procedures commenced. Before the experimental procedures, enamel surfaces were standardized by cleaning with a prophylaxis brush and non-fluoridated pumice, followed by gentle polishing at low speed for 10 seconds to ensure a uniform surface for color measurements.

### Group Allocation and Experimental Protocol

The teeth were randomly divided into eight groups ( $n = 15$  per group) according to tooth type (primary or permanent) and treatment protocol. Randomization was performed using a computer-generated simple randomization sequence (<https://www.random.org>).

**Group 1:** SDF without rinsing (primary)

**Group 2:** SDF followed by rinsing with water (primary)

**Group 3:** SDF + KI without rinsing (primary)

**Group 4:** SDF + KI followed by rinsing with water (primary)

**Group 5:** SDF without rinsing (permanent)

**Group 6:** SDF followed by rinsing with water (permanent)

**Group 7:** SDF + KI without rinsing (permanent)

**Group 8:** SDF + KI followed by rinsing with water (permanent)

In all groups, 38 % SDF was applied to the enamel surface using a microbrush applicator tip and left in place for 1 minute. In the relevant groups (Groups 3, 4, 7, and 8), a saturated potassium iodide solution (Riva Star, SDI, Bayswater, Australia) was applied immediately after the SDF. In Groups 2, 4, 6, and 8, the treated surface was rinsed using a gentle air–water spray without pressure. In Groups 1, 3, 5, and 7, the surface was gently wiped with a dry cotton roll. After treatment, all specimens were stored in an incubator in a dark environment to minimize light-induced color changes.

#### Color Measurement

Color assessments were conducted at five time points: baseline, immediately after application, and at 24 hours, 72 hours, and 1 week. A spectrophotometer (Vita Easyshade Advance, Vita Zahnfabrik, Bad Säckingen, Germany) was used for all measurements. The device was calibrated before each session according to the manufacturer's instructions. Measurements were taken on the buccal enamel surface, with the probe tip placed perpendicular to the surface to ensure consistency.

Color data were recorded according to the CIE Lab\* system, where L\* indicates lightness, a\* represents the red-green axis, and b\* represents the yellow-blue axis. Color change ( $\Delta E$ ) between time points was calculated using the following formula:  $\Delta E = \sqrt{[Li - L0^*]^2 + [ai - a0^*]^2 + [bi - b0^*]^2} / 2$ . A  $\Delta E$  value of  $\geq 3.7$  was used as the perceptibility threshold, in accordance with studies identifying this level as the minimum color difference detectable by the human eye.<sup>21-23</sup> All measurements were recorded and organized in a Microsoft Excel spreadsheet for documentation.

#### Statistical Analysis

All statistical analyses were performed using SPSS version 29.0.1 (IBM Corp., Armonk, NY, USA). The normality of the data distribution was assessed using the Shapiro–Wilk test. Descriptive statistics were expressed as mean  $\pm$  standard deviation (SD). Intragroup comparisons across different time points were performed using repeated measures analysis of variance (ANOVA). When significant differences were found, pairwise comparisons

were conducted with Bonferroni adjustment. Intergroup differences at each time point were analyzed using one-way ANOVA followed by Tukey's post-hoc test. A significance level of  $p < 0.05$  was considered statistically significant.

#### Results

Table 1 presents the mean  $\Delta E$  values for all groups at each measurement time point. In both primary and permanent teeth, Groups 1 and 5 (SDF without rinsing) consistently exhibited the highest  $\Delta E$  values, with statistically significant differences observed over time ( $p < 0.001$ ;  $p < 0.01$ ). In contrast, Groups 4 and 8 (SDF + KI + rinsing) showed the lowest  $\Delta E$  values, remaining below the threshold considered clinically significant for noticeable discoloration ( $\Delta E < 3.7$ ) at both the 1-hour and 24-hour intervals. Across all time points, Groups 2, 3, 6, and 7 exhibited clinically observable levels of discoloration. Although there were no statistically significant differences among these groups ( $p > 0.05$ ).

The L\* values at each time point are presented in Table 2. At baseline, no statistically significant differences in L\* values were observed among the primary and permanent tooth groups. By the 1-week evaluation, Groups 1 and 5 exhibited the lowest L\* values (Group 1:  $75.51 \pm 1.33$ ; Group 5:  $73.27 \pm 4.39$ ), indicating pronounced darkening of the enamel surface. In contrast, Groups 4 and 8 maintained significantly higher L\* values, suggesting minimal change in enamel brightness over time.

Changes in the L\* parameter ( $\Delta L$ ) over time are presented in Table 3. A negative  $\Delta L$  value indicates a reduction in lightness, corresponding to visible darkening of the enamel surface. The most pronounced reduction in lightness was observed in Groups 1 and 5 (SDF without rinsing), with  $\Delta L$  values progressively decreasing from 1 hour to 1 week ( $p < 0.001$ ). At 1 week, Group 1 reached  $-8.53 \pm 1.36$  and Group 5  $-12.21 \pm 3.49$ , indicating substantial darkening. In contrast, Groups 4 and 8 (SDF + KI + rinsing) demonstrated the lowest lightness loss at all time points.

Figures 1 and 2 present representative images of the permanent and primary tooth groups, respectively, at different observation time points across all experimental groups.

**Table 1.** Mean  $\Delta E$  values ( $\pm$  SD) of all groups at different time points (1 hour, 24 hours, 72 hours, and 1 week)

Groups	$\Delta E_{1 \text{ hour}}$	$\Delta E_{24 \text{ hours}}$	$\Delta E_{72 \text{ hours}}$	$\Delta E_{1 \text{ week}}$	p
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Group 1	7.69 $\pm$ 0.98 <sup>a</sup>	9.54 $\pm$ 3.01 <sup>a</sup>	11.70 $\pm$ 1.90 <sup>a</sup>	10.60 $\pm$ 2.07 <sup>a</sup>	<0.001*
Group 2	5.39 $\pm$ 2.52 <sup>b</sup>	5.64 $\pm$ 3.26 <sup>b</sup>	6.09 $\pm$ 3.27 <sup>b</sup>	6.02 $\pm$ 3.18 <sup>c</sup>	0.919
Group 3	5.68 $\pm$ 1.06 <sup>b</sup>	5.96 $\pm$ 1.25 <sup>b</sup>	5.07 $\pm$ 3.53 <sup>b</sup>	5.63 $\pm$ 2.32 <sup>c</sup>	0.865
Group 4	2.99 $\pm$ 1.39 <sup>c</sup>	3.53 $\pm$ 1.38 <sup>b</sup>	4.72 $\pm$ 1.39 <sup>b</sup>	4.85 $\pm$ 2.10 <sup>c</sup>	0.025*
Group 5	8.67 $\pm$ 2.67 <sup>a</sup>	10.10 $\pm$ 2.78 <sup>a</sup>	12.14 $\pm$ 2.10 <sup>a</sup>	13.53 $\pm$ 2.69 <sup>a</sup>	0.003*
Group 6	5.99 $\pm$ 1.65 <sup>b</sup>	6.16 $\pm$ 1.19 <sup>b</sup>	6.99 $\pm$ 1.82 <sup>b</sup>	7.83 $\pm$ 1.09 <sup>b</sup>	0.002*
Group 7	5.13 $\pm$ 2.36 <sup>b</sup>	5.42 $\pm$ 1.67 <sup>b</sup>	6.03 $\pm$ 1.05 <sup>b</sup>	5.66 $\pm$ 0.94 <sup>c</sup>	0.583
Group 8	3.20 $\pm$ 1.06 <sup>c</sup>	3.64 $\pm$ 1.10 <sup>b</sup>	5.06 $\pm$ 1.65 <sup>b</sup>	5.07 $\pm$ 1.39 <sup>c</sup>	<0.001*

Note: Different superscript letters within the same column indicate statistically significant differences between groups. \*indicates statistically significant differences within groups across time points ( $p < 0.05$ ).

Table 2. Mean L\* values (± SD) of all groups at baseline and after treatment (1 hour, 24 hours, 72 hours, and 1 week)

Groups	L* <sub>Baseline</sub>	L* <sub>1 hour</sub>	L* <sub>24 hours</sub>	L* <sub>72 hours</sub>	L* <sub>1 week</sub>	p
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Group 1	84.04 ± 0.85 <sup>a</sup>	78.46 ± 0.93 <sup>a</sup>	77.83 ± 1.59 <sup>a</sup>	75.10 ± 1.30 <sup>a</sup>	75.51 ± 1.33 <sup>a</sup>	0.002*
Group 2	84.34 ± 1.81 <sup>a</sup>	82.54 ± 2.41 <sup>b</sup>	81.04 ± 3.64 <sup>b</sup>	79.33 ± 3.54 <sup>b</sup>	78.92 ± 3.17 <sup>c</sup>	0.016*
Group 3	85.64 ± 1.42 <sup>a</sup>	82.09 ± 1.58 <sup>b</sup>	81.67 ± 3.68 <sup>b</sup>	81.76 ± 3.57 <sup>b</sup>	83.14 ± 3.07 <sup>c</sup>	0.272
Group 4	83.94 ± 1.99 <sup>a</sup>	82.12 ± 2.02 <sup>b</sup>	81.72 ± 2.24 <sup>b</sup>	82.93 ± 4.01 <sup>b</sup>	82.93 ± 2.02 <sup>c</sup>	0.077
Group 5	85.48 ± 1.74 <sup>a</sup>	78.60 ± 4.06 <sup>a</sup>	76.39 ± 3.06 <sup>a</sup>	74.60 ± 3.06 <sup>a</sup>	73.27 ± 4.39 <sup>a</sup>	0.001*
Group 6	82.90 ± 1.97 <sup>b</sup>	77.80 ± 1.74 <sup>a</sup>	77.42 ± 1.83 <sup>a</sup>	76.67 ± 1.86 <sup>a</sup>	76.01 ± 1.47 <sup>b</sup>	0.004*
Group 7	84.48 ± 1.87 <sup>a</sup>	81.21 ± 1.84 <sup>b</sup>	79.84 ± 0.87 <sup>b</sup>	79.38 ± 1.36 <sup>b</sup>	80.78 ± 2.29 <sup>c</sup>	0.040*
Group 8	85.09 ± 1.82 <sup>a</sup>	82.99 ± 1.73 <sup>b</sup>	81.99 ± 1.81 <sup>b</sup>	80.77 ± 1.83 <sup>b</sup>	81.51 ± 1.62 <sup>c</sup>	0.003*

Note: Different superscript letters within the same column indicate statistically significant differences between groups. \*indicates statistically significant differences within groups across time points (p < 0.05).

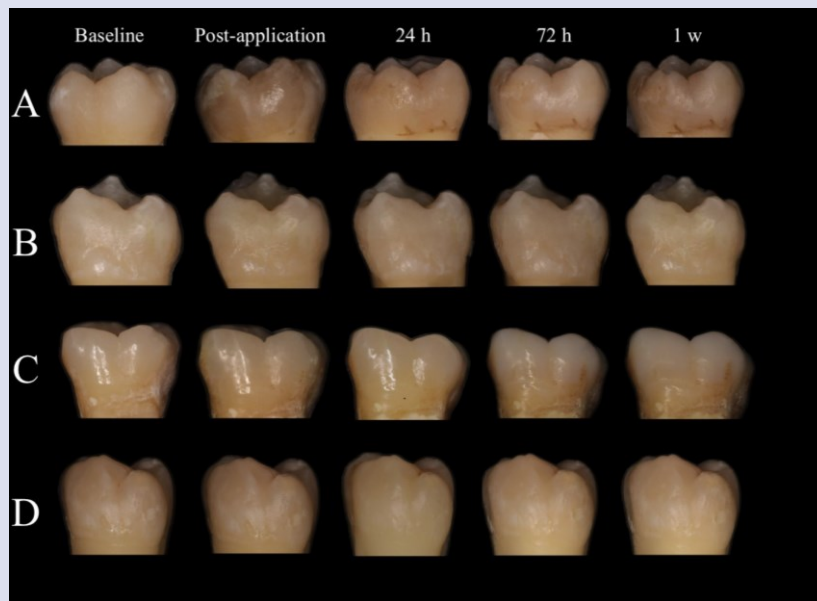


Figure 1. Representative images of permanent tooth groups at different observation time points: (A) Group 1- without rinsing; (B) Group 2 – rinsing; (C) Group 3 – KI without rinsing; (D) Group 4 – KI with rinsing.

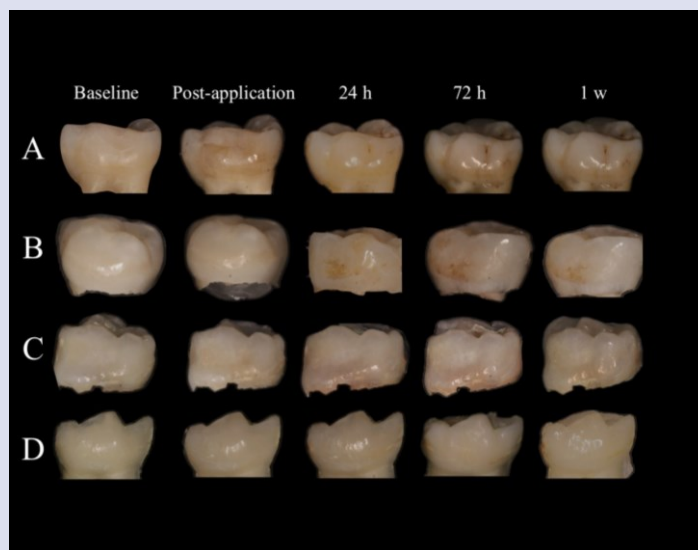


Figure 2. Representative images of primary tooth groups at different observation time points: (A) Group 1- without rinsing; (B) Group 2 – rinsing; (C) Group 3 – KI without rinsing; (D) Group 4 – KI with rinsing.

Table 3. Mean  $\Delta L$  values ( $\pm$  SD) of all groups at different time points (1 hour, 24 hours, 72 hours, and 1 week)

Groups	$\Delta L_{1 \text{ hour}}$	$\Delta L_{24 \text{ hours}}$	$\Delta L_{72 \text{ hours}}$	$\Delta L_{1 \text{ week}}$	p
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Group 1	-5.59 $\pm$ 1.38 <sup>a</sup>	-6.21 $\pm$ 1.68 <sup>a</sup>	-8.94 $\pm$ 1.50 <sup>a</sup>	-8.53 $\pm$ 1.36 <sup>a</sup>	<0.001*
Group 2	-1.80 $\pm$ 2.07 <sup>b</sup>	-3.30 $\pm$ 3.02 <sup>b</sup>	-5.01 $\pm$ 3.07 <sup>b</sup>	-5.42 $\pm$ 2.96 <sup>c</sup>	0.002*
Group 3	-3.55 $\pm$ 2.15 <sup>b</sup>	-3.96 $\pm$ 4.19 <sup>b</sup>	-3.88 $\pm$ 4.05 <sup>b</sup>	-2.50 $\pm$ 3.71 <sup>c</sup>	0.272*
Group 4	-1.82 $\pm$ 0.78 <sup>c</sup>	-2.22 $\pm$ 0.86 <sup>b</sup>	-1.01 $\pm$ 3.56 <sup>b</sup>	-1.01 $\pm$ 0.99 <sup>c</sup>	0.059*
Group 5	-6.88 $\pm$ 2.97 <sup>a</sup>	-9.09 $\pm$ 2.83 <sup>a</sup>	-10.88 $\pm$ 2.82 <sup>a</sup>	-12.21 $\pm$ 3.49 <sup>a</sup>	<0.001*
Group 6	-5.10 $\pm$ 2.04 <sup>b</sup>	-5.48 $\pm$ 1.34 <sup>b</sup>	-6.23 $\pm$ 1.63 <sup>b</sup>	-6.89 $\pm$ 1.38 <sup>b</sup>	0.005
Group 7	-3.27 $\pm$ 1.41 <sup>b</sup>	-4.63 $\pm$ 1.99 <sup>b</sup>	-5.10 $\pm$ 1.31 <sup>b</sup>	-3.70 $\pm$ 2.36 <sup>c</sup>	0.038
Group 8	-2.10 $\pm$ 0.73 <sup>c</sup>	-3.10 $\pm$ 0.85 <sup>b</sup>	-4.32 $\pm$ 1.26 <sup>b</sup>	-3.58 $\pm$ 1.32 <sup>c</sup>	<0.001*

Note: Different superscript letters within the same column indicate statistically significant differences between groups. \*indicates statistically significant differences within groups across time points ( $p < 0.05$ ).

## Discussion

The present in vitro study evaluated the discoloration effects of 38% SDF on sound enamel surfaces of both primary and permanent teeth and examined the potential mitigating influence of KI application and post-treatment rinsing. Although the discoloration potential of SDF on demineralized dentin and enamel has been extensively reported, evidence for its effects on sound enamel remains limited. In particular, direct comparisons between primary and permanent teeth have been scarce. Based on the present findings, the null hypothesis was rejected, as SDF, with or without KI and rinsing, produced statistically significant color changes in sound enamel.

Our results showed that SDF application without rinsing caused the greatest discoloration in both dentition types. The absence of a rinsing step likely allows more silver-containing compounds to remain on the enamel surface, thereby intensifying visible staining. In contrast, the groups receiving SDF + KI followed by rinsing exhibited the lowest  $\Delta E$  values, often remaining near or below the clinical perceptibility threshold at early time points. This supports earlier reports that KI, through silver iodide formation, can reduce silver precipitation and limit staining.<sup>22,23</sup> Intermediate discoloration levels were seen in Groups 2, 3, 6, and 7, but these were still lower than in the non-rinsed SDF-only groups (1 and 5). Among these, KI without rinsing (Groups 3 and 7) produced slightly better results than SDF alone with rinsing (Groups 2 and 6). This suggests that KI application may be more critical than rinsing alone in reducing discoloration, although the combination remains the most effective.

From a clinical perspective, these findings confirm that sound enamel, especially in permanent teeth, is susceptible to SDF-induced discoloration. This may be related to the structural characteristics of permanent enamel, which could facilitate deeper silver ion penetration. Historical studies have shown that SDF can infiltrate up to 20  $\mu\text{m}$  into sound enamel.<sup>11</sup> Although Horst and Heima<sup>6</sup> suggested that mature, healthy enamel is generally resistant to SDF staining, they also acknowledged that microscopic porosities or incomplete maturation can permit silver ion retention.

Our results are in line with clinical studies showing that SDF may stain caries-free enamel under certain conditions.<sup>24,25</sup> Tsai et al.<sup>26</sup> reported that prophylactic SDF

application in young children resulted in no staining (32.8%), transient or wipeable staining (31.1%), and permanent staining (36.1%). This variation may indicate the presence of subclinical demineralization that is not visible during routine examination.<sup>26</sup> Patel et al.<sup>17</sup> similarly observed a substantial reduction in mean gray values for sound enamel after SDF application, while Nguyen et al.<sup>27</sup> found extremely high  $\Delta E$  values for SDF-treated enamel compared to SDF + KI. Such findings challenge the assumption that discoloration is confined to visibly demineralized surfaces.

Moreover, SDF-induced staining has been detected on intact surfaces with minor irregularities and on proximal areas after application.<sup>17</sup> Given the greater porosity of immature permanent enamel, some authors have recommended avoiding contact with these teeth during primary dentition treatment.<sup>6,14</sup> On the other hand, some reports indicate that staining on sound enamel and root dentin may be minimal and potentially reversible through polishing.<sup>28</sup>

In the present study, all specimens were examined using dental loupes rather than a stereomicroscope, which is generally considered the gold standard for detailed surface evaluation. This methodological choice was intentional, as the aim was to simulate clinical conditions more realistically. In daily practice, clinicians rely on dental loupes rather than stereomicroscopes to assess tooth structure. Interestingly, even in teeth that appeared clinically sound under loupe magnification, discoloration was still observed following SDF application. This finding suggests that SDF may reveal subtle or subclinical alterations that are not detectable under routine clinical examination. Thus, the use of dental loupes in this study not only increases the clinical relevance of the findings but also highlights the potential of SDF to disclose early changes that would otherwise remain unnoticed.

This study has certain limitations. First, the in vitro design cannot fully replicate the oral environment, where saliva, pH changes, dietary chromogens, and mechanical forces could alter both the extent and progression of discoloration. Second, only short-term changes were evaluated; long-term stability, regression, or intensification of staining remain unknown. Third, using extracted teeth may introduce variability in enamel porosity despite strict selection criteria. Fourth,

spectrophotometric measurements provide objective data but not subjective aesthetic perception, which is important for patient acceptance. Finally, the effects of repeated SDF applications or post-treatment polishing—common in clinical settings—were not examined. Future studies should focus on in vivo models, long-term follow-up, and the development of optimized protocols that combine SDF's cariostatic benefits with minimal aesthetic impact, particularly in visible areas of the dentition.

## Conclusions

Within the limitations of this in vitro study, 38% silver diamine fluoride was found to cause clinically perceptible discoloration of sound enamel in both primary and permanent teeth, particularly when applied without rinsing. The combined use of potassium iodide followed by rinsing immediately after SDF application proved most effective in minimizing staining, maintaining  $\Delta E$  values below the perceptibility threshold during the early observation period. Therefore, special caution is warranted when using SDF on esthetically sensitive areas or newly erupted permanent teeth, and patients or caregivers should be informed of the potential for staining to ensure informed consent and enhance treatment acceptance. When using SDF near newly erupted permanent teeth, clinicians should employ isolation to prevent accidental contact, promptly remove any excess material if contact occurs, and consider adjunctive KI application to reduce staining. These teeth should also be monitored during the eruption period, as immature enamel can remain susceptible to discoloration even after the initial application. Despite these aesthetic concerns, SDF remains a valuable option for managing high caries risk, especially when accompanied by adjunctive measures to mitigate discoloration.

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## Conflicts of Interest Statement

The authors declare no conflicts of interest in relation to this study.

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