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ORIGINAL RESEARCH

The effect of silver diamine fluoride and potassium iodide on the adhesion and microleakage of pit and fissure sealant: an *in-vitro* study

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Abstract

Background: Silver Diamine Fluoride (SDF) is utilized to halt the progression of dental caries without inflicting pain or necessitating invasive procedures. Regrettably, it discolors the decayed teeth and imparts a black hue to them. Potassium iodide (KI) causes tooth-colored reactions upon interaction with silver ions. The aim of this study is to evaluate the effect of SDF with or without KI on the adhesion and microleakage of pit and fissure sealant (FS) to tooth enamel. **Methods**: Sixty extracted sound human permanent caries-free molars or with grade 1 caries according to the modified International Caries Detection and Assessment System II (ICDAS II) were randomly divided into three groups: FS, SDF + FS and SDF + KI + FS. Adhesion and microleakage tests were done for each group, which consisted of 20 teeth. To test FS adhesion to tooth structure, the specimen was decoronated 2 mm below the cementoenamel junction, fixed in acrylic and subjected to a universal testing machine to determine the shear bond strength (SBS), detachment resistance and adhesive remaining index. For the microleakage test, specimens were immersed in a 1% methylene blue solution for 24 hours. **Results**: The FS group showed the highest mean SBS (35.12 ± 1.13 Mpa), followed by the SDF + KI + FS group (27.33 ± 1.1 Mpa), then the SDF + FS group (18 ± 0.9 Mpa) with a statistically significant difference between the three groups. However, the adhesive remnants index (ARI) index score and microleakage test showed no statistically significant differences between the three groups. **Conclusions**: Pretreating fissures with SDF with or without KI before applying sealant may adversely affect the adhesion to the tooth structure and not affect the microleakage of the FS.

Keywords

Silver diamine fluoride; Potassium iodide; Adhesion; Microleakage; Pit and fissure sealant; Shear bond strength

1. Introduction

Having a comprehensive understanding of preventive dentistry is an important initial measure in decreasing the prevalence of caries [1]. Enhancing parental awareness of preventive dental appointments can enhance the oral well-being of their young children [2]. It is crucial to maintain proper oral hygiene practices, including brushing teeth twice a day, regular flossing, consuming a balanced diet and scheduling regular visits to the dentist for fluoride treatments and sealants to protect the teeth [3].

Silver, fluoride and ammonia form a colorless alkaline silver diamine fluoride solution. Silver-diamine is a stable composite of heavy-metal halide coordination complexes [4]. SDF releases two to three times more fluoride than sodium, strontium and acidulated phosphate fluoride, found in foams, gels and varnishes [5]. Silver diamine fluoride partially seals tiny channels of dentin. Silver diamine makes dentin less permeable and more resistant, increasing minerals and hardness, decreasing lesion size and allowing silver compound buildup. Furthermore, it suppresses bacterial development in infected dentinal tubules. Silver fluoride creates fluorapatite, which resists acid decalcification better than hydroxyapatite in tubular and peritubular dentine [6]. Dental caries can be arrested using SDF without inflicting any pain or requiring invasive procedures. Unfortunately, it stains the carious teeth and makes them black, deterring its use in visible areas [7]. Moreover, it has an unpleasant metallic taste. Some clinicians apply fluoride varnish over the SDF to mask its unpleasant taste [8]. Additionally, composite or glass ionomer cement (GIC) can be used to restore SDF-treated lesions [9].

An effective method for addressing tooth discoloration produced by SDF is to do a follow-up application of potassium iodide (KI), which produces tooth-colored reaction products instead of darker colors. KI reacts with silver ions to form silver iodide, which is a white substance [10]. Research has shown that it is not recommended to mix KI with silver diamine fluoride prior to application. However, it is permissible to use KI after the tooth treated with silver diamine fluoride has completely dried [9]. Silver iodide (AgI) is a yellowish substance that is insoluble in water but precipitates and is washed away. SDF releases the antimicrobial silver ions, but residual ions can precipitate as silver sulfide (Ag_2S) due to the addition of the KI solution after the SDF and subsequent removal of excess silver ions [11]. The adhesion of the sealer to the tooth and the occurrence of microleakage are interdependent. If the sealer forms a strong bond with the tooth and there is no leakage at the interface between the sealer and the tooth, then adhesion and microleakage are often not influenced [12].

Non-invasive and minimally invasive techniques have been suggested as preventive methods for addressing early non-cavitated carious lesions utilizing SDF owing to fluoride's ability to promote remineralization and the antibacterial properties of Silver. KI is employed to reduce the intensity of staining induced by SDF. In an integrated approach of silver-modified atraumatic restorative technique fissure sealant is placed after the application of SDF to conceal the black color of the carious lesion for better aesthetics, enhance chewing function, prevent food accumulation and maintain satisfactory oral hygiene [4, 6–11]. However, there is insufficient evidence on the impact of SDF and KI pretreatment of fissures on sealant adhesion and microleakage. Hence, this study aims to evaluate and contrast the effect of silver diamine fluoride with or without potassium iodide on the adhesion and microleakage of pit and fissure sealant to tooth enamel.

The study's objectives were to: determine the shear bond strength (SBS) of teeth sealed with FS, SDF + FS and SDF + KI + FS; assess the remaining sealant on the teeth of FS, SDF + FS and SDF + KI + FS using the ARI test; evaluate the microleakage in teeth sealed using FS, SDF + FS and SDF + KI + FS. The null hypotheses tested were that, application of SDF and SDF + KI would not affect FS adhesion, and that there would be no statistically significant difference in the residual sealant and microleakage between teeth sealed with FS, SDF + FS or SDF + KI + FS.

2. Materials and methods

This study evaluated the effect of SDF with or without KI on the adhesion and microleakage of Clinpro (3M ESPE, USA) fissure sealant (FS) to human molar enamel fissures. The materials utilized in this study are shown in Table 1.

This study was conducted at the University College of Dentistry Research Center (KSU-CDRC) lab in Riyadh, Saudi Arabia. This *in-vitro* study was performed using 60 human-extracted permanent molars. The teeth extracted due to poor periodontal condition and traumatic injury were selected in this study. The post extraction time of the teeth utilized in this study was less than 1 month.

The required sample size was determined by assuming an alpha error probability of 5% and study power of 80%. The estimated sample size for each group was 20, determined by comparing proportions with an effect size of 0.9169. Thus, the total sample size = (number of groups $\times$ number per group) which was sixty (60). The sample size was estimated using the statistical software G*Power 3.1.9.7 (Franz Faul, Kiel, SH, Germany). The effect size was calculated based on a study conducted by Pérez-Hernández *et al.* [6], which found that microleakage did not occur in 27 (50.94%) of specimens treated with SDF before sealant administration. In contrast, microleakage occurred in only 6 (10.9%) of specimens when sealant was applied without prior SDF treatment [6]. Adhesion FS group (n = 10), SDF + FS group (n = 10), SDF + KI + FS group (n = 10) and microleakage FS group (n = 10), SDF + FS group (n = 10), SDF + KI + FS group (n = 10) tests were performed on each group consisting of ten teeth. This sample in each group is as per the current recommendation provided by Academy of Dental Materials guidance on *in vitro* testing of dental composite bonding effectiveness to dentin/enamel using micro-tensile bond strength (μTBS) approach.

The investigation included teeth based on the criteria specified by the International Caries Detection and Assessment System II (ICDAS II). Teeth that met the following inclusion criteria were selected in this study: (i) upper or lower permanent molars without caries (Code 0). (ii) upper or lower permanent molars with caries Code 1—visual change in enamel, opacity or discoloration white or brown is visible at the entrance of the pit, or fissure is seen after prolonged air drying. The exclusion criteria consist of (i) primary molars, (ii) permanent premolars and anterior teeth, (iii) permanent molars with ICDAS II caries Codes 2, 3, 4 and (iv) molars with fractured lines or structural alteration.

Immediately following extraction, molar teeth were thoroughly cleansed in flowing water, and all blood and adherent tissue were removed using curettes. All 60 teeth (ICDAS 0 (n = 24), ICDAS 1 (n = 36)) were soaked in 1% thymol solution to eliminate bacteria and other microorganisms and placed in a deionized water compartment at 37 °C with temperature regulation.

A prophylactic brush was used to cleanse the teeth, removing plaque and debris from the enamel surfaces. The fissures and grooves were thoroughly flushed with water. Teeth were randomly assigned to three groups: Fissure sealant (FS) only, Silver Diamine Fluoride + Fissure Sealant (SDF + FS), Silver Diamine Fluoride + Potassium Iodide + Fissure Sealant (SDF + KI + FS) each containing 20 teeth. After following the research protocol, each group was divided into two subgroups containing ten teeth, each subjected to the adhesion test (AT) and microleakage test (MT).

The SDF was applied following the manufacturer's instructions. A drop of 38% SDF (1224128, Riva Star, SDI, Brunsdon Street, Bayswater, Vic, Australia), gray label, was applied onto a non-absorbent mixing pad and then was carried out using a micro-brush on the occlusal central grooves of the tooth and kept for 3 minutes. The tooth was cleaned with a wet cotton pellet and air-dried. Molars were kept in deionized water (37 °C + 1 °C) for seven days. Fissure sealant was applied to the teeth as in the previous group. The teeth in the current group were treated with fissure sealant, similar to the below mentioned method.

The SDF + KI application was carried out as per the manufacturer's instructions. SDF was applied using a micro-brush.

TABLE 1. Materials utilized in this study.

Material	Composition	Manufacturer
Fissure sealant (Clinpro™ 3M ESPE)	Bisphenol A-glycidyl methacrylate (Bis-GMA), Triethylene glycol dimethacrylate (TEGDMA) silane, tetrabutylammonium tetrafluoroborate, diphenyl hexafluorophosphate, ethyl-4-(dimethylamino) benzoate (EDMAB), titanium hydroxide, hydroquinone.	Batch: 12637, 3M ESPE, St. Paul, Minnesota, USA
SDF/KI	30–35% silver fluoride and <60% ammonia solution (44,800 ppm Fluoride) Saturated Potassium Iodide solution.	Batch: 1224128, Riva Star, SDI, Brunsdon Street, Bayswater, Vic, Australia

Bis-GMA: Bisphenol A-glycidyl methacrylate; TEGDMA: Triethylene glycol dimethacrylate; SDF: Silver Diamine Fluoride; KI: Potassium iodide.

A separate micro-brush was used to apply KI immediately following the SDF application. A single droplet of the green-labeled Riva Star solution (1224128, Riva Star, SDI, Brunsdon Street, Bayswater, VIC, Australia), manufactured by SDI in Bayswater, Australia, was placed on a mixing pad that does not absorb liquids. From there, it was applied to the central grooves of the occlusal surfaces using a micro brush. At first, the treated surface had a creamy white appearance, and the application of KI continued until the surface became transparent. The tooth was cleansed with a moist cotton pellet and then dried using an air syringe. The molars were immersed in deionized water at a temperature of 37 °C ± 1 °C for a duration of seven days. The teeth were treated with fissure sealant, similar to the below mentioned group. The specimens were subjected to a temperature of 37 °C in an oven for a duration of 24 hours, mimicking the body's internal temperature, in preparation for the subsequent stage.

Fissure sealant was applied per the manufacturer's instructions. Phosphoric acid (37%) etching gel (Super Etch Jumbo, Australia) was applied along the enamel occlusal pits and fissure for 20 seconds. The acid etchant was rinsed with water spray for 10 seconds. The tooth was dried for 10 seconds using a compressed air stream until the enamel appeared icy. Sealant (Clinpro™ 3M ESPE) was then slowly applied using a syringe needle into the pits and fissures and stirred by the sealant tip to eliminate any possible bubbles. Polymerization was done using curing light (D-2000 LED light, APOZA Enterprise co., LTD., New Taipei, Taiwan) with a wavelength of 430–490 nm and a light intensity of 1200 mW/cm^2 for the 20 seconds.

2.1 Adhesion test

The specimens were de-coronated 2 mm below the (Cemento Enamel Junction) CEJ. Teeth were embedded into a Poly Vinyl Chloride (PVC) using self-cure orthodontic resin material (Interacryl ortho, Interdent, Slovenia). Vertical depth orientation holes of approximately 1 mm deep were placed in the major cusp tips of all the molar teeth by diamond-coated 1 mm depth marker bur (201802, Two striper, Abrasive technology, Plymouth Meeting, PA, USA) having a round and flat stopping surface attached to the high-speed hand piece (101873, Dentsply Sirona, Bensheim, Bergstraße, HE, Germany). Cusps were then partially flattened following the extent of the depth holes by grinding with an Automata machine equipped with 600 grit Carbimet polishing discs (Buehler, USA) without exposing dentin or sealant material. A cylindrical object made of specialized putty index material (with a diameter of 2 mm and a thickness of 2 mm) was inserted into the middle groove to assemble the specimen. A universal testing machine (Instron 5965 Material Testing System; Instron Corp, Canton, MA, USA) was used to measure the adhesion. The edge of the customized stainless-steel knife was directed between the interface of the specimen (Fig. 1).

The interface was between the tooth structure and the fissure sealant buildup. The ramp rate or the speed of the load cell was 1 mm/minute. The data obtained from each sample was recorded in (Portable document format) PDF and Excel format. The specimen was examined under a digital microscope (3D digital microscope, Hirox, Tokyo, Japan) with a magnification of (50×) for the evaluation of the adhesive remnants index (ARI) (Fig. 2). The ARI scored is as follows: (0) No sealant is visible in the enamel; (1) 50% of the sealant remains in the enamel; (2) More than 50% of the sealant remains in the enamel; (3) All of the sealant remains in the enamel [13].

2.2 Microleakage test

The specimens underwent an ageing process through thermocycling with 1500 cycles between the temperatures of 5 °C and 55 °C, dwelling time of 30 seconds and transfer time (dripping) of 10 seconds, using a Thermocycler (Thermocycler THE-1100, Mechatronik GmbH, Feldkirchen-Westerham, Germany). The specimens were subjected to cold temperatures for 15 seconds, dripping for 10 seconds, then warm temperatures for 15 seconds and then dripping for 10 seconds. This cycle was repeated for a duration of 1500 cycles, equivalent to 3 months.

After the ageing process, teeth were coated with nail polish 1 mm from the periphery of the sealant. All teeth were immersed in a 1% methylene blue solution for 24 hours. Specimens were rinsed with water to clean the dye material and embedded in Poly Vinyl Chloride (PVC) with transparent self-cure orthodontic resin material (Interacryl ortho, Interdent, Slovenia) for handling. Samples were sectioned mesio-distally with a low-speed saw under water cooling (Isomet 2000; Buehler Ltd, Lake Bluff, NY, USA), and two extremes were obtained: extreme 1 and extreme 2. Each sample was examined with a Digital Microscope (Hirox, USA) 50× (Fig. 3). The degree of

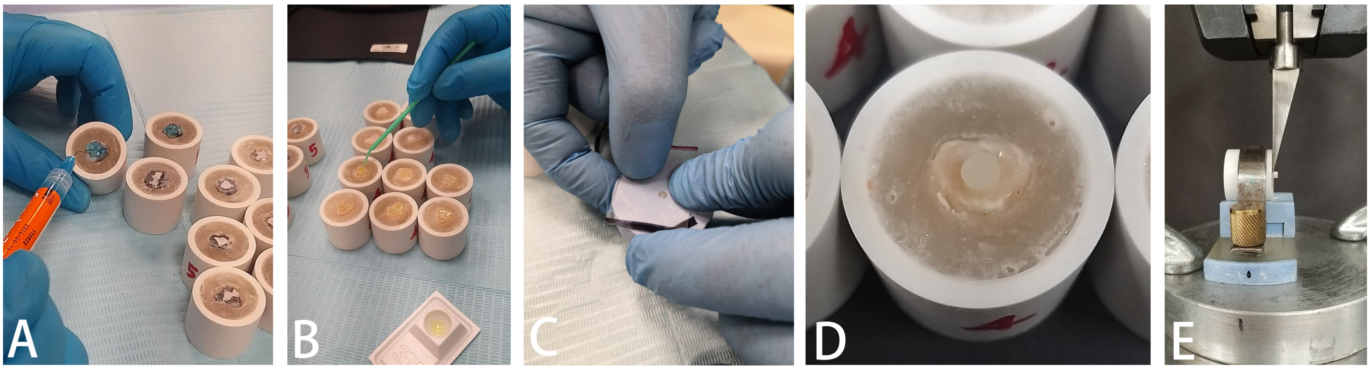

FIGURE 1. Preparation for adhesion test. (A) Acid Etching application, (B) Bonding agent application, (C) Putty Index placed at the center of the occlusal surface, (D) Sealant Application, (E) Universal testing machine with customized stainless steel knife edge.

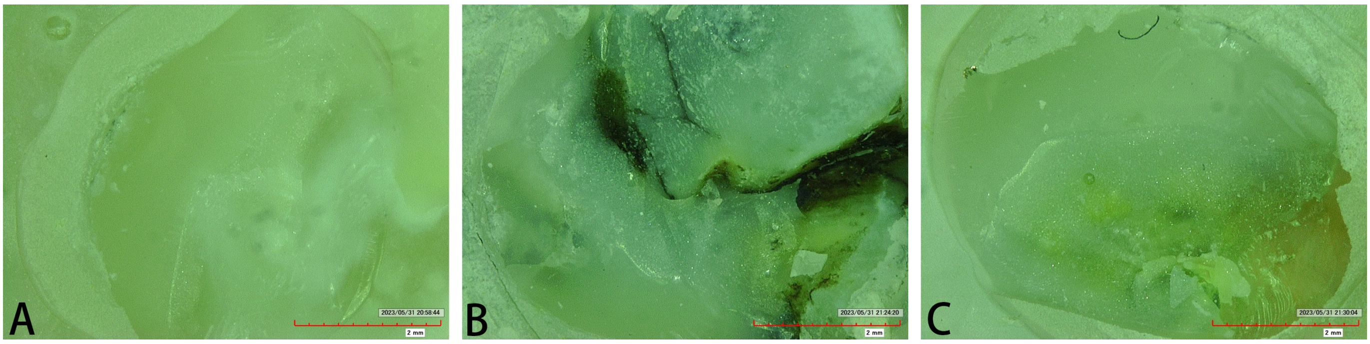

FIGURE 2. Specimens' evaluation of the Adhesive Remnants Index (ARI) under digital microscope 50× showing remaining sealant in enamel. (A) FS group, (B) SDF + FS group, (C) SDF + KI + FS group.

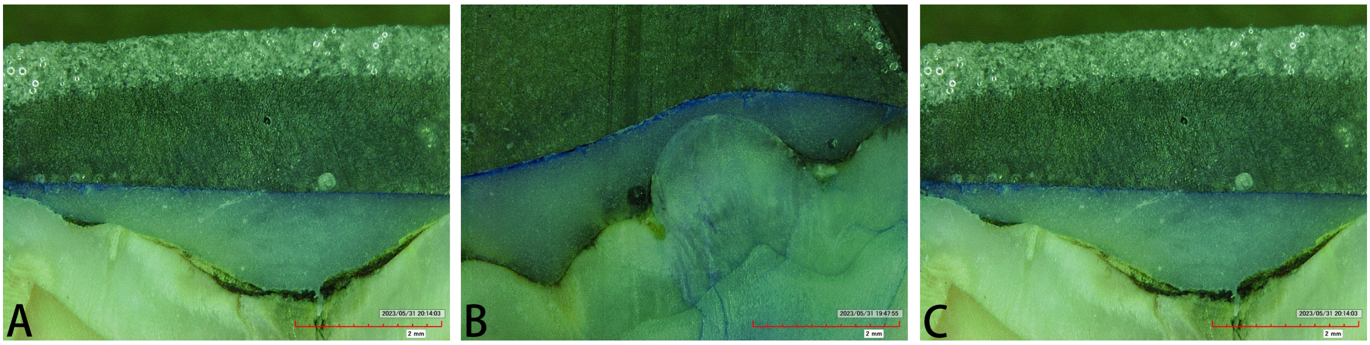

FIGURE 3. Microleakage examination under digital microscope 50×. (A) FS group, (B) SDF + FS group, (C) SDF + KI + FS group.

the leakage was determined using a microleakage scale as follows: (0) No microleakage, (1) Microleakage in the interface tooth-sealant, (2) Microleakage penetrates to the bottom of the fissure [6].

The data's normality was assessed using the Shapiro-Wilk test. The results indicated that the SBS was normally distributed for all the groups ($p > 0.05$). Descriptive SBS mean and standard deviation values were calculated across different groups (FS, SDF + FS and SDF/KI + FS). One-way Analysis of variance (ANOVA) test was applied to compare the mean SBS values across various groups. Furthermore, Tukey's *post-hoc* test was applied to the pairwise comparison of SBS. A Chi-square test and Fisher's exact test were used to find the relationship comparison of samples of different groups based on the ARI index. A similar Chi-square test and Fisher's exact tests were used to compare the proportion of teeth with varying grades of microleakage. All the data analysis was performed using IBM-SPSS version 25 (Armonk, NY, USA). A p-value < 0.05 was considered statistically significant for all the statistical tests.

3. Results

A total of 60 molars with ICDAS 0 (n = 24) and ICDAS 1 (n = 36) were considered in this study. Of the sixty teeth, 30 teeth with ICDAS 0 (n = 12) and ICDAS 1 (n = 18) were subjected to SBS analysis after intervention. Similarly, the remaining 30 ICDAS 0 (n = 12) and ICDAS 1 (n = 18) teeth were tested for microleakage. Comparison of mean SBS values between molars with ICDAS 0 and ICDAS 1 did not show any significant difference ($p > 0.05$). Table 2 shows SBS's mean and standard deviation values measured in different groups. The FS group showed the highest mean SBS (35.12 ± 1.13 Mpa), followed by the combined SDF + KI + FS group (27.33 ± 1.1 Mpa) whiles the SDF + FS group showed the lowest mean SBS (18 ± 0.9 Mpa). When mean SBS values (Mpa) were compared among three different groups using the One-way ANOVA test, a statistically significant difference was observed among them ($F = 669.064$, $p < 0.001$). Similar results were observed when mean SBS values were compared among different groups in Newton ($F = 674.163$, $p < 0.001$).

Further pairwise comparison using Tukey's honestly significant difference (HSD) test showed a statistically significantly higher mean SBS (Mpa) in the FS group than in SDF + KI + FS ($p < 0.001$). Similarly, the FS group demonstrated a statistically significantly higher SBS (Mpa) than the SDF + FS group ($p < 0.001$). Comparable differences were observed with SBS measured in Newtons. The columns with different alphabet ical letters in indicate statistically significant differences at $p < 0.05$ (Table 2).

Nearly 13 (43.3%) of the samples from all the groups showed less than 50% of the remaining sealant in the enamel, while 12 (40%) of all the teeth exhibited more than 50% remaining sealant. However, only 3 (10%) of the teeth showed 100% remaining sealant in the enamel. No statistically significant difference was observed when the remaining sealant was compared across different groups ($\chi^2 = 8.414$, $p = 0.124$). Similarly, ARI test revealed no statistically significant difference in remaining sealant between ICDAS 0 and ICDAS 1 scores ($\chi^2 = 0.626$, $p = 1.000$) (Table 3).

In the microleakage test, 4 (40%) samples of the FS group and 2 (20%) samples of the SDF + FS showed microleakage in the interface of the tooth-sealant. No microleakage was observed in 6 (60%) FS, (70%) SDF + FS, and (100%) SDF + KI + FS groups with no statistically significant difference ($p = 0.082$) at extreme 1. Similarly, extreme 2 showed no statistically significant difference in microleakage across the different groups ($p = 0.469$). When comparing the microleakage status between molars with ICDAS 0 and ICDAS 1 scores, no statistically significant difference was found at extreme 1 ($p = 1.000$) and extreme 2 ($p = 1.000$) as shown in Table 4.

4 (66.7%) of the samples in the FS group and 2 (33.3%) in the SDF + FS group showed microleakage in the tooth sealant interface. However, microleakage in the interface of the tooth sealant had no statistically significantly in difference ($p = 0.122$). Comparably, microleakage penetrating to the bottom of the fissure had no statistically significant difference between the different groups ($p = 1.00$). The microleakage in the interface tooth-sealant did not show any significant difference in molars with caries status of ICDAS 0 and ICDAS 1 ($p = 1.00$). Similarly, the microleakage penetration to the bottom of the fissure did not differ significantly between molars with ICDAS 0 and ICDAS 1 ($p = 1.00$), as shown in Table 5.

4. Discussion

In recent years, the usage of SDF has gained popularity because of its antimicrobial effect through silver and fluoride, which inhibits the growth of bacteria that cause tooth decay.

TABLE 2. Comparison of mean SBS values among different groups.

Variables	n	Mean	SD	Std. Error	95% Confidence Interval for Mean		F/t	p
					LB	UB		
SBS (Mpa)								
ICDAS 0	12	26.67	6.80	1.96	22.35	30.99	−0.091	0.928¶
ICDAS 1	18	26.92	7.63	1.80	23.12	30.71		
SBS (N)								
ICDAS 0	12	188.52	48.06	13.87	157.98	219.05	−0.108	0.915¶
ICDAS 1	18	190.60	53.63	12.64	163.93	217.26		
SBS (Mpa)								
FS	10	35.12	1.13^A	0.36	34.32	35.93	669.064	<0.001§
SDF + FS	10	18.00	0.90^C	0.29	17.35	18.65		
SDF + KI + FS	10	27.33	1.10^B	0.35	26.55	28.12		
SBS (N)								
FS	10	248.28	7.98^A	2.52	242.57	253.99	674.163	<0.001§
SDF + FS	10	127.71	6.19^C	1.96	123.28	132.14		
SDF + KI + FS	10	193.32	7.76^B	2.45	187.77	198.86		

Mpa: Mega Pascal; ICDAS: International Caries Detection and Assessment System; SBS: Shear Bond Strength; FS: Fissure Sealants; SDF: Silver Diamine Fluoride; KI: Potassium Iodide; SD: Standard Deviation; Std. Error: Standard Error; LB: Lower Bound; UB: Upper Bound; N: Newton. Different alphabetical superscript ^{A,B,C} indicates statistically significant difference (p < 0.05) between FS, SDF+ FS and SDF+ KI+ FS.
¶independent t-test, §One-way ANOVA.

TABLE 3. Classification of ARI test.

Groups	0 = The remaining sealant does not appear in the enamel		1 = −50% of remaining sealant in the enamel		2 = +50% of the remaining sealant in the enamel		3 = 100% of the remaining sealant in the enamel		χ^2	*p*
	n	%	n	%	n	%	n	%		
FS	0	0.0	4	40.0	5	50.0	1	10.0		
SDF + FS	2	20.0	5	50.0	1	10.0	2	20.0	8.414	0.124
SDF + KI + FS	0	0.0	4	40.0	6	60.0	0	0.0		
Total	2	6.7	13	43.3	12	40.0	3	10.0		
ICDAS 0	1	8.3	5	41.7	5	41.7	1	8.3		
ICDAS 1	1	5.6	8	44.4	7	38.9	2	11.1	0.626	1.000
Total	2	6.7	13	43.3	12	40.0	3	10.0		

ARI: Adhesive Remnant Index; FS: Fissure Sealants; SDF: Silver Diamine Fluoride; KI: Potassium Iodide; ICDAS: International Caries Detection and Assessment System.

TABLE 4. Microleakage status in the analyzed extremes by study group.

Groups	Extreme 1						Extreme 2					
	No microleakage		Microleakage in the interface tooth-sealant		Microleakage penetrating to the bottom of the fissure		No microleakage		Microleakage in the interface tooth-sealant		Microleakage penetrating to the bottom of the fissure	
	n	%	n	%	n	%	n	%	n	%	n	%
FS	6	60.0	4	40.0	0	0.0	7	70.0	3	30.0	0	0.0
SDF + FS	7	70.0	2	20.0	1	10.0	7	70.0	1	10.0	2	20.0
SDF + KI + FS	10	100.0	0	0.0	0	0.0	8	80.0	2	20.0	0	0.0
Total	23	76.7	6	20.0	1	3.3	22	73.3	6	20.0	2	6.7
p	0.082						0.469					
ICDAS 0	10	43.5	2	33.3	0	0.0	12	40.0	9	40.9	2	33.3
ICDAS 1	13	56.5	4	66.7	1	100.0	18	60.0	13	59.1	4	66.7
Total	23	100.0	6	100.0	1	100.0	30	100.0	22	100.0	6	100.0
p	1.000						1.000					

FS: Fissure Sealants, SDF: Silver Diamine Fluoride, KI: Potassium Iodide; ICDAS: International Caries Detection and Assessment System.

TABLE 5. Extent of microleakage in different groups.

Groups	Microleakage in the interface Tooth-sealant				Microleakage penetrates to the bottom of the fissure			
	No		Yes		No		Yes	
	n	%	n	%	n	%	n	%
FS	6	25.0	4	66.7	10	34.5	0	0.0
SDF + FS	8	33.3	2	33.3	9	31.0	1	100.0
SDF + KI + FS	10	41.7	0	0.0	10	34.5	0	0.0
Total	24	100.0	6	100.0	29	100.0	1	100.0
p	0.122				1.000			
ICDAS 0	10	83.3	2	16.7	12	100.0	0	0.0
ICDAS 1	14	77.8	4	22.2	17	94.4	1	5.6
Total	24	80.0	6	20.0	29	96.7	1	3.3
p	1.000				1.000			

FS: Fissure Sealants; SDF: Silver Diamine Fluoride; KI: Potassium Iodide; ICDAS: International Caries Detection and Assessment System.

Additionally, SDF has the advantage of fluoride acting as a remineralizing agent [14, 15]. However, unesthetic black discoloration is the main drawback reported by patients and dentists [16]. This undesired side effect of the black dent can be mitigated by applying KI after applying SDF and removing the resulting white precipitate [17]. Although several studies revealed a beneficial effect, there is insufficient evidence to establish an apparent clinical advantage of SDF + KI treatment on tooth staining owing to methodological differences [18]. Prior to applying sealants, treating the fissures with SDF would leverage antimicrobial and remineralizing properties of SDF and its physical sealing ability. This method would offer benefits for the prevention of tooth decay, especially for patients who are at a greater risk of developing cavities [16].

Researchers found no statistically significant differences between the bond strength of the self-etch and etch-and-rinse techniques in teeth treated with different concentrations of SDF [12]. Literature has presented conflicting findings regarding bond strength. Greenwall-Cohen *et al.* [4] (2020), proposed that, the application of SDF weakens the bond between adhesive materials and damaged teeth by creating a new interface at the tooth-restoration complex. This prevents the adhesive agents from penetrating the tooth-restoration complex [4]. However, Knight *et al.* [10] found that rinsing the teeth with silver fluoride and KI and then air drying them did not impact the bond strength of glass ionomer cement (GIC). Thus far, no studies have determined the effects of SDF + KI on adhesion or microleakage when used as a pretreatment for fissures prior to the application of FS. In the adhesion test, SBS was employed to enhance the FS's adhesion to the tooth structure. This test enables the efficient evaluation of adhesive systems, the analysis of different substrates at various depths, and the preservation of teeth [19]. Shear bond tests are a well-established *in vitro* testing procedure used to quantify adhesive force and, in this research, all the treated teeth were stored in deionized water for 7 days in order to maintain hydration, before subjected to adhesion and microleakage test [20].

In this study, fissures pretreated with SDF showed the lowest SBS, indicating a possible higher rate of contamination. Nevertheless, fissures that have been pre-treated with SDF and KI are expected to have lower levels of contamination compared to fissures treated with SDF alone, leading to a considerably greater bond strength (SBS). Speculatively, the interaction between SDF and KI may result in the formation of pores and irregularities, which could enhance the attachment of FS to enamel compared to the SDF + FS group. Furthermore, it is important to acknowledge that the bonding of the sealant substance was influenced by the method of application, preparation of the enamel, and presence of surface impurities. This conclusion is backed by the study conducted by Farahat *et al.* [21], who investigated the influence of simultaneously applying SDF and KI on the adhesive strength of composite restorations to dentin using both total-etch and universal adhesives. Their investigation showed that the use of KI + SDF resulted in a reduction in SBS compared to the FS group, which is consistent with the findings of the current study [21].

However, Pérez-Hernández *et al.* [6] observed no statistically significant difference in the adhesion between FS with or without SDF. The group that received SDF treatment achieved superior results compared to the group that did not. The authors asserted that the utilization of SDF may have the ability to enhance resistance to detachment, which is in direct opposition to the conclusions found in the current study [6]. The force needed to detach the FS from the samples using the universal testing machine (Instron™) was considered high, and it might be feasible to utilize the pretreatment of SDF with or without KI in a clinical setting, as the bond strength (SBS) was statistically significantly greater in fissures treated with sealant alone compared to those pretreated with SDF or SDF + KI. Therefore, the null hypothesis stating that SDF has no effect on the adhesion of FS was rejected due to the statistically significant decrease in SBS seen after applying SDF. Similarly, the null hypothesis stating that SDF + KI has no effect on the adherence of FS has been rejected because there was a statistically significant decrease in SBS.

Throughout the years, assessing ARI scores has been a commonly studied aspect of research on orthodontic adhesives. The adhesive remnant score system is a qualitative and subjective method that is quick, straightforward and does not require specialized equipment [22]. After assessing ARI, the microscopic examination indicated that two samples (20%) from the SDF + FS group had detached from the enamel. In contrast, the other two groups did not show any complete detachment. In comparison, less than 50% of the remaining sealant in the enamel was observed in 40% FS, 50% SDF + FS, and 40% SDF + KI + FS groups. Nevertheless, we observed the greatest proportion of remaining sealant in the enamel in the SDF + KI + FS group, accounting for 60%. This was followed by the FS group with 50%, and the SDF + FS group with just 10%. Finally, we observed that the enamel sealant contained only one sample (10%) in the FS group and two samples (20%) in the SDF + FS group, whereas no sealants were detected in the SDF + KI + FS group. The roughening of the tooth surface and the enhanced adhesion of the FS may be attributed to the chemical interaction occurring between the SDF and KI. Therefore, it is recommended that future research investigates the surface characteristics of enamel following the application of SDF with KI in order to gain a better understanding of its impact on the FS. Upon conducting a comprehensive analysis of these findings across all groups, it was determined that there was no statistically significant difference. This outcome is comparable to the findings of Pérez-Hernández *et al.* [6].

A study by Mézquita-Rodrigo *et al.* [23] evaluated the ARI of FS after treating the enamel with different new-generation self-etching agents, and they noticed high adhesive failure rates in their samples. However, unlike the outcomes of their research, this study pre-treated the enamel with SDF, with or without KI, prior to applying the FS, and no statistically significant distinction was observed. Therefore, this study discovered that there was no notable disparity in the amount of sealant left on teeth that were sealed with FS, SDF + FS or SDF + KI + FS. This suggests that the null hypothesis was not disproven. According to Pérez-Hernández *et al.* [6], state that when the sealant is removed, a portion remains adhered to the surface of teeth. Hence, it is imperative to conduct routine patient check-ups in order to monitor the state of the sealant.

The microleakage test demonstrated that pretreating the fissure with SDF or SDF + KI yielded better results compared to FS without any pretreatment. All instances treated with SDF + KI showed no dye penetration, while 70% of cases treated with SDF and 60% of cases treated with FS did not show dye penetration. Nevertheless, there was no statistically significant difference observed in the microleakage at the interface of the tooth sealant across the different groups ($p = 0.122$). Similarly, microleakage penetrating to the bottom of the fissure did not vary significantly across different groups ($p = 1.00$). The results demonstrated that the sealing ability of FS remained unaffected when enamel was pre-treated with either SDF or SDF + KI. By integrating SDF and KI with FS, it is probable that the spaces between the FS and tooth structure can be efficiently sealed, perhaps resulting in a reduction in microleakage around the tooth structure. The findings of the current investigation regarding the use of SDF for fissure pretreatment align with the results published by El Habashy and Tekeya. Their study shown that the use of SDF did not have a significant impact on FS microleakage in extracted premolars [16].

Similarly, this study's findings align with those reported by Pérez-Hernández *et al.* [6], who also observed a significantly higher level of microleakage (81.66%) when FS was applied without prior SDF treatment. Applying the sealant following SDF pretreatment led to a reduction in microleakage, with a rate of 47%. The current investigation found that the microleakage rate was 40% in sealant without SDF pretreatment and 20% in sealant with SDF pretreatment, with no significant difference observed. The disparity in findings between the two studies may be attributed to discrepancies in the application of SDF. In prior studies, SDF was administered twice with a one-week interval between applications. In our study, however, it was applied once for a duration of three minutes, followed by the placement of a sealant.

In a study conducted by Germán-Cecilia *et al.* [24], fluoride varnish (FV) was utilised as a preliminary treatment prior to the application of two different types of fissure sealants (FS). It was noted that the use of FV before applying FS led to an increase in microleakage, regardless of the FS material. This effect was most pronounced in demineralized enamel [24]. However, our study used a high fluoride content material (SDF) to pretreat tooth samples. Microleakage penetrating to the bottom of the fissure did not differ significantly across different groups. The findings indicated that the efficacy of FS in the sealant was not compromised when the enamel was pretreated with either SDF or SDF + KI. Hence, the null hypothesis was not rejected, as no statistically significant difference in microleakage was observed between teeth sealed with FS, SDF + FS or SDF + KI + FS.

Pitchika *et al.* [25] compared self-etch adhesive and conventional FS in SBS and microleakage and found that the self-etch adhesive FS was significantly inferior to the traditional FS. Moreover, Hosseinipour *et al.* [26] assessed the microleakage of a self-adhesive flowable composite, a self-adhesive fissure sealant and a conventional fissure sealant, and they found that the traditional FS had less microleakage than the other groups. Based on these findings, it was concluded to use conventional FS for its characteristics. Also, the 3M FS used in this study is considered one of the most commonly used sealants in clinical practice. Moreover, it has been reported that the surface roughness of all the sealants increases with the duration of immersion in various acidic beverages. The degree of increase differs for each commercial brand. The 3M FS demonstrated the best performance both before and after immersion in the beverages [27].

This was the first study to test the pretreatment of the fissures with SDF/KI before applying FS. Utilizing potassium iodide (KI) in combination with silver diamine fluoride (SDF) resulted in a reduction in discoloration and could serve as a viable treatment option prior to the use of fluoride varnish (FS). However, SBS was lower for SDF + FS group, but higher for SDF + FS + KI, the bonding to the tooth structure was shown to be poorer compared to the use of FS alone. Further studies are recommended to test adhesion and microleakage of different generations of fissure sealant materials after pretreatment of fissures with SDF + KI. Moreover, future studies should also investigate the effect of SDF + KI pretreatment on adhesion and microleakage of sealants following the utilization of various etching times and bonding protocols. Additionally, it is necessary to conduct enamel surface characterization investigations following the application of SDF and SDF + KI in order to gain insight into the adhesion of the sealant. The adhesion and microleakage characteristics of sealants in this study were not significantly affected by the caries status of the molar teeth, as determined by ICDAS 0 and ICDAS 1. Further studies should include scanning electron microscopy (SEM) and energy dispersive scanning spectroscopy (EDS) analysis.

5. Limitations of the study

In contrast to the intricate clinical setting, the current investigation was conducted in a laboratory environment. The study's conclusions could be negatively impacted by the comparatively small sample size. A sample size of 60 teeth with 24 ICDAS 0 and 36 ICDAS 1 codes were chosen based on allocation ratio of 1:0.66 that would result in no significant difference in SBS and microleakage values of the teeth sealed with SDF or SDF + KI. The absence of a bonding agent between the FS and SDF + KI may have compromised the outcomes. Comparing the outcomes obtained was difficult due to the limited availability of studies.

6. Conclusions

Based on the study's constraints, it can be inferred that the application of SDF to the fissures, with or without KI, had a negative impact on the sealant's ability to adhere to the tooth structure. The application of SDF and SDF + KI to the fissures led to a notable decrease in the adhesion of sealants to the tooth, in comparison to sealants administered to untreated fissures. Therefore, it is important to be careful when applying sealants to pre-treated fissures with SDF and KI in order to prevent any negative impact on the adhesion of the sealant. The residual sealant was not substantially influenced by SDF pre-treatment of the fissures, regardless of the presence or absence of KI. The application of SDF to the fissures, independent of the presence of KI, did not have a significant effect on the microleakage of the FS.

AVAILABILITY OF DATA AND MATERIALS

The data utilized in this are contained within this article.

AUTHOR CONTRIBUTIONS

KAm—significant contribution to the concept and design of the study data collection and analysis and interpretation of data, review, writing the manuscript and final approval of the version of the article for publication. SAM—supervision, significant contribution to the concept and design of the study, analysis and interpretation of data and preparation of the article, making critical edits related to the relevant intellectual content of the manuscript, and final approval of the version of the article for publication. MAB—supervision, significant contribution to the concept and design of the study, analysis and interpretation of data and final approval of the version of the article for publication. DA—data collection, review, writing the manuscript and final approval of the version of the article for publication. KAq—Analysis and interpretation of data, and final approval of the version of the article for publication. AK—significant contribution to the concept and design of the study, analysis and interpretation of data, and final approval of the version of the article for publication.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the ethics committee of the research and innovation center of Riyadh Elm University, Riyadh, Saudi Arabia (IRB# FPGRP/2023/728/908/831). Since it is an in vitro study utilizing human teeth, the institution waived the requirement for informed consent.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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