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THE EFFECT OF POTASSIUM IODIDE APPLICATION ON THE BOND STRENGTH OF ORTHODONTIC BRACKETS BONDED TO SILVER DIAMINE FLUORIDE PRETREATED DENTIN - "AN IN-VITRO STUDY"

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ABSTRACT

Background: The main difficulties encountering clinicians with patients suffering from enamel defects are bonding of orthodontic brackets to these enamel defects as well as sensitivity due to sound dentin exposure.

Aim: This study aimed at evaluating the effect of Potassium Iodide (KI) application on the bond strength of orthodontic brackets bonded to Silver Diamine Fluoride (SDF) pretreated sound dentin.

Methodology: Upper premolar teeth ($n = 36$) were collected and were randomly divided into three groups ($n = 12$). **Group I** (control) untreated sound dentin, **Group II** exposed dentin pretreated with SDF and **Group III** exposed dentin pretreated with SDF/KI. An adhesive (Assure plus) was then applied strictly according to the manufacturing's instructions. Then, each orthodontic bracket was bonded to the sound dentin surface using a direct resin composite. Fatigue bond strength test was performed via the step-test method. After debonding procedure of the brackets from the tooth surface, adhesive remnant index (ARI) scores on dentin were evaluated.

Results: There was statistically insignificant differences in fatigue bond strength test results among the three tested groups as $P > 0.05$.

Conclusion: Pretreatment of sound dentin with SDF or SDF/KI has no adverse effect on the bond strength between orthodontic brackets and sound dentin.

KEY WORDS: Silver Diamine Fluoride; Potassium Iodide, Fatigue bond strength, Adhesive remnant index.

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INTRODUCTION

Interceptive as well as corrective orthodontic practice have been commonly dealing with patients suffering from enamel defects.[1]

Molar-incisor hypo-mineralization (MIH) is a condition associated with inevitable dental complications that might influence the quality of patient's life and create challenging treatment protocols to dental clinicians. With (MIH) condition, teeth are more prone to hypersensitivity and rapid development of dental caries. The main difficulties in these cases are bonding of orthodontic brackets to these enamel defects as well as sensitivity due to dentin exposure.[2]

Silver Diamine Fluoride (SDF) is indicated for desensitization of the teeth with non-carious lesions, with exposed root surfaces or the teeth with active dentinal lesions. Additionally, it is used for arresting carious lesions in highly caries-risk patients.[3,4]

The use of SDF for the indicated cases, is considered a safe, barely non-invasive approach, that is effective and affordable to those who cannot tolerate long sessions, geriatric and medically compromised patients.[5,6]

Silver diamine fluoride $Ag(NH_3)2F$ is a clear, colorless, and odorless alkaline solution, containing silver and fluoride ions. Diamine-silver ion is a complex of two molecules of ammonia attached to a silver ion, which renders it less oxidizing and more stable.[7]

Silver ions can interact with the proteins and DNA of the bacterial cell wall. At the same time, it helps the remineralization of demineralized inorganic substances of the tooth by the formation of fluorohydroxyapatite, calcium fluoride and silver phosphate producing a more dissolution resistant surface to acids.

Silver precipitates and calcium fluoride occludes dentinal tubules which reduce their patency that can deliver profound, long-lasting relief of hypersensitivity.[3,8,9,10]

The main drawback associated with the application of SDF is the persistant black staining caused by silver ions precipitation as Ag_2S on enamel or dentin which can react with organic substances, leaving behind black discoloration on the teeth.[5]

The black staining related to SDF in aesthetic regions is a main concern for patients. To reduce this effect and improve patient satisfaction, application of saturated potassium iodide (KI) solution immediately after SDF is suggested. It was reported that (KI) prevents staining through the precipitation of excess silver ions as creamy white silver-iodide (AgI), which is insoluble in water.[4,5]

The strength of the adhesive bond between the orthodontic brackets and the tooth surface may get reduced due to the altered tooth structure with enamel hypoplasia. If bonding the bracket on demineralized tooth structure is an essential step, it is recommended to protect and stabilize the demineralized surface before brackets positioning.[11]

The present in-vitro study aimed at evaluating the effect of Silver Diamine Fluoride (SDF) solely and Silver Diamine Fluoride with Potassium Iodide (KI) on the bond strength of orthodontic brackets to sound dentin.

The null hypothesis tested was that the application of KI has no effect on the bond strength of orthodontic brackets bonded to Silver Diamine Fluoride (SDF) pretreated dentin.

METHODOLOGY

Sample size calculation

The sample size calculations were performed depending on a previous study as a reference.[6] As reported in this reference, the minimum accepted sample size was 12 sample per each group.

The feedback within each group was distributed normally with a standard deviation 1.6 and the approximate mean difference was 1.9. This performed when power was 80% and probability of type I error was 0.05.

Total sample size = 12 per each group

Tooth selection and preparation

Maxillary premolar teeth ($n = 36$) were collected from patients having extractions for orthodontic reasons. The teeth were washed with water and stored for one week in solution of chloramine T 0.5% at 4^{o}C to be disinfected.[12] The proposal of the current work was approved by Research Ethics Committee - Faculty of Dentistry - October 6 University, Giza, Egypt (No.# RECO6U/8-2020) and conducted following the principles of Helsinki Declaration.

The inclusion criteria for the tooth selection were intact caries-free enamel surface with no cracks, attrition or abrasion, no previous orthodontic treatment or dental bleaching.

The enamel of the buccal surface was carefully removed with a diamond bur using a high-speed handpiece *(# 3195, KG Sorensen, Barueri, Brazil)* with water-cooling spray, then the exposed dentin was examined meticulously under a stereomicroscope at magnification of 20× to guarantee the absence of any enamel islet.

The prepared teeth were divided into three groups *(n = 12)*:

1. Group I (Control): Orthodontic brackets were bonded to exposed non-treated sound dentin.
2. Group II (SDF): Orthodontic brackets were bonded to Silver Diamine Fluoride pretreated dentin.
3. Group III (SDF/KI): Orthodontic brackets were bonded to Silver Diamine Fluoride followed by Potassium Iodide pretreated dentin.

All thirty-six teeth were etched with 37% Super etch phosphoric acid gel for 15 seconds, rinsed for 5 seconds with tap water and then were air dried for 10 seconds.

Teeth from group I, were kept without dentin treatment before bonding with adhesive. Teeth from group II, were treated with SDF solution from the silver capsule for 60 seconds using micro-brush then were rinsed and air dried according to the manufacturing's recommendations. Teeth from group III, were treated with SDF solution from the silver capsule for 60 seconds using micro-brush, followed by passive application of potassium iodide using the green brush from green capsule until creamy white precipitate turned clear. Teeth were then rinsed and air dried.

The SDF was applied after acid etch as it facilitates the SDF permeation into dentin and removes smear layer and smear plug which decreases the surface bio-load.[13]

As recommended by the manufacturer, Assure PLUS adhesive was painted as one coat on the dentin surface for 15 seconds, gently dried with air spray for 5 seconds, then light-cured for 10 seconds.

Stainless steel maxillary premolar orthodontic brackets were positioned at the middle one third of the prepared dentin buccal surfaces, after applying a thin layer of Assure PLUS adhesive to the base of each bracket and gently air-dried. This was followed by application of adhesive composite resin (Transbond XT) onto the base of the brackets. Each orthodontic bracket was pressed firmly to the tooth surface by the application of moderate compressive force for 10 seconds to obtain steady smooth adhesive thickness.[14] The excess resin composite was properly removed with a scaler from the bracket margins. Each bracket was light cured for 10 seconds from each side with total time of 40 seconds, using light curing device. All samples were prepared by the same operator.

TABLE (1) Materials used in the study, according to the data provided by the manufacturers

Name	Composition/ Specifications	Manufacturer
Assure PLUS Bis-GMA,	Bisphenol A-glycidyl methacrylate (10 – 30%) Ethanol (50 – 75%) Hydroxyl Ethyl Methacrylate (HEMA) 10-MDP phosphate monomer	Reliance Orthodontic Products, Itasca, IL, USA
Riva Star, silver diamine fluoride SDF	Silver fluoride (35 – 40%) Ammonia (15 – 20%) Deionized water (balance).	SDI, Bayswatch, Australia 11272362
Riva Star, potassium iodide KI	Potassium iodide Deionized water.	SDI, Bayswatch 11272362
Super etch	37% wt phosphoric acid gel 9.6ml, 12gm	SDI Limited, Victoria, Australia 8100052
Transbond XT Adhesive (Light Cure)	Silane-treated quartz Bis-GMA, Bis-EMA Silane-treated silica Diphenyl Iodonium Hexa-Fluorophosphate	3M Unitek - Monrovia, USA
Stainless Steel 1st Bicuspid Brackets	Cross-MW, MBT 0.022-inch, No. 104/204, Torque -7, Angulation 0, Width 2.8, In/Out 0.7	HT co., Ltd. Korea
Light Curing Device	LED light curing - Elipar S10 cordless	3M ESPE - Dental Products - St Paul, USA.

All specimens were stored for 24 hours in distilled water at 37°C. Subsequently, the specimens were thermo-cycled between 5°C - 55°C for 500 cycles with a dwell time of 5 seconds (SD Mechatronik thermocycler, Germany), simulating the thermal changes effect in the oral environment, as recommended by the ISO TS 11450 standard in 2003.[15] The transfer time between baths was 8 seconds.

After thermocycling, rubber molds (14 mm length x14 mm width x17 mm depth) were used to mount all specimens' roots into auto-polymerizing acrylic resin blocks (Cold cure acrylic, Acrostone Inc., Egypt) up to 1 mm apical to the cemento-enamel junction to position the bonding surface perpendicular to the horizontal plane.[12]

Fatigue Bond Strength Test

Fatigue bond strength was evaluated via Staircase step-test method, employing a computer-controlled material testing machine *(Model 3345, Instron Industrial Products, Norwood, USA)*. A load cell of 5 kN was applied and data were recorded using computer software *(Bluehill Lite; Instron Instruments)*.

Mounted samples were tightened to the lower compartment of the testing machine.

Fatigue bond strength test was performed under compressive load applied occlusally, using a mono-beveled chisel attached to the upper movable compartment of the testing machine, traveling at crosshead speed of 0.5 mm/sec.

In staircase step-test the sample was subjected to predetermined number of cycles, at each of an increasing stress levels sequence, until the sample failed.[16]

The load level below the expected material's fatigue failure was selected to start the step-test. Each specimen was then tested at that load level until either, failure of the specimen or run-out at the previous set number of cycles was occurred. If failure occurred, the load level and the numbers of cycles were recorded. If run-out achieved, the load level was increased by a predetermined increment of stress, and the same specimen was run again at the new load level.[16,17]

Cyclic loading at 1.6 Hz frequency was applied, which is corresponding to the reported oral chewing frequency[17]. The maximum number of cycles applied at each load step was 1,000 cycles. If the sample got survived through the 5,000 cycles, the stress level was increased by load of 10 N incrementally. The initial applied load was 36 N, followed by 10 N successive steps.[16,17]

The software was set to record the applied load and the number of cycles data corresponded to the specimen fracture. The maximum fatigue load (L_E) N for each sample was calculated depending on the following equation.[18]

$$L_E = L_0 + \Delta L\ (N_{fail} / N_{life})$$

Where L_0 is the previous maximum fatigue load that did not cause sample failure, ΔL is the amount of increase of load step, N_{fail} is the number of cycles to failure at the failure load step ($L_0 + \Delta L$), and N_{life} is the cyclic fatigue life (1,000 cycles).

The fatigue bond strength in MPa was calculated by the failure load (N) / the bracket base area (mm^2).

Adhesive remnant index (ARI) scoring

Following the brackets' debonding, the dentin surface of each tooth and bracket base was inspected under a stereomicroscope (SZ1145TR, Olympus Japan) at 20X magnification, and the ARI scores were calculated based on the amount of adhesive remained on the tooth surface.

The Adhesive Remnant Index (ARI) was recorded according to the following scale:

The ARI score is (0) when no adhesive remained on the dentin surface, (1) when less than 50% of the adhesive remained on the dentin surface, (2) when 50% or more of the adhesive remained on the dentin surface and (3) when the whole adhesive remained on the detin showing bracket base impression.[11,19]

Additionally, each of these scores were corresponded to one of the following types of failure: Adhesive failure: < 20% of the adhesive was remained, mixed failure: 20 -80% of the adhesive was remained or cohesive failure: > 80% of the adhesive was remained.[19]

All data were collected and statistically analyzed.

RESULTS

Statistical analysis was performed with SPSS 16® (Statistical Package for Scientific Studies), Graph Pad Prism and Microsoft Office Excel 365.

The data exploration was performed with Shapiro Wilk and Kolmogorov Smirnov normality tests. The data showed non-significant results as *P-value* > 0.05 which failed to reject the null hypothesis, and the concluded data were derived from non-parametric data.

Fatigue Bond Strength

The mean bond strength values (MPa) and the standard deviation were summarized in tables 2 and presented graphically in figure 1. In group I (control), mean (MPa) ± standard deviation of bond strength was (8.32±2.49) MPa, while minimum was (5.35 MPa) and maximum was (12.37 MPa), while in group II (SDF) mean ± standard deviation was (7.98±2.34) MPa, while minimum was (4.4 MPa) and maximum was (12.3 MPa). In group III (SDF/KI) mean ± standard deviation of bond strength was (7.33±2.19) MPa, while minimum was (4.25 MPa) and maximum was (11.63 MPa).

Kruskal-Wallis test was used to compare between all groups which revealed insignificant differences between the results as $P > 0.05$. Tukey's Post-Hoc test was used for multiple comparisons, which revealed also insignificant difference as $P > 0.05$ in means with the same superscript letters (insignificant difference between the three groups).

Adhesive Remnant Index (ARI)

The ARI score distribution for the different groups and their mode of failure are shown in tables 3 and 4 and figures 2 - 6 respectively.

Comparison between the percentage of ARI and mode of failure of all groups was performed by Chi square test which revealed insignificant differences between them as *P>0.05*.

ARI score of the 50% of the specimens of the control group was 0 and 50% was 1. For the SDF and SDF/KI groups, the ARI score of 58.3% of the specimens was 0 and 41.6% was 1.

Types of failure mode was adhesive failure for 91.7% of the specimens of the control group while 8.3% was mixed failure. For SDF and SDF/KI groups 100% of specimens showed adhesive failure.

TABLE (2) Fatigue bond strength MPa (mean, minimum, maximum and standard deviation) for group I (control), group II (SDF) and group III (SDF/KI).

	N	Min.	Max.	M.	SD.	P value
Control	12	5.35	12.37	8.32 [a]	2.49	
SDF	12	4.4	12.3	7.98 [a]	2.34	0.58ns
SDF/KI	12	4.25	11.63	7.33 [a]	2.19	

Min; minimum ***Max; maximum*** ***M; mean*** ***SD; standard deviation***
N; total count ***ns; insignificant difference*** ***Means with the same superscript letters were insignificantly different.***

TABLE (3) ARI scores and their corresponding percentage for group I (control), group II (SDF) and group III (SDF/KI).

Groups	ARI Scores and %				
	n	0 - (%)	1 - (%)	2 - (%)	3 - (%)
Control	12	6 - (50%)	6 - (50%)	0 - (0)	0 - (0)
SDF	12	7 - (58.3%)	5 - (41.6%)	0 - (0)	0 - (0)
SDF/KI	12	7 - (58.3%)	5 - (41.6%)	0 - (0)	0 - (0)
P value		0.71	0.66	------	------

Percentage values were insignificantly different as P >0.05.

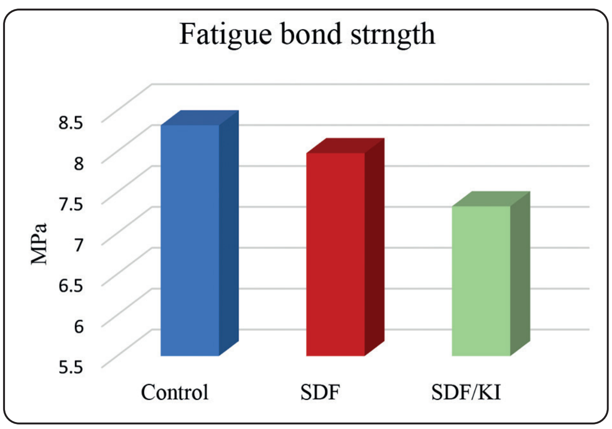

Fig. (1) Bar chart representing the mean values of fatigue bond strength (MPa) for group I (control), group II (SDF) and group III (SDF/KI).

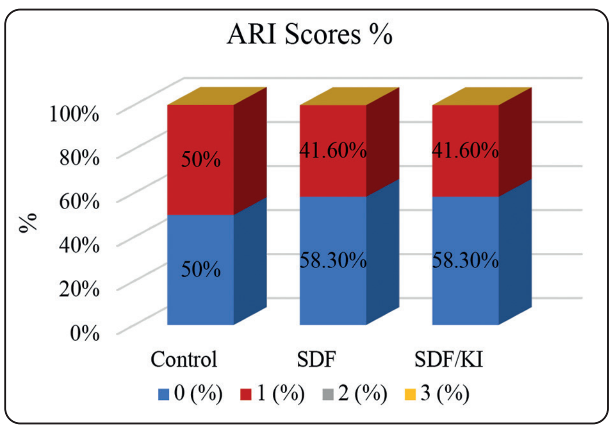

Fig. (2) Bar chart showing ARI scores and their corresponding percentage for group I (control), group II (SDF) and group III (SDF/KI).

TABLE (4) Types of failure mode and their corresponding percentage of the three testing groups

Groups	Types of failure mode and %			
	n	Adhesive - (%)	Mixed - (%)	Cohesive - (%)
Control	12	11 - (91.7%)	1 - (8.3%)	0 - (0)
SDF	12	12 - (100%)	0 - (0)	0 - (0)
SDF/KI	12	12 - (100%)	0 - (0)	0 - (0)
P value		0.29 ns	0.31ns	-----

Percentage values were insignificantly different as P >0.05.

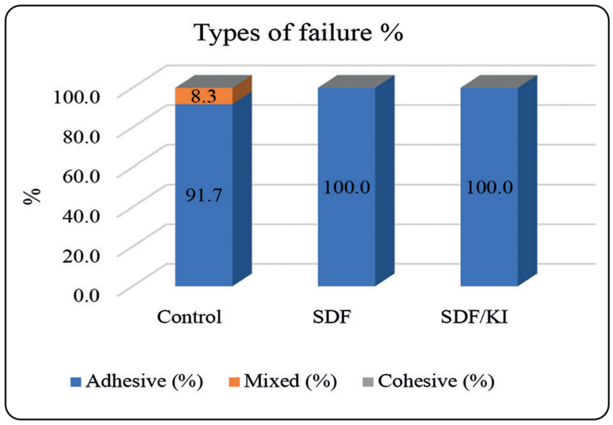

Fig. (3) Bar chart showing types of failure mode and their corresponding percentage of the three testing groups

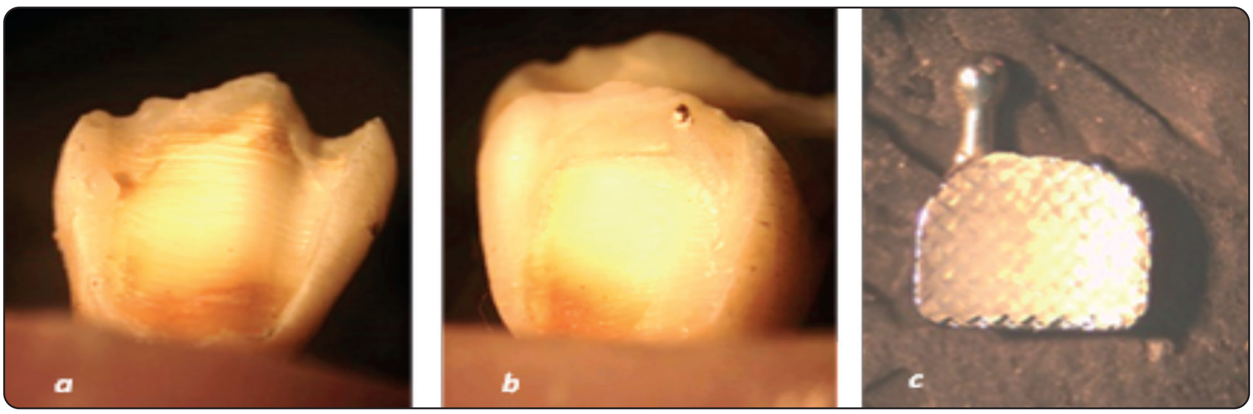

Fig. (4) Stereomicroscope pictures for ARI score of control group a) Tooth 0 score b) Tooth 1 score c) de-bonded bracket

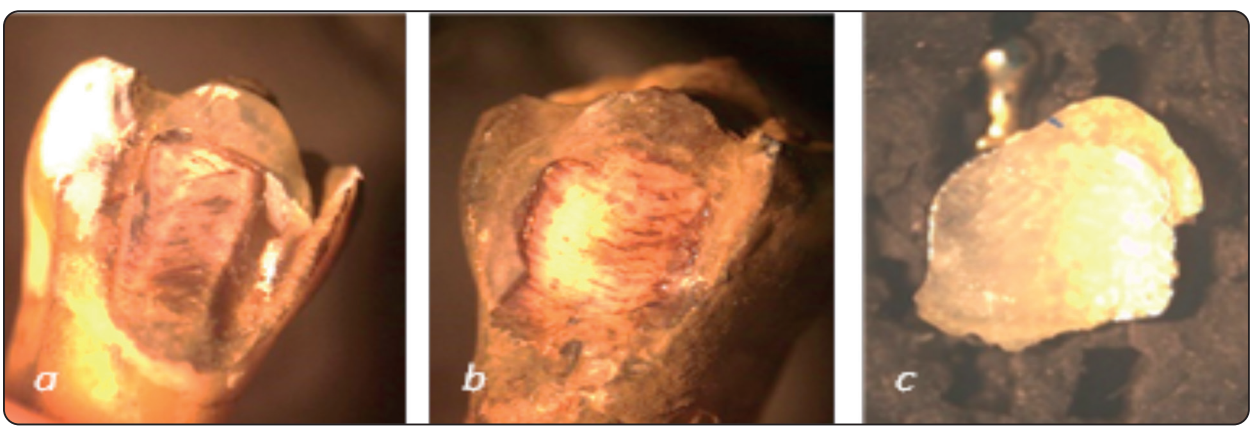

Fig. (5) Stereomicroscope pictures for ARI score of SDF group a) Tooth 0 score b) Tooth 1 score c) de-bonded bracket

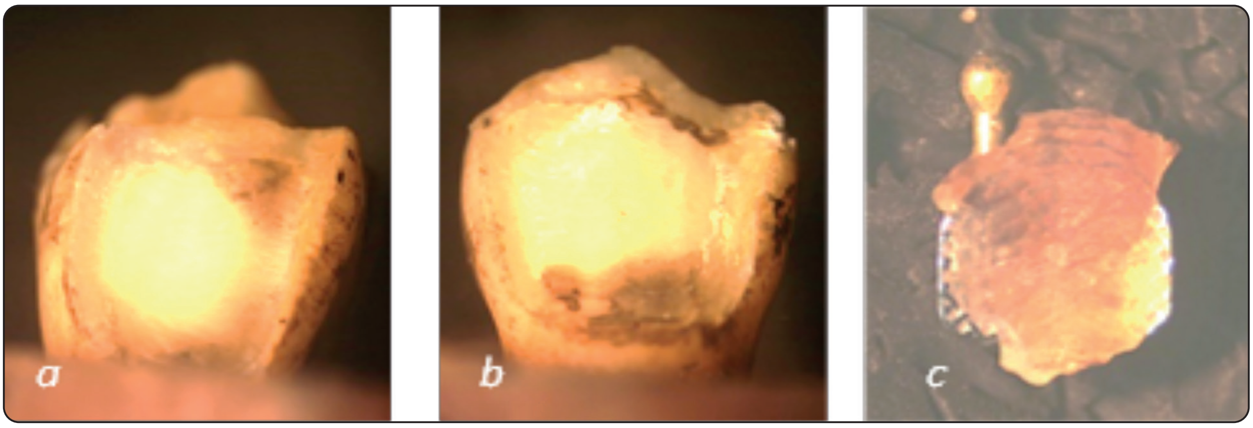

Fig. (6) Stereomicroscope pictures for ARI score of SDF/KI group a) Tooth 0 score b) Tooth 1 score c) de-bonded bracket

DISCUSSION

The principal objective of the present study was to evaluate the effect of pretreatment of sound dentin with SDF and SDF/KI, on the bond strength between orthodontic brackets and sound dentin.

The SDF has been introduced to the dental market because it possesses many advantages including caries prevention, but it has the drawback of tooth discoloration.[20]

The main advantage of using KI solution with SDF is the masking effect of the black stain caused to the teeth with the application of SDF alone.[21]

The SDF concentration of 38% was chosen for this study according to previous studies, which concluded that this concentration is the optimum for arresting and preventing caries in primary teeth in comparison to 12% concentration.[22,23]

Rinsing the samples with water was recommended while using SDF as stated in previous studies that rinsing the mouth after SDF application can prevent the significant reduction in bond strength between the applied adhesive rein and sound dentin.[3,24]

Assure™ PLUS consists of hydroxyl ethyl methacrylate (HEMA) molecule which can aid in the moisture control at bonding step. HEMA was recommended to be used in dentin adhesion because of its hydrophilic properties and hydrophobic functional groups that allow a better infiltration of monomers which result in better bond strength after polymerization.[25] The presence of 10-Methacryloyloxydecyl Dihydrogen Phosphate monomer (MDP) as a main component of Assure PLUS adhesive, enables a dual adhesion mechanism through micromechanical bonding and chemical bonding to the dental substrates via ionic bond to the calcium component of hydroxyapatite. Additionally, the presence of ethanol as a hydrophilic monomer with mild-etching properties, it enhances the bond to dentin.[11]

In order to evaluate the cyclic loading effect on the bond strength, Staircase (step-test) method was employed to characterize the total fatigue life of the material for a predetermined number of cycles.[12]

Cyclic fatigue with the thermal cycling procedures have been recognized as extremely decisive in-vitro tests to predict the bonded orthodontic brackets long-term survival intraorally.[17]

The adhesive remnant index score was selected to determine the amount of adhesive remained on the dentin surface as it is straightforward and a rapid procedure that does not need special equipment.[19] The score of ARI is depending on the bond strength, the bracket base design, quality of the prepared tooth structure and the adhesive composition.[26]

The bond strength values resulted in the current study considered accepted regarding the retention of brackets to the dental tissues. As orthodontic brackets commonly remain intraorally for about 2 years, the optimum bonding strength should not be below 6–8 MPa to resist the forces arising from the dentofacial region.[25,26] Previously, it was declared that the minimum required bond strength value for clinically successful bracket bonding is 5.9–7.8 MPa.[11,27]

Results of the present work showed insignificant difference in bond strength of the adhesive junction between the bracket and the tooth substrate when dentin was treated with SDF in comparison to the untreated dentin. This was in agreement with previous study stated that application of SDF had no effect on the bond strength between the resin composite materials and sound dentin.[28]

The results of this study also showed insignificant decrease in fatigue bond strength with the use of SDF/KI.

The insignificant reduction in the bond strength values after the treatment with SDF and KI might be explained by the effect of SDF application that stimulates production of silver iodide and calcium fluoride when reacted with hydroxyapatite, both are having the ability to occlude dentinal tubules. This agreed with the finding of Seifo et al in their study.[3] Farahat et al investigation showed that application of KI with SDF reduces the bond strength of adhesive explaining that they can interfere with the infiltration of the bonding agent into the intertubular and peritubular dentin resulting in less hybrid layer formation.[29]

In another study, Lutgen et al evaluated different bond strength tests using 38% SDF on enamel and dentin to assess the bond stability of self-etch universal adhesives. The results showed reduction in the bond stability of the universal adhesives to both enamel and dentin.[24,30]

Additionally, Uchil et al stated that, precipitation of silver granule on the denatured collagen fibrils following the SDF application resulted in reducing the bond strength of restorative material to dentin treated with SDF, resulting in adhesive failure.[13]

On the other side, another study suggested an increase in bond strength of the resin materials to dentin following SDF application and prevented a decrease in bond strength over time.[3]

In agreement with the results of the current work, previous studies found out that application of KI solution on sound dentin immediately after treatment with SDF, had not shown any negative affect on bonding with resin composite materials.[28,31]

This is concurrent with the recorded scores of ARI after brackets' failure in the present study. ARI score for the most of samples after bracket debonding in the three groups was 0, indicating adhesive-free sound dentin surface followed by ARI score 1. These scores indicate that bond strength was not significantly compromised after application of SDF and SDF/KI. This agrees with the results reported in a previous study.[11]

Although adequate bonding of orthodontic bracket is necessary for force application in orthodontics, debonding is also crucial. The ideal adhesive systems should provide sufficient bond strength without any deleterious effect on the tooth structure during debonding. Easier debonding of orthodontic brackets is more favorable and resulting in lower adhesive remnant indices (ARIs).[27,32] The low ARI score was validated by the adhesive mode of failure which indicates a relatively lower bond strength of the adhesive to the sound dentin in comparison to its bond strength to orthodontic brackets.

Limitations of the study

The forces applied on the orthodontic bracket clinically during debonding are combinations of tensile, shear and torsion forces which had not been taken into consideration.

The pH and the enzymatic changes were not simulated in these in-vitro conditions.

Conclusions:

Pretreatment of sound dentin with SDF or SDF/KI has no adverse effect on the bond strength between orthodontic brackets and sound dentin.

Recommendation:

Further clinical research would be needed to establish conclusive evidence.

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