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Effect of Silver Diamine Fluoride on Shear Bond Strength of Resin-Modified Glass Ionomer and Nano-hybrid Resin Composite to Caries-Affected Dentin: An In-vitro Study

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Aim: The aim of this in-vitro study was to compare the effect of silver diamine fluoride (SDF) on the shear bond strength of resin-modified glass ionomer cement (RMGIC) and nano-hybrid resin composite (NHRC) to caries-affected dentin (CAD).
Material and methods: Thirty-six carious deciduous molars with no pulp involvement, fillings, structural or congenital defects were randomly allocated into 2 groups; group (I): RMGIC, group (II): NHRC. Each group was further subdivided into 2 subgroups; subgroup A: pretreated with 38% SDF, subgroup B: restorative material was applied without pretreatment with SDF. Shear bond strength (SBS) was assessed using Universal Testing machine. Mode of failure was evaluated using stereomicroscope. The significance level was set at $p \leq 0.05$. Statistical analysis was done using R statistical analysis software version 4.1.3 for Windows.
Results: Group I showed significantly higher SBS than Group II ($p<0.001$). In group I, there the difference between both subgroups was non-significant ($p=0.847$). However, in group II, subgroup B had statistically significant higher SBS than subgroup A ($p<0.001$). Both groups and subgroups showed no statistically significant difference regarding mode of failure. ($p>0.05$).
Conclusion: SDF seems to interfere with bonding of nanohybrid resin composite to caries affected dentin. On the other hand, it seems not to interfere with bonding of resin-modified glass ionomer cement.

Keywords: Minimally invasive dentistry, SDF, adhesive restorative materials.

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Introduction

Silver Diamine Fluoride (SDF) is considered an efficient evidence-based material in managing dental caries, particularly in deciduous teeth. SDF is a bactericidal agent which inhibits demineralization and enhances remineralization. Also, it protects dentin collagen from degradation by inhibiting collagenases.[1]

In silver modified atraumatic restorative technique, SDF is applied following selective caries excavation of soft carious dentin to achieve better contact between SDF and denatured dentin. Tooth is then restored with glass ionomer cement (GIC), aiming to halt further progression of carious lesion by the action of SDF and cut off nutrients to any residual bacteria by placing chemically sealed restoration to preserve tooth structure and maintain pulp vitality.[2]

Resin modified glass ionomer cement (RMGIC) was developed to improve mechanical properties and decrease moisture sensitivity by combining the advantages of both composite and glass ionomer. Resin modified glass ionomer cement retains many of the advantages of conventional GIC such as inherent adhesion with enamel and dentin and fluoride releasing and recharging capability.[3] Resin modified glass ionomer cement has some advantages over conventional GIC such as greater working time, decreased setting time, earlier finishing and aesthetics closer to composite resin.[4] In comparison to conventional GIC, RMGIC has higher bond strength, higher early strength and wear resistance, and lower moisture sensitivity, giving rise to lower solubility and disintegration.[3]

Also, continuous innovations in resin composite materials made it feasible to have an aesthetic restoration with high mechanical properties, wear-resistance, and durability. Nano-hybrid resin composite (NHRC), which is composed of nano-fillers blended with micro-fillers, shares many of the advantages of composite resin. It has been extensively used as a dental restoration due to its different properties, such as instant setting process, broad range of handling characteristics, mechanical and aesthetic properties.[5] Moreover, the advancements made to dental adhesives have also improved the performance and longevity of resin composite restorations.[6]

Literature on SDF effect on bonding efficiency of direct restorative materials has inconclusive findings.[7] Puwanawiroj et al.,[8] and Zhao et al.,[9] reported that SDF did not impair the bond strength between GIC and CAD. On the other hand, Soliman et al.,[10] and Sa'ada et al.,[11] found that pretreatment of non-carious dentin with SDF improved the shear bond strength to RMGIC compared to the control group.

Where Wu et al.,[12] and Duker et al.,[13] found that pretreatment of dentin with SDF had no significant effect on bond strength to resin composite, Firouzmandi et al., [14] and Siqueira et al.,[15] revealed that SDF enhanced the bond strength of NHRC to carious dentin. Although SDF is generally accepted as treatment for caries in deciduous teeth, yet there is no solid evidence regarding bonding efficacy of adhesive restorative materials to caries-affected dentin (CAD) following SDF application.[7] Also, there are limited studies comparing the effect of SDF on bond strength of RMGIC and NHRC. Therefore, the present study was performed to compare shear bond strength of RMGIC and NHRC, when used as restorative materials on natural CAD pretreated with SDF in deciduous molars.

The null hypothesis was that SDF would have no effect on SBS of RMGIC and NHRC to CAD. Also, that there would be no statistically significant difference between SBS of RMGIC and NHRC to CAD whether pretreated or not with SDF.

Materials and Methods

This in-vitro study was performed to compare the effect of silver diamine fluoride (SDF) on the shear bond strength of resin-modified glass ionomer cement (RMGIC) and nano-hybrid resin composite (NHRC) to caries-affected dentin (CAD).

Sample size calculation

A power analysis was designed by adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.20 (20%) i.e., power=80%, and effect sizes of (f=0.585) and (Ω=0.624) calculated based on the results of Wang, Angelina Shuhua, et al.[16], the calculated sample size (n) was predicted to be 36 specimens for testing shear bond strength (9 specimens per subgroup). Sample size calculation was performed using G*Power Version 3.1.9.4.[17]

Sample collection and storage

Fifty human carious deciduous molars, extracted due to over retention or for orthodontic purposes, were collected using a protocol approved by the Ethics Committee of the Faculty of Dentistry, Ain Shams University. They were collected from anonymous patients from the Department of Paediatric Dentistry and Dental Public Health at Faculty of Dentistry, Ain Shams University. Collected teeth were examined under stereomicroscope (BX60, Olympus, Japan) at a 40x magnification to exclude teeth with cracks, structural or congenital defects.

Only 36 primary molars with occlusal or occluso-proximal dentinal caries that extended less than one quarter of the crown i.e., Slack index score D2 and at least two intact walls remaining were selected for the study. Deciduous molars with pulpal involvement, fillings, cracks, structural or congenital defects were excluded. All teeth were debrided using a hand-scaler and pumice slurry. They were then kept in distilled water at 4˚C for not more than one month.

Sample grouping

Thirty-six specimens were serially numbered and randomly divided into two groups (18 specimens each). Each group was randomly subdivided into two subgroups (9 specimens each). The groups were designated as follows:

Group I: Resin modified glass ionomer cement
Subgroup A: SDF
Subgroup B: Without SDF
Group II: Nano-hybrid composite resin
Subgroup A: SDF
Subgroup B: Without SDF

Specimen preparation

The roots of each tooth were sectioned 2 mm below the cemento-enamel junction using a low-speed diamond disc with copious air-water coolant spray. The occlusal enamel was ground in a horizontal direction perpendicular to the long axis of the tooth using a low-speed diamond disc with water coolant to reach a flat dentin surface.[18]

The endpoint of dentin caries excavation was determined using caries-detecting dye along with visual examination. Caries-detecting dye (Seek, Ultradent, South Jordan, UT, USA) was applied on the dentin surface for 10 sec. The dentin surface was then rinsed and dried for 10 sec using air-water coolant. Three colours were shown after drying: dark red colour indicates caries-infected dentin (CID), pink indicates CAD, while yellow indicates normal dentin. The superficial layer of the carious lesion (i.e. CID) with dark red colour was excavated with a sharp spoon excavator size 51/52 (DENTSPLY MAILLEFER – U.S.) until reaching the light pink zone (i.e. CAD). By visual inspection, CAD exhibited a glossy appearance and a dark yellow or faint brownish colour. Evaluation of this step was performed by two study-independent operators.

The surfaces were smoothened with wet silicon carbide abrasive paper (six hundred grit) and cleaned with pumice slurry. Specimens were then placed in self-cured acrylic resin (Acrostone™, Egypt) within polyvinyl rings of 2 cm diameter and 1 cm height.

Application of materials

A) Silver diamine fluoride:

A 38% SDF solution (Kids-e-dental, Mumbai, India) was applied to dentin surface for 1 minute using micro brush. After 3 minutes, dentin surface was rinsed for 30 sec with distilled water and gently dried with compressed air flow before any further surface treatment.

B) Resin-modified glass ionomer cement:

A thin layer of conditioner (25% polyacrylic acid, Ketac™ Conditioner, 3M ESEP, St. Paul, MN, U.S.A) was applied to dentin surfaces using a microbrush for 10 sec. It was then washed for 15 sec and gently dried with compressed air flow.

A rubber catheter of 2 mm height and 3 mm internal diameter was placed perpendicular to the polished flat CAD, filled with RMGIC (GC Fuji II LC™, GC corporation, Tokyo, Japan) and light cured for 20 sec using light curing unit (Woodpecker, LED.D, Guangdong, China) with light intensity 1000 mW/cm^2. Light intensity was checked periodically using a radiometer.

Rubber catheters were then cut using sharp lancet and a thin layer of nano-filled coating agent (Equia coat, GC corporation, Tokyo, Japan) was applied on RMGIC buttons using a microbrush and light cured for 20 sec.

C) Nano-hybrid composite resin:

Two separate layers of universal dental adhesive (All-Bond Universal, Bisco, Inc., Schaumburg, IL, USA) were applied on dentin surfaces using a microbrush for 10 sec for each coat. It was then gently dried for 10 sec with compressed air flow. Finally, adhesive was light cured for 10 sec.

An increment of NHCR, (Filtek™ Z250 XT, 3M™ ESPE™) was packed into the rubber catheter and light cured for 20 sec. Rubber catheters were then cut using sharp lancet.

Testing procedure

All Specimens were coded and stored in distilled water at 37 ˚C for 24 hours before testing. They were then subjected to thermocycling in a thermocycling apparatus (Sd Mechatronic Themocycler, Germany) at 500 cycles between 5°C and 55°C in controlled water bath with 30 sec dwell time in each bath and transfer time of 15 sec.

Shear bond strength (SBS) was assessed using universal testing machine (Instron, Comten Industries, U.S.A). A shear load was applied with a chisel shaped blade parallel to the bonded interface with fixed pace of 1 mm/min until fracture occurred. The bond strength was calculated by dividing the maximum failure load in Newton (N) by the surface area of the bonded interface (mm^2) and expressed in mega-Pascals (MPa). (Figure 1)

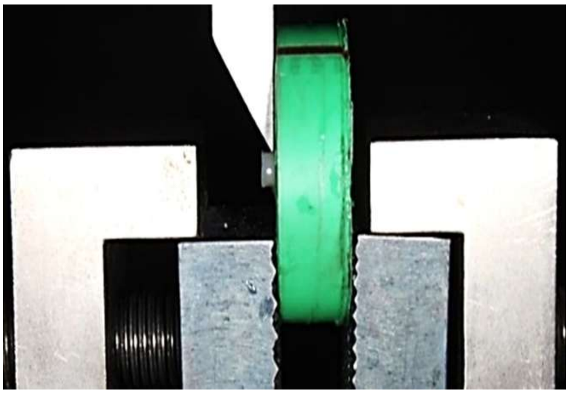

Figure 1: Specimen loaded in the testing machine.

Modes of failure were evaluated by two independent examiners who were calibrated and blinded (Demonstrators at Department of Biomaterials, Ain Shams University) using stereomicroscope (BX60, Olympus, Japan) at 40x magnification. Modes of failure were classified as: Adhesive failure between the dentin surface and the restorative material, Cohesive failure within dentin, Cohesive failure within the restorative material, and Mixed failure, which is a combination of adhesive and cohesive failures.

All specimens were evaluated blindly by two independent examiners at department of Biomaterials, Ain Shams University. The intra and inter examiner reliability were calibrated using Kappa statistic. Kappa statistic of intra examiner reliability was 0.9 which indicated consistency of the examiner in the evaluation of mode of failure over time and 0.81 for inter examiner reliability which indicated strong agreement between the examiners.

Statistical analysis

Independent t-test was used to compare shear bond strength between study subgroups while mode of failure was assessed using Fisher's exact test. The significance level was set at $p \leq 0.05$. Statistical analysis was done with R statistical analysis software version 4.1.3 for Windows.

Results

Shear bond strength (SBS)

Descriptive statistics of the SBS (MPa) of the different subgroups were illustrated in (Table 1) and (Figure 2).

Subgroups IA and IB showed significantly higher SBS compared to subgroups IIA and IIB respectively (p<0.001). In group I, both subgroups showed no statistically significant difference (p=0.847). However, in group II, subgroup B had significantly higher SBS than subgroup A (p<0.001).

Table 1: Mean and standard deviation (SD) values of shear bond strength (MPa) in different subgroups.

Subgroup \ Group	RMGIC (I)	NHRC (II)	p-value
With SDF (A)	7.18 ± 0.43	2.76 ± 0.26	**<0.001***
Without SDF (B)	7.10 ± 1.24	3.82 ± 0.48	**<0.001***
p-value	**0.847ns**	**<0.001***	

***; significant ($p \leq 0.05$) ns; non-significant.**

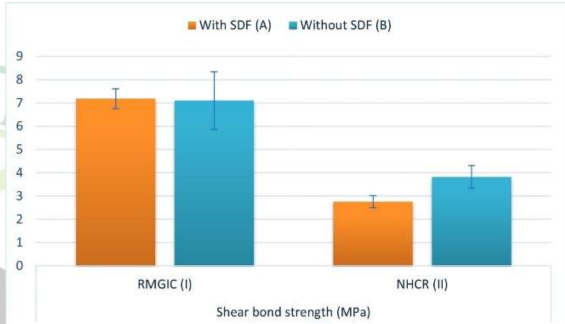

Figure 2: Bar chart showing mean and standard deviation values for shear bond strength (MPa) in different subgroups.

Mode of failure

There was no significant difference between different subgroups regarding mode of failure (p>0.05). (Table 2) (Figure 3)

Table 2: Frequency, and percentage values of mode of failure among studied groups.

Subgroup \ Group	Mode	RMGIC (I)	NHRC (II)	p-value
With SDF (A)	**Adhesive**	1 11.11%	4 (44.44%)	**0.214ns**
	Cohesive in dentin	1 (11.11%)	2 (22.22%)	
	Cohesive in material	0 (0.0%)	0 (0.0%)	
	Mixed	7 (77.78%)	3 (33.33%)	
Without SDF (B)	**Adhesive**	3 (33.33%)	5 (55.56%)	**0.698ns**
	Cohesive in dentin	0 (0.0%)	0 (0.0%)	
	Cohesive in material	2 (22.22%)	1 (11.11%)	
	Mixed	4 (44.44%)	3 (33.33%)	
p-value		**0.164ns**	**0.637ns**	

***; significant ($p \leq 0.05$) ns; non-significant**

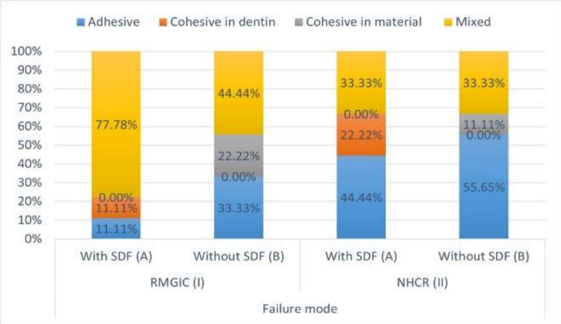

Figure 3: Stacked bar chart showing failure mode among studied groups.

The most prevalent modes of failure were mixed failure in IA and IB with percentage of (77.8%) and (44.4%) respectively and adhesive failure in IIA and IIB with percentage of (44.4%) and (55.6%) respectively. (Figure 4)

Figure 4: Mode of failure assessment. A: An example of adhesive failure in IA, B: An example of cohesive failure in material in IB, C: An example of cohesive failure in dentin in IIA, D: An example of mixed failure in IIB.

Discussion

Silver diamine fluoride (SDF) has been used for several years and has shown promising results in caries prevention and arrest. However, staining of the tooth structure following SDF application can negatively affect patient and parent satisfaction. Tooth-coloured restorative materials can be applied over SDF-arrested carious lesions to mask the black staining caused by SDF for better aesthetics. Restoring cavitated lesions also improves tooth function, prevents food accumulation and reduces the potential for incidence of secondary caries.[9]

However, evidence for the possible effect of SDF on bonding of direct restorative materials to dentin is not well established.[7] Therefore, the present study was performed to assess if pre-treating caries-affected dentin (CAD) with SDF would adversely affect shear bond strength (SBS) of resin-modified glass ionomer cement (RMGIC) and nano-hybrid resin composite (NHRC) to dentin or not.

The present study used decayed deciduous molars as they represent one of the most common challenges in the daily routine of paediatric dentists.[19] Freshly extracted primary molars were used within one month after extraction to avoid degenerative changes in dentinal protein which can affect bond strength testing.[20]

Natural CAD was used as the substrate for the study to mimic the clinical settings in which the bonding substrate is commonly CAD.[21] Previous studies suggested the use of SDF as a liner under restorative material to harden caries infected or affected dentin.[(8-13)] The natural carious lesion includes different organic acids, hydrolytic enzymes, and whitlockite crystals that closes most of the dentinal tubules, which is far more complicated than artificially created carious lesion. Moreover, the strong acids used for artificial demineralization process may influence the restorative procedures, which therefore would deteriorate the bonding process.[22]

Silver diamine fluoride has different commercial concentrations. The concentration of 38% was used due to its proved effectiveness in arresting dentin caries in comparison to 30%, 12% and 10% concentrations as evident in the literature.[23] SDF was applied according to clinical recommendations in subgroup A of both groups followed by rinsing off the SDF-treated tooth surface to eliminate the excess silver precipitate in order to improve adhesion.[24]

Light cured RMGIC was used in the present study, as it is one of the excellent choices as a fluoride-releasing restorative material, which has been regarded to be more efficient than giomers and compomers in terms of sustained fluoride release and rechargeability.[25] Moreover, RMGIC has higher bond strength in comparison to that of conventional glass ionomer cement (GIC), as well as lower moisture sensitivity and solubility.[3]

Whereas NHRC was used in the study because of its easy handling and high mechanical properties suitable for use in high-stress-bearing areas. It is also characterized by its high polishability, and superior aesthetics owing to its nano-sized filler particles and high filler content.[26]

Universal adhesive was selected for bonding owing to its unique bonding properties, simplicity, and versatile modes of application. The acidic nature of its functional monomer, 10-MDP, gives it the potential to demineralize dental substrate, so it can be used in etch-and-rinse, self-etch, and selective-etch modes. This acidic nature also enables universal adhesive to achieve micromechanical retention in addition to chemical bonding between its functional monomer, and calcium in hydroxyapatite.[6] Universal adhesive was applied to CAD using self-etch technique. This was preferred over etch-and-rinse application mode to achieve shallower demineralization and eliminate the dryness step after rinsing of phosphoric acid that may lead to collapse of the collagen network, and inhibition of resin monomer penetration into the decalcified dentin.[27] In addition, phosphoric acid removes calcium ions from the dentin surface which may prevent ionic bonding between calcium and 10-MDP, decreasing the bond strength to dentin.[28]

Shear bond strength was used for testing bonding efficacy. This test is the most used method for bond strength testing as it is a quick, simple, and reliable method. It is not technique sensitive as it does not need further processing of specimens after the bonding procedure.[29]

According to the results of the study, RMGIC (Group I) showed significantly higher SBS to CAD compared to NHRC (Group II) with or without SDF pretreatment (Subgroup A or B). Moreover, SDF pretreatment did not significantly influence SBS of RMGIC to CAD. However, it significantly impaired SBS of NHRC to CAD. These results can be justified by differences in pH values of polyacrylic acid (pH=1.5-2), and the universal adhesive (pH=3.2) and bonding mechanisms of RMGIC and NHRC.[30,31]

The polyacrylic acid in the conditioning step produces partial demineralization of dentin surface, which allows the HEMA component to enhance surface wetting and microporosity, which increases surface area for chemical bonding between polyacrylic acid of RMGIC and calcium in hydroxyapatite in addition to micromechanical bonding.[30] Moreover, the positively-charged silver ions that results from SDF application on dentin surface can improve the chemical bonding with the negatively-charged carboxyl groups of RMGIC.[11]

The universal adhesive (All-Bond Universal, Bisco, Inc., Schaumburg, IL, USA) exhibits an ultra-mild pH value and utilizes high percentage of ethanol and water as solvents (30-60 wt.%), high concentration of HEMA and low concentration of MDP.[31] The less the acidity of the adhesive monomer, the less amount of smear layer eliminated and hence the less the demineralization of the superficial dentin which is important for monomer infiltration and achievement of a well impregnated hybrid zone.[32] Whereas the higher the percentage of the solvent, the longer its retention in the hybrid zone and the lower the ability of formation of polymers with high reticulation. This may decrease the degree of monomer conversion and the bond strength values as well.[31] Moreover, higher concentration of HEMA in relation to that of MDP may cause HEMA to compete with MDP by bonding to hydroxyapatite, thereby impairing chemical bond of MDP to dentin.[33] In addition, silver precipitate that results from SDF application on dentin surface can adversely affect micromechanical bonding and hybrid layer formation in dentin.[34]

As regard to the SBS of the tested restorative materials to CAD (Intergroup comparison), the results of the present study were in line with Koizumi et al.,[34] and Shetty et al.,[35]who showed that bond strength of GIC was not affected by pretreatment with SDF. However, other studies reported conflicting results, where Aldosari et al.,[36] found that RMGIC exhibited significantly lower bond strength to sound dentin than nano-ceramic resin composite in both SDF and control groups. While Haradwala et al.,[37] found no statistically significant difference in bond strength of conventional GIC and resin composite following SDF/KI surface treatment.

The reported differences in results of the forementioned studies could be explained by difference in either the substrate [35,34, 36], materials used[35, 34, 36, 37],conditioner [35]or adhesive generation and etching strategy[34, 36, 37.]

Regarding the influence of SDF application on SBS of the tested materials (Intragroup comparison), a number of studies supported the present findings and revealed that SDF application did not influence the bonding of RMGIC to dentin.[34, 38, 39] Studies also reported that SDF significantly compromised the bonding of resin composite to dentin.[35,40.]

On the other hand, other studies reported that SDF enhanced the bond strength of RMGIC to non-carious dentin compared to the control group. This finding came in contrast with the present study results which may be attributed to the different substrate used.[10,11.]

The study findings were also in contrast with Duker et al.,[13] and Firouzmandi et al.,[14]. The former study reported that SDF had no significant effect on bond strength of resin composite to dentin when compared to the control group. While the latter reported that SDF application increased the bond strength of resin composite in comparison to the control group. These differences may be caused by the etch-and-rinse strategy used for bonding composite resin in both studies.

Regarding the mode of failure, the study revealed no statistically significant difference between subgroups. However, mixed mode of failure was prevalent in RMGIC group in subgroup A (77.8%) and subgroup B (44.4%) whereas adhesive mode of failure was prevalent in NHRC group in subgroup A (44.4%) and subgroup B (55.6%). Mixed mode of failure can be correlated with higher bond strength of RMGIC whereas adhesive mode of failure may be a possible indicator of lower quality of the hybrid layer formed with NHRC using universal adhesives in self-etch mode.

These results agreed with previous studies which reported that mixed failure of GIC was more common and that adhesive failure of NHRC was more common in both SDF and control groups.[8,40.]

Aldosari et al.,[36] however, reported that adhesive mode of failure was dominant in both RMGIC and resin composite whether pretreated or not with SDF. While Haradwala et al.,[37] found that mixed mode of failure was prevalent in both groups. This contradiction could be attributed either to difference in substrate (sound premolars)[36] or in etching strategy (etch and rinse mode).[37]

The present study compared the effect of silver diamine fluoride on shear bond strength of two commonly used restorative materials, RMGIC and NHRC, when applied to natural CAD. Laboratory testing of these materials could give an insight of their clinical performance.

In addition, the study applied strict measures to ensure maximum level of standardization such as controlled application protocol for the used materials that was performed by a single operator.

However, some points must be taken into consideration. For example, the in vitro nature of the study does not exactly mimic the oral environmental conditions.

The use of natural CAD presented several difficulties as a substrate due to the great variability among carious lesions in size, depth, and shape. In addition, evaluation of the endpoint of dentin caries excavation was subjective although this step was performed by a single well-trained study-independent operator.

Another limitation is that shear bond strength testing has limited generalizability to the clinical success and longevity of restorations. Ideally, the longevity of restorations should be tested clinically.

The findings of this study rejected the null hypothesis in which SDF detrimentally affected SBS of NHRC while having no significant effect on RMGI. In addition to the significant difference between RMGIC and NHRC after SDF application.

Conclusion

Within the limitations of the present study, the following conclusions could be drawn:

SDF seems to interfere with bonding of nanohybrid resin composite to caries affected dentin. On the other hand, it seems not to interfere with bonding of resin-modified glass ionomer cement.

Data availability

The data of this study are available on request from the corresponding author.

Ethics approval and consent to participate

All study procedures were carried out according to the guidelines of Declaration of Helsinki, and the study protocol was registered and approved by Faculty of Dentistry, Ain Shams University, Research Ethics Committee (No: FDASU-RECEM122003). Informed consent was signed by all legal guardians to use their children extracted deciduous molars for study purposes. Being potentially infectious material, these teeth were disposed at the end of the study in medical waste container to be sent for incineration.

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Competing interests

The authors declare no competing interests.

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