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Effect of Silver Diamine Fluoride on Microtensile Bond Strength to Dentin

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Clinical Relevance

Silver diamine fluoride (SDF), a caries arresting and preventing agent, does not adversely affect the bond strength of resin composite to non-carious dentin. As the evidence grows to support the role of SDF in caries management, its role in operative dentistry will also likely grow.

SUMMARY

The aim of this *in vitro* study was to investigate the effect of the cariostatic and preventive agent silver diamine fluoride (SDF) on the microtensile bond strength of resin composite to dentin. Forty-two caries-free, extracted molars were flattened occlusally and apically using a diamond saw, and the exposed occlusal dentin was polished with a series of silicon carbide papers, all under water irrigation. The teeth were then randomly divided into six groups of seven teeth each that were treated as follows: 1) Peak SE self-etch bonding agent; 2) 12% SDF + Peak SE; 3) 38% SDF + Peak SE; 4) Peak LC etch-and-rinse bonding agent; 5) 12% SDF + Peak LC; and 6) 38% SDF + Peak LC. Four-millimeter buildups of Amelogen Plus were incrementally placed on all teeth; after a 24-hour storage period in distilled water, the specimens were sectioned perpendicular to the adhesive interface to produce beams of cross-sectional surface area measuring approximately 1 mm^2. The beams were placed on a microtensile testing machine, which utilized a single-speed pump motor and force gauge at 20 kgf × 0.01 second to record maximum tensile force before failure occurred. Two-way analysis of variance and post hoc Tukey tests were performed to compare the effects of the SDF on microtensile bond strength, with statistical significance set at α = 0.05. None of the experimental groups treated with different concentrations of SDF showed a significant difference in bond strength compared to the control groups, and there was no significant difference in bond strength between self-etch

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DOI: 10.2341/11-344-L

and etch-and-rinse groups. However, the effect of SDF on self-etch bonded teeth compared to etch-and-rinse bonded teeth was statistically significant (*p*=0.0363), specifically at the 12% concentration. SDF does not adversely affect the bond strength of resin composite to non-carious dentin.

INTRODUCTION

Dental caries continues to be a prevalent disease, even in developed nations.[1] Traditionally the discipline and practice of operative dentistry have been intimately linked with our understanding of the caries disease process. Indeed, it has been noted that the primary reason directing operative preparation and filling of a tooth is to repair destruction from a carious lesion.[2] In recent years, advancement in our understanding of the caries process[3] and the development of adhesive restorative materials have created the ability to practice with a minimally invasive dentistry philosophy in mind.[4]

Silver diamine fluoride [$Ag(NH_3)_2F$] (SDF) is a solution that has been used to arrest dental caries in countries throughout the world since the early 1970s, primarily in pediatric populations.[5] The components of SDF solution are found in Table 1. Mainly marketed in East Asia and South America, SDF currently does not have Food and Drug Administration approval in the United States—only recently has SDF attracted the attention of the National Institutes of Health.[6] Although its mechanism of action is not well understood, it has been proposed that SDF's chemical components contribute the following benefits: silver-salts stimulate dentin sclerosis/calcification, silver nitrate acts to kill bacteria, and fluoride aids in remineralization and prevention.[7]

The technique for SDF use is fairly simple; a small cotton pellet or brush is used to paint approximately one drop of SDF onto the cavitated carious lesions in a quadrant for at least one minute.[5,7] As long as they are not into the pulp or symptomatic, frank cavitated lesions are preferable because access to salivary minerals enhances remineralization.[5] After the lesions have been exposed to SDF for the determined period of time, the SDF is rinsed off.[7] The main adverse effect that is commonly reported is that the caries lesion is stained dark by the SDF.[7]

Recently published studies[8–10] report that when applied to cavitated caries lesions with no removal of decayed tooth structure, SDF has demonstrated arrest of caries with no further progression after two to three years. It is notable that the lesions in these studies were not filled after treatment with SDF; cavitations were left open. Restorations are generally indicated for cavitated lesions in part to seal out bacteria-harboring plaque and to improve the cleansability of the tooth.[11] Although *in vitro* studies[12,13] indicate that SDF treatment is compatible with glass ionomer restorations, to the authors' knowledge there are no published English-language studies that address the effect of SDF on the bond strength of resin composite to dentin. This *in vitro* study aimed to test the following null hypotheses: 1) SDF has no effect on the bond strength of composite resin to dentin; and 2) the type of adhesive, etch-and-rinse vs self-etch, does not affect the adhesion of composite resin to dentin in teeth treated with SDF.

MATERIALS AND METHODS

Forty-two noncarious, extracted molars were collected according to human subjects' regulations at the University of Texas Health Science Center in Houston, TX (USA) and were stored in 0.9% sodium chloride/0.2% sodium azide solution. Occlusal enamel was ground flat using a model trimmer (Model 3C 1/2HP, Whip Mix, Louisville, KY, USA) under running water, then abraded and smoothed sequentially with 240-, 320-, and 600-grit silicon carbide (SiC) paper on a water-cooled lathe (Ecomet 6, Buehler, Evanston, IL, USA) to expose a flat dentin surface. Tooth roots were removed with a diamond bur and high-speed handpiece. Pulp chambers were cleaned with a large round bur and slow-speed handpiece as well as a spoon excavator; chambers were then filled with bonded resin composite to act as support.

The specimens were randomly divided into six groups of seven teeth each. Each group was further prepared as follows.

Group 1—Exposed flat dentin surface was treated with a self-etch bonding system (Peak SE, Ultradent, South Jordan, UT, USA), according to manufacturer's instructions.

Group 2—Exposed flat dentin surface was treated with 12% SDF solution (Ancarie 12% Cariostatico, Maquira Dental Products, Maringa, PR, Brazil) for three minutes, followed by a rinse for 30 seconds with distilled water.[9] Then the dentin surface was treated with the same self-etch bonding system used in group 1.

Group 3—Exposed flat dentin surface was treated with 38% SDF solution (Saforide, Toyo Seiyaku Kasei Ltd, Osaka, Japan) for three minutes, followed

Table 1: *Manufacturer and Composition of Silver Diamine Fluoride (SDF) Solutions[a] and Adhesives[b]*

Agent	Composition
Ancarie 12% Cariostatico[a] (Maquira Dental Products, Maringa, PR, Brazil)	Ammonium hydroxide, silver nitrate, hydrofluoric acid, water
Saforide[a] (Toyo Seiyaku Kasei Ltd, Osaka, Japan)	Ammonium hydroxide, silver nitrate, hydrofluoric acid, water
Peak SE™[b]	
Primer	Bis-GMA, HEMA, ethanol, methacrylic acid, water
Bond	Bis-GMA, HEMA, ethanol, methacrylic acid, silica filler
(Ultradent, South Jordan, UT, USA)	
Peak LC™[b]	
Etch	35% Phosphoric acid
Primer	Bis-GMA, HEMA, ethanol, methacrylic acid, water
Bond	Bis-GMA, HEMA, ethanol, methacrylic acid, silica filler
(Ultradent, South Jordan, UT, USA)	

Abbreviations: Bis-GMA, bisphenol A diglycidyl ether dimethacrylate; HEMA, 2-hydroxyethyl methacrylate.

by a rinse for 30 seconds with distilled water. Then the dentin surface was treated with the same self-etch bonding system used in group 1.

Group 4—Exposed flat dentin surface was treated with an etch-and-rinse bonding system (Peak LC, Ultradent), according to manufacturer's instructions.

Group 5—Exposed flat dentin surface was treated with 12% SDF solution (Ancarie 12% Cariostatico, Maquira Dental Products) for three minutes, followed by a rinse for 30 seconds with distilled water. Then the dentin surface was treated with the same etch-and-rinse bonding system used in group 4.

Group 6—Exposed flat dentin surface was treated with 38% SDF solution (Saforide, Toyo Seiyaku Kasei Ltd) for three minutes, followed by a rinse for 30 seconds with distilled water. Then the dentin surface was treated with the same etch-and-rinse bonding system used in group 4.

Following treatment with respective adhesives (according to manufacturer instructions), 4-mm-thick buildups of microhybrid composite (Amelogen Plus, Ultradent) were placed, with increments limited to 1 mm. Curing was accomplished with a halogen curing light (Optilux 501, Kerry, Danbury, CT, USA), which was verified to have a light output of 600 mW/cm^2 throughout the study, as indicated by the unit's radiometer.

After storage in distilled water for 24 hours at 37°C, the restored specimens were sectioned occluso-gingivally into serial slabs approximately 1.0 mm thick by a slow-speed water-cooled diamond saw (Isomet 11–1180, Buehler). Each slab was then sectioned into composite/tooth structure beams measuring approximately 1.0 $\times$ 1.0 mm in cross section by the same slow-speed water-cooled diamond saw. Ten to 15 beams were yielded from each restored specimen; seven beams from each specimen were chosen at random for testing, for a total of 49 beams for each test group. After storage in distilled water for 24 hours at 37°C, the bonded surface area of each beam was calculated using measurements taken by a digital caliper (Absolute Digimatic, Mitutoyo Corporation, Kawasaki, Kanagawa, Japan). The ends of the beams were affixed to the test block of a microtensile testing machine (BISCO, Schaumburg, IL, USA) with cyanoacrylate glue (Zapit, Dental Ventures of America, Corona, CA, USA). The microtensile testing machine utilized a single-speed pump motor and force gauge at 20 kgf $\times$ 0.01 second to record maximum tensile force before failure occurred; force gauge readings in kgf were converted to MPa using the following equation: 1 kgf/$_{mm}{}^2$ = 9.80665 MPa. The type of failure was observed and recorded as adhesive, cohesive in dentin, cohesive in resin, or mixed.

Although seven beams per tooth were tested for microtensile strength, multiple beams derived from the same tooth may not be considered independent

Table 2: *Resin/Dentin Microtensile Bond Strengths in MPa (Standard Deviation [SD])*[a]

Group	n, beams	Bond Strengths[b]	a	cd	cr	m
1: Control with Peak SE	49	32.96 (6.72) A,C	28.6	0.0	69.4	2.0
2: 12% SDF with Peak SE	49	23.99 (8.04) A,*	59.2	0.0	24.5	16.3
3: 38% SDF with Peak SE	49	32.73 (10.54) A,D	61.2	0.0	36.7	2.0
4: Control with Peak LC	49	30.81 (2.55) B,C	61.2	2.0	32.7	4.1
5: 12% SDF with Peak LC	49	39.00 (11.46) B,*	36.7	8.2	32.7	22.4
6: 38% SDF with Peak LC	49	34.41 (10.48) B,D	53.1	0.0	36.7	10.2

Abbreviation: SDF, silver diamine fluoride.
[a] *Mean (SD) microtensile bond strength values (MPa) obtained on tested groups (n=7 teeth) and distribution of failure modes (%) (a = adhesive, cd = cohesive in dentin, cr = cohesive in composite resin, m = mixed).*
[b] *Mean bond strengths with same letters are not significantly different (α=0.05). Mean bond strengths indicated with an asterisk (*) are significantly different (α=0.05). Statistical analysis with two-way ANOVA and post hoc Tukey tests (α=0.05).*

samples. Thus, the mean of the seven beams from each tooth was used as the value for that tooth, resulting in a sample size of seven per group. At a significance level of 5%, and assuming a hypothesized effect size no less than 1.25, a sample size of seven could provide a statistical power of 90%. Two-way analysis of variance (ANOVA) and post hoc Tukey tests were performed to compare the effects of the SDF on bond strengths, with statistical significance set at $\alpha = 0.05$. The statistical unit was teeth, not beams.

RESULTS

The study used a total of 42 teeth, with the bond strength for each tooth being determined by the average bond strength of seven beams from each tooth. The means and standard deviations for each tooth are shown in Table 2. None of the experimental groups treated with different concentrations of SDF showed a significant difference in bond strength compared to the control groups, and there was no significant difference in bond strength between self-etch and etch-and-rinse groups. However, the effect of SDF on self-etch bonding compared to etch-and-rinse bonding was statistically significant (p=0.0363). There was no significant difference between the self-etch and etch-and-rinse bond strengths for the control groups (no SDF) or the groups treated with 38% SDF solution, but bond strengths were significantly lower for self-etch vs etch-and-rinse when using a 12% SDF solution. In all groups, the most common failure types were adhesive and/or cohesive in resin. Cohesive in resin failures indicate that since the adhesive interface was still intact, actual bond strengths were likely higher than reported.

DISCUSSION

This study sought first to examine if pretreating noncarious dentin with SDF adversely affects the bond strength of composite resin to dentin. As noted earlier, the results from this study indicate no significant difference in bond strengths between control groups (no pretreatment with SDF) and experimental groups (pretreatment with 12% or 38% SDF). Based on the results of this study, the null hypothesis that SDF has no effect on the bond strength of composite resin to dentin is affirmed. The clinical implication of these findings is that if SDF is used to arrest and/or prevent dental caries in a tooth, bond strength to the noncarious dentin of that tooth will be unaffected.

Secondarily, this study sought to examine if self-etch or etch-and-rinse adhesives were preferable for dentin pretreated with SDF. The results from this study indicate that overall there was no significant difference in bond strength between self-etch or etch-and-rinse groups. However, pretreatment with 12% SDF resulted in significantly lower bond strengths for self-etch groups than for etch-and-rinse groups.

This finding is difficult to reconcile, since pretreatment with 38% SDF did not result in significantly different bond strengths for self-etch vs etch-and-rinse groups. The authors offer the following twofold explanation. The significant difference in bond strength noted with pretreatment with 12% SDF might be related to one of the components of SDF solution—hydrofluoric acid.[14] It has been noted[15] that hydrofluoric acid generally has a detrimental effect on resin bond strength to dentin. Etching with phosphoric acid after exposure to hydrofluoric acid tends to result in higher bond strengths.[15] This phenomenon seems consistent with the finding in this study that etch-and-rinse adhesive outperforms self-etch adhesive when the dentin is pretreated with 12% SDF.

Although etch-and-rinse adhesive in this study also resulted in higher bond strength than did self-etch adhesive when the pretreatment was with 38% SDF, the difference was not statistically significant. This may be due to differences in manufacturing techniques. Saforide is produced and marketed in Japan, and it is only available in 38% solution. Ancarie Cariostatico is produced and marketed in South America, and it is available in 12% or 30% solution. Only 38% Saforide and 12% Ancarie Cariostatico were available to the authors for this study, so it was not possible to compare differing concentrations of SDF made by the same manufacturer. Based on the results of this study, with its limitations, the null hypothesis that the type of adhesive does not affect the adhesion of composite resin to dentin in teeth treated with SDF is rejected. In light of this, it may be preferable to utilize an etch-and-rinse adhesive following pretreatment of dentin with SDF.

The traditional approach to the operative management of cavitated carious lesions is to mechanically remove soft, bacteria-rich, infected dentin prior to filling the cavity with a suitable restorative material[11]; based on the current evidence, this is still a reasonable perspective because highly infected dentin is not remineralizable.[3] However, there is evidence to indicate that removal of soft infected dentin may not be necessary.[16] For example, a landmark 10-year clinical study[17] of ultraconservative restorations indicated that if a well-sealed adhesive resin restoration is placed over infected dentin, the result is an arrested lesion. Furthermore, it has been noted[18] that if a well-sealed resin restoration is placed over infected dentin in a cavitated lesion, bacterial count and activity are reduced over time. From a biological perspective, these findings present an intriguing challenge to the need to remove infected dentin prior to restoration. However, the discussion of need for or extent of caries excavation seems likely to continue, as it has been recently reported[19] that underlying soft infected dentin may compromise the fracture strength of a composite resin filling.

In contrast to bacteria-rich, infected dentin, affected dentin is relatively low in bacterial count and structurally maintains enough collagen to remineralize[3]—it does not need to be removed prior to restorative filling. Similarly, lesions that have arrested do not need to be excavated.[11] Dentin caries that is either affected or arrested tends to demonstrate lower bacterial activity than does infected dentin—What if the active caries process found in infected dentin could be arrested on contact by the dental practitioner? And would there still be rationale for excavation, especially considering the evidence that caries does not progress under sealed restorations?[16–18] Recent clinical studies[8–10] indicate that SDF might be able to address at least the first question, with regard to arresting dental caries.

Based upon the success that SDF has demonstrated *in vivo* in arresting and preventing caries,[8–10] as well as its apparent initial bonding compatibility *in vitro* with glass ionomers[12,13] and composite resins, SDF may potentially find an important niche in the operative dentist's arsenal. The existing clinical studies[8–10] already seem to indicate the usefulness of SDF in a public health setting. With regard to the biological management of caries, SDF seems to offer the ability to chemically control or eliminate the spread of the disease in a frank cavity. This property may reduce the need to use a handpiece or hand instrument to mechanically remove highly infected dentin—the potential to prepare and place a filling without the "drill" would be appealing to both the conservative-minded dentist and the anxious-minded patient.[20] Indeed, evidence indicating that well-sealed margins are the key to halting the progress of caries[16–18] seems to lend support to the use of SDF for this purpose, which itself adds a preventive effect *via* its fluoride content.[7] At least one case report[21] in the literature details placing a glass ionomer restoration over a SDF-treated lesion; in this case, caries is removed from the dentino-enamel junction but left pulpally.

Despite the prospects that SDF offers for cariology and minimally invasive dentistry, questions still remain—the authors can identify at least the following questions that would benefit from further investigation:

- The actual mechanism of action of SDF on a carious lesion is still not well understood[6,7]—What type of interactions occur at a molecular level that lead to the observed clinical results? One *in vitro* study[22] indicates a strong antibacterial effect of SDF, as it inhibited *Streptococcus mutans* biofilm formation on demineralized dentin.

- What is the nature of the carious dentin after treatment with SDF? Although clinical studies[8–10] have reported that SDF arrests caries, is the tooth structure more akin to affected or sclerotic dentin in physical properties (ie, hardness), or is it simply softened dentin minus active infection? Chu and Lo[23] reported that superficial dentin of primary teeth may experience an increase in microhardness, but deeper dentin appears to be less affected. This may have implications for the longevity of whatever restoration is placed over the lesion.[19]
- Does SDF exert a cytotoxic effect on pulpal cells? SDF is not known to produce pulpal damage[24]; Gotjamanos[25] reported a favorable response in primary teeth treated with SDF, including the formation of reparative dentin. The thickness of dentin required to protect the pulp chamber in SDF-treated teeth is still unknown.
- The final question is an esthetic question. It known that SDF stains the caries lesion with dark coloration[7,24]; furthermore, our study found that noncarious dentin treated with SDF will also stain after the resin adhesive is light-cured—this phenomenon occurred in both self-etch and etch-and-rinse teeth. The dark staining, whether in carious or noncarious dentin, may create an esthetic challenge when the restorative material is composite. An Australian group[12,21,22] has been investigating the use of potassium iodide to mask the staining with a white precipitate; the long-term effect of this treatment, as well as its interaction with various restorative materials, has yet to been determined.

CONCLUSION

To conclude, SDF seems to present exciting possibilities for the minimally invasive treatment and prevention of dental caries. Although this *in vitro* study indicates the bonding compatibility of SDF-treated noncarious dentin with a resin composite filling, further investigation will be beneficial in determining the role of SDF in operative dentistry.

Acknowledgements

The authors would like to acknowledge Drs Jarvis Chan and Tilly Peters for their technical assistance in preparing this article.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 23 January 2012)

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