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Bond Strength of GIC, RMGI, and Resin Composite to Silver Diamine Fluoride Treated Artificial Carious Dentin

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Bond Strength of Various Restorative Materials to Silver Diamine Fluoride Treated Artificial Carious Dentin

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Bond Strength of GIC, RMGI, and Resin Composite to Silver Diamine Fluoride Treated Artificial Carious Dentin

Carolynn Vuong

Abstract

Purpose: The purpose of this study was to evaluate the shear bond strength (SBS) of various restorative materials – pure glass ionomer cement (GIC), resin-modified glass ionomer (RMGI), and resin composite to artificial carious dentin treated with silver diamine fluoride (SDF).

Methods: Extracted human permanent molars were sectioned and put in demineralizing solution to create artificial carious lesions and subsequently treated with SDF and exposed to human saliva. Various restorative materials, consisting of GIC, RMGI, and composite, were placed and analyzed for differences in shear bond strengths. Statistical analysis was performed using ANOVA and a post-hoc Tukey HSD test ($P<0.05$).

Results: ANOVA revealed statistically significant differences in the mean shear bond strengths (mean ± SD MPa) of the three groups (GIC, RMGI, composite) ($P=0.020$). GIC exhibited the highest shear bond strengths in MPa (11.6 ± 4.1) followed by composite (9.2 ± 3.7) and RMGI (7.7 ± 3.8). Statistically significant differences were found between mean bond strengths of GIC and RMGI ($P=0.016$). Failure mode analysis revealed 100% adhesive failures in the RMGI and Composite groups. GIC exhibited 53% adhesive and 47% mixed failure modes.

Conclusions: Glass ionomer cement shows higher shear bond strength to SDF-treated artificial carious dentin compared to composite and resin-modified glass ionomer.

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List of Abbreviations

ART = Atraumatic Restorative Treatment

ECC = Early Childhood Caries

GIC = Glass Ionomer Cement

RMGI = Resin-Modified Glass Ionomer

SBS = Shear Bond Strength

SDF = Silver Diamine Fluoride

SMART = Silver-Modified Atraumatic Restorative Technique

Introduction

Dental caries is the most common chronic disease of childhood and continues to be a significant public health concern. In the United States, the prevalence of total caries (untreated and treated) was 45.8 percent among youth aged 2-19 years, with the prevalence of untreated caries at 13 percent.[1] Early childhood caries (**ECC**) is defined as the presence of one or more decayed, missing (due to caries), or filled tooth surfaces in a child under six years of age.[2] Severe ECC is commonly first noted in the primary maxillary incisors, generally due to prolonged use and/or inappropriate contents of the nursing bottle. However, sites of carious lesions can spread rapidly to posterior teeth as the child develops due to the bacterially-mediated infectious nature of ECC spreading via vertical and horizontal transmission through human reservoirs. Early diagnosis and treatment of ECC is crucial in preventing pain and infection that may develop with untreated disease. Because conventional treatment for ECC may be difficult or impossible due to age, behavior, cost, or other variables, alternative treatments have been developed to eliminate or substantially reduce the progression of disease.

Silver diammine fluoride, or silver diamine fluoride (**SDF**), as it is most commonly cited in literature, is a topical medicament used in dentistry to arrest and prevent dental caries across the age spectrum. SDF exists as a colorless solution containing silver, ammonia, and fluoride that arrests caries.[3] Versions of silver nitrate (AgNO3) and fluoride varnish (NaF) have been used in various countries around the world. In Japan, for example, silver-containing medicaments have been used for decades as treatment for dental caries. Aqueous 38 percent SDF became approved by the Food and Drug

Administration in August 2014 as a device for treatment in reducing tooth sensitivity.[4] In its off-label use, SDF has also been proven to arrest caries and remineralize tooth structure as well as act as an antimicrobial and resist biofilm formation.[5] In pediatric dentistry, topical application of SDF has been a mainstay of non-invasive treatment, and clinical studies have demonstrated the efficacy of SDF in arresting dentin caries in primary teeth.[6] Due to its ease of application and its low cost, SDF has gained popularity as a first-line treatment for ECC in young children.[7]

The concept of minimal (or minimum) intervention dentistry has become an increasingly popular alternative therapy in the context of treatment of dental caries, shifting to a more prevention-focused paradigm.[8] With advances in diagnostics, technology, operative techniques, and biomaterials, dentistry has evolved from a surgical approach to one that focuses more on evidence-based, preventive, and less invasive care.

As a form of minimal intervention dentistry, the atraumatic restorative treatment (**ART**) approach was developed in the 1980s to combat the global health problem of untreated caries and has been endorsed by the World Health Organization (WHO) and International Association of Dental Research (IADR) as an appropriate restoration and prevention option for caries in areas with limited access to dental treatment.[9] The ART concept focuses on treating dental caries by stopping its further progression typically without the use of a dental handpiece. Treatment involves the removal of soft carious tooth structure with hand instruments followed by restoration of the cavity and sealing any remaining at-risk pits and fissures, commonly using glass ionomer cement (**GIC**).

While the ART approach originally was aimed for use in rural communities and developing countries usually with limited access to conventional dental treatment, ART has become a common alternative treatment choice in dentistry, especially for patients who cannot tolerate local anesthesia, the dental drill, or longer treatment times. In the primary dentition, studies have shown that Class I ART glass-ionomer restorations have no statistically significant differences in survival rates compared to conventional resin-based composites after 24 months, and a meta-analysis has demonstrated high survival rates in both primary and permanent tooth single-surface lesions.[10,11] Overall, the ART procedure is largely pain-free and readily accepted by patients, making it an attractive treatment choice for the management of ECC.

With the introduction of SDF in the era of ART, the silver-modified atraumatic restorative technique (SMART) was developed.[12] SMART involves placing SDF on carious tooth structure either with or without caries removal by hand instruments and subsequently restoring and sealing off the carious lesion with an ART restoration. The SMART procedure combines advantages of the antibacterial and remineralizing characteristics of SDF to arrest caries with the atraumatic, minimally invasive, sealing, and preventive effects of ART.

While many studies have shown the safety, efficacy, and caries-arresting properties of SDF, fewer studies have examined the bond strength to SDF-treated carious dentin. A review of the literature reveals a mixed consensus on bond strength following SDF application. A systematic review and meta-analysis examining the influence of SDF on the in vitro bonding performance of adhesive materials to SDF found no significant difference between SDF-treated and untreated dentin controls to GIC.[13] The same review also found that SDF has an overall effect that interferes with the bonding of adhesive systems (self-etching and etch-and-rinse systems) when applied immediately after SDF placement and not rinsed; although, when SDF is rinsed, the adverse effect is mitigated. The meta-analysis mainly included studies to sound dentin, with only a few studies having investigated carious dentin. However, in clinical use, SDF is used predominantly to treat carious lesions, and therefore requires study of bonding strengths of materials applied to SDF under these conditions. Moreover, carious and demineralized dentin incorporates much more silver precipitate compared to non-carious, sound dentin which may influence bond strength.[14] Most studies also analyzed placement of GIC or an adhesive material only immediately after SDF treatment, which may not fully reflect clinical use. Despite this, Ng et al. showed that allowing SDF to set for one week prior to placement of a GIC restoration improved shear bond strength to carious dentin.[15] In addition, the authors found that the use of conditioner before GIC placement significantly improved bond strength. Puwanawiroj et al. examined microtensile bond strength of GIC to SDF-treated carious primary molar dentin also following a delay after SDF treatment and found no significant differences in bond strength compared to sound controls.[16]

Altogether, these findings point to a possibility that SDF treatment on carious lesions can affect the bond strength of various materials. With the growing and widespread use of SDF as a preventive and caries-arresting medicament, many dentists are faced with choices in restoring these treated lesions. This study aims to study the shear bond strengths (**SBS**) of glass ionomer cement (**GIC**), resin-modified glass ionomer (**RMGI**), and resin-based composite to SDF-treated artificial carious dentin.

Materials and Methods

Study sample

A total of fifty-one extracted, non-carious human permanent molars obtained from patients at University of California, San Francisco, School of Dentistry were used for this study. The teeth were extracted for clinical reasons only without personal identifiers, exempting this study from the need for human subject board review. All extracted molars were gamma irradiated for 24 hours for sterilization. A flowchart of the study design is shown in Figure 1.

Specimen preparation

The teeth were sectioned along the occlusal plane to expose dentin just gingival to the dentino-enamel junction and polished to 400-grit with silicone carbide sandpaper. The samples were then stored in deionized water for one week. Sectioned molars were coated with Revlon #270 nail varnish to expose a 3mm x 3mm window of dentin. Artificial carious lesions were created by exposing samples to demineralizing solution of acetic acid (66 h on a rocker at medium speed in 0.05 M acetate buffer containing 2.2 mM calcium and phosphate at pH 5.0). The samples were then mounted in Ultradent specimen molds (UltraTester Bonding Clamp and Bonding Mold Inserts, Ultradent Products, Inc., South Jordan, Utah, USA). Advantage Arrest Silver Diamine Fluoride

38% (Elevate Oral Care LLC, West Palm Beach, Florida, USA) was applied with a microbrush for 30 seconds and excess removed with a cotton roll and rinsed with water. Samples were stored in 100% humidity at 37˚C for a total of one week. After the first six days, fresh, unstimulated human saliva was collected from one donor (CV) who was instructed to brush teeth and not eat for three hours, and a thin layer of saliva was applied to the samples to mimic salivary pellicle formation. The samples were prepared for bonding 24 hours later.

Samples were then divided randomly into three groups (n=17 in each group):

1. Pure glass ionomer cement - GC Fuji IX GP capsules (GC America Inc., Alsip, Illinois, USA)
2. Resin-modified glass ionomer - GC Fuji II LC capsules (GC America Inc., Alsip, Illinois, USA)
3. Resin-based composite - Heliomolar (Ivoclar Vivadent AG, Schaan, Liechtenstein)

After storage, all samples were lightly rinsed and dried for 5 seconds. Samples in group one (GIC) and two (RMGI) were exposed to GC Cavity Conditioner (GC America Inc., Alsip, Illinois, USA) (20% polyacrylic acid and 3% aluminum chloride hexahydrate) for 10 seconds and rinsed thoroughly with water. For samples in group one, high viscosity GIC capsules (GC Fuji IX) were activated and triturated for 10 seconds and applied with a plastic instrument using UltraTester shear bond testing clamps and molds (UltraTester Bonding Clamp and Bonding Mold Inserts, Ultradent Products, Inc., South Jordan, Utah, USA). For samples in group two, RMGI capsules (GC Fuji II LC) were activated and triturated for 10 seconds and applied with a plastic instrument using UltraTester shear bond testing clamps and molds. Group two samples were then light cured for 20 seconds using a 420-480 nm wavelength LED standard curing light (Satelec, Acteon Group, Merignac, France). Samples in group three were exposed to Ultra-Etch 35% phosphoric acid (Ultradent Products Inc, South Jordan, Utah, USA) for 20 seconds, rinsed thoroughly, and air dried. OptiBond SoloPlus (Kerr Corporation, Orange, California, USA) was applied with a microbrush for 15 seconds and air thinned for three seconds. The samples were then light cured for 20 seconds. Heliomolar composite (Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied with a plastic instrument using UltraTester shear bond testing clamps and molds. Group three samples were then light cured for 20 seconds. Samples in all three groups were then incubated at 100% humidity at 37˚C for 24 hours prior to shear bond strength testing.

Microshear bond strength test and failure mode analysis

The bonded interface of each sample was subjected to a shear bond strength test using a universal testing machine (UltraTester Bond Strength Testing Machine, Ultradent Products, Inc., South Jordan, Utah, USA). Shear bond strength in MPa was calculated by dividing the peak load at failure with the specimen surface area.

Mode of failure for each sample was assessed by examining fractured surfaces under light microscopy at X20 magnification by one observer (CV) and classified failure modes as adhesive (failure between the restorative material and the dentin surface), cohesive (failure within the restorative material), or mixed (combination of partial cohesive and partial adhesive). Examples of failure modes are shown in Figure 2.

Statistical analysis

A sample size of 17 was chosen per group. A Kolmogorov-Smirnov test was run and showed that the data was normally distributed. Statistical analysis was performed using one-way analysis of variance (ANOVA) and post hoc Tukey HSD comparisons with SPSS statistical software (IBM Corp. Released 2017. IBM SPSS Statistics for Macintosh, Version 25.0. Armonk, NY, USA). The α-type error was set at 0.05 for all statistical analyses.

Results

The results of the one-way ANOVA (Table 1) showed that the restorative material (GIC, RMGI, composite) had a significant effect on shear bond strength values. ($P=0.020$, $P<0.05$). GIC showed higher bond strength values compared to those of RMGI and composite. GIC (n=17) had a mean SBS of 11.6 MPa (median 10.6, SD=4.1). GIC bond strength values in this study fell within a similar range of the GIC samples in Ng et al. upon which this thesis is based. RMGI (n=17) had a mean SBS of 7.7 (median 5.5, SD=3.9). Composite (n=17) had a mean SBS of 9.2 (median 8.9, SD=3.7). Results of the post hoc comparisons with the Tukey HSD test are shown in Table 2. The difference between the mean shear bond strength values of GIC vs RMGI was statistically significant ($P=0.016$, $P<0.05$). The differences between GIC vs composite and RMGI vs composite were not statistically significant (P>0.05) (Table 2). Results are summarized in Tables 1 and 2.

Results of failure mode fractographic analysis under SEM are shown in Table 3. All specimens in the RMGI group and composite group displayed adhesive failures (100%). Specimens in the GIC group displayed both adhesive (53%) and mixed (47%) failure modes. No complete cohesive failure within the restorative material was seen in any group.

Discussion

In this study, we assessed the shear bond strength of various restorative materials to SDF-treated artificial carious dentin. Several studies have studied the bond strength of restorative materials to SDF-treated sound dentin and the bond strength of GIC to SDF-treated carious dentin. Comparing the bond strengths between these various restorative materials gives the clinician evidence-based guidance on how to restore an area that may involve carious dentin previously treated with SDF. This study found that GIC demonstrated the highest shear bond strength values (11.6 ± 4.1), followed by composite (9.2 ± 3.7) and RMGI (7.7 ± 3.9). GIC demonstrated higher shear bond strength values compared to RMGI at a significant level (P=0.016, P<0.05) and higher but not statistically significant shear bond strengths compared to composite (P=0.189). Multiple studies have found the trend of relatively higher bond strength values of GIC to SDF-treated dentin compared to sound dentin controls but not at a significant level (P>0.05).[16–18]

The higher bond strength values of GIC compared to RMGI and composite to SDF-treated artificial carious dentin is in contrast to their respective bond strengths to sound dentin, where composite exhibits the highest bond strength, followed by RMGI, and GIC with the lowest bond strength.[19] The bonding mechanism of GIC relies mainly on chemical bonds between free negatively-charged hydrophilic carboxyl groups in GIC to the positively-charged calcium of hydroxyapatite in dentin.[20] In contrast, the bonding mechanism of resin-based composite relies on micromechanical retention, forming hybrid layers within dentin collagens and resin tags within dentinal tubules.[21] The bonding of RMGI is a hybrid of the two, setting with both chemical and micromechanical polymerization reactions varying with time of light cure activation.[22] These differences in bonding mechanisms may explain the varying bond strength values in this study.

Application of SDF to dentin results in remineralization and incorporation of various ions, especially in previously demineralized, carious dentin. Mei et al. used micro computed technology to show that SDF application to carious dentin resulted in a highly remineralized zone rich in calcium and phosphate ions.[23] Willershausen et al. found that SDF formed a film on the dentin surface and deposits were detected in some dentinal tubules.[24] Rossi et al. took SEM cross section images of dentin tubules of sound dentin vs SDF-treated carious dentin of primary teeth and showed that SDF-treated lesions displayed more hypermineralized intertubular dentin and partially blocked dentin tubules with silver precipitate.[14] With RMGI and composite relying on micromechanical bonding within dentinal cutubles and collagen matrix, these restorative materials may exhibit decreased bond strengths to SDF-treated carious dentin as the dentinal tubules and collagen network become partially blocked or plugged. Thus, the open dentinal tubules and collagen matrix upon which micromechanical bonding with resin tags and hybrid layers relies is impossible if a blockage is present. This can account for the lower bond strength values of RMGI and composite seen in this study. Conversely, GIC relies on chemical bonding and not micromechanical bonding. Furthermore, increased incorporation of positively-charged silver ions and silver deposits into SDF-treated carious dentin can lead to improved chemical bonding to the negatively-charged carboxyl groups of GIC, which may explain the higher shear bond strength values of GIC seen in this study.

Regarding modes of failure, all specimens in RMGI and composite groups displayed adhesive failures, while the GIC group was split between adhesive (53%) and mixed (47%). No specimens in this study exhibited only a cohesive mode of failure. The absolute adhesive failure mode of the restorative materials that rely more on micromechanical bonding (RMGI and composite) suggests that the adhesive interface may be impaired by the film and blocked tubules induced by SDF on carious dentin. The higher proportion of mixed failures in GIC may be due to stronger chemical bonds to the ions incorporated into SDF-treated carious dentin.

Li et al. analyzed SDF-treated carious dentin with quantitative backscattered electron scanning electron microscopy and found that silver particles could penetrate into dentinal tubules at depths up to 2490 μm (mean 744.7 ± 448.7 μm). Their EDX spectrum analysis also revealed that carbon, oxygen, phosphorus, chlorine, silver, and calcium were the main elements detected in the lesions treated with SDF.[25]

When considering clinical implications, our results suggest that if SDF has been used to treat a carious lesion, GIC may exhibit superior bond strengths over RMGI and composite. This may be due to silver precipitate from SDF penetrating into carious dentin and blocking dentin tubules, thereby impeding bond strength of materials that rely on micromechanical retention. It also may be due to increased chemical bonding of GIC to ions deposited from SDF incorporated into carious dentin.

Limitations and Future Studies

Limitations in this study include implicit differences with in vitro studies compared to clinical scenarios. The demineralized carious lesions were artificially created to provide consistent samples for bond strength testing whereas clinical carious lesions can vary widely. Furthermore, shear bond strength testing also has limited generalizability to the overall clinical success of restorations.

Another limitation involved the use of permanent molars over primary molars in this study. SMART restorations are primarily performed in primary teeth, and there are differences in structures of dentin between primary and permanent teeth. However, due to the need to section teeth to create flat dentin lesions, permanent teeth were chosen due to their availability and larger dentin surface area.

Future studies can involve *in vivo* studies comparing various restorative materials on SDF-treated dentin. Moreover, future research can be done comparing each restorative material to a sound dentin control.

Conclusion

Based on the results of this in vitro study of the adhesion of GIC, RMGI, and composite bonded to SDF-treated artificial carious dentin, the following conclusions can be made:

1. The shear bond strength of GIC bonded to SDF-treated artificial carious dentin was significantly higher than that of RMGI ($P=0.016$, $P<0.05$)
2. GIC showed higher mean shear bond strengths to SDF-treated artificial carious dentin compared to composite, but the result was not statistically significant ($P=0.189$).
3. Composite showed higher mean shear bond strengths to SDF-treated artificial carious dentin compared to RMGI, but the result was not statistically significant ($P=0.512$).
4. All samples exhibited adhesive failure except 47% of the GIC samples that exhibited mixed failures, showing that the adhesive bond between GIC and SDF-treated artificial carious dentin was stronger compared to RMGI and composite.

Figures

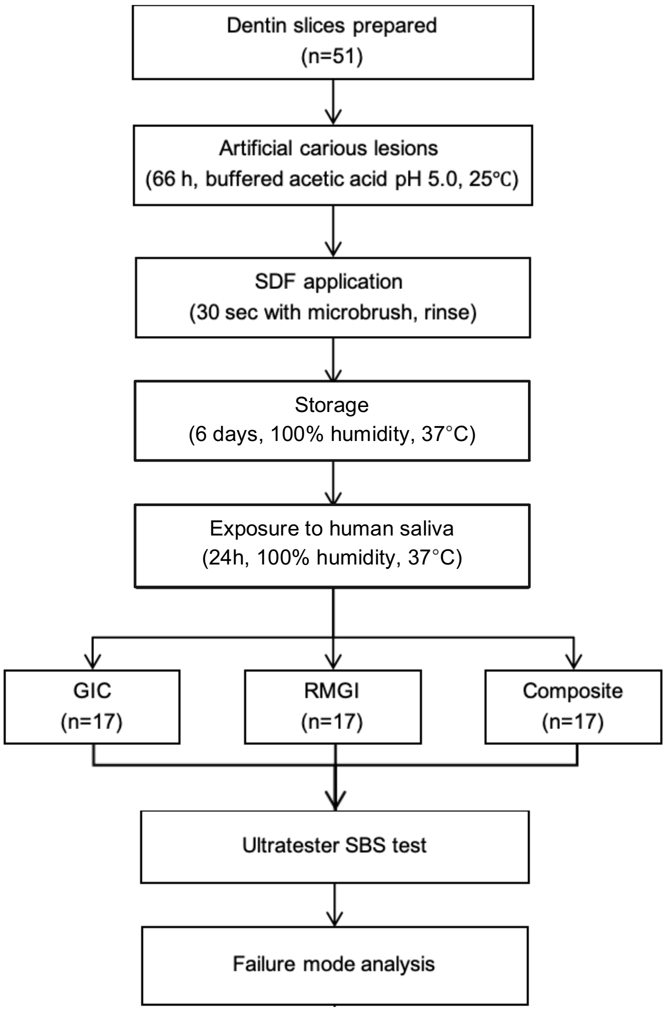

Figure 1. Flowchart of the study.

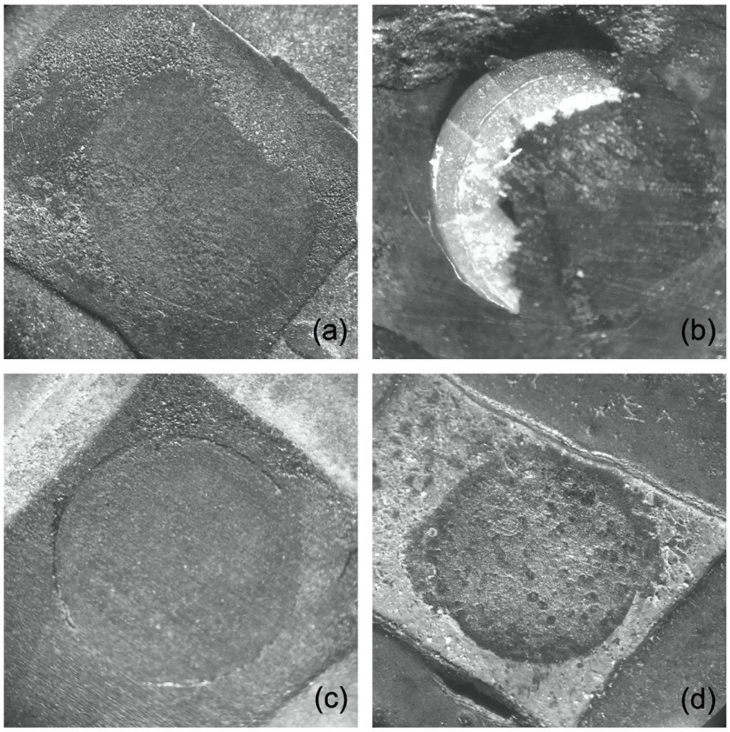

Figure 2. Fracture interfaces of shear bond strength test under scanning electron microscopy (20x). (a) GIC adhesive failure; (b) GIC mixed failure; (c) RMGI adhesive failure; (d) Composite adhesive failure.

Tables

Table 1. Shear Bond Strength Values of Restorative Material to SDF-treated Artificial Carious Dentin (MPa) and Analysis of Variance results.

Restorative Material	Sample Size	Mean (± SD)	Range
GIC*	10*	13.2 ± 3.4*	8.5-17.7*
GIC	17	11.6 ± 4.1	5.2-19.8
RMGI	17	7.7 ± 3.9	4.9-19.8
Composite	17	9.2 ± 3.7	5.1-17.3
Total	51	9.5 ± 4.1	

F-Ratio = 4.240
P = 0.020
SD = Standard deviation
P = Probability
*Shaded row includes data from Ng et al. upon which this thesis is based. Samples were prepared in the same manner except for exposure to human saliva.[15]

Table 2. Post Hoc Multiple Comparisons Tukey HSD.

Restorative Material	Compared to	Mean Difference	*P* (significance)	95% Confidence Interval
GIC	RMGI	*3.8353**	*0.016*	[0.622, 7.049]
	Composite	2.3588	0.189	[-0.855, 5.572]
RMGI	GIC	*-3.8353**	*0.016*	[-7.049, -0.622]
	Composite	-1.4765	0.512	[-4.690, 1.737]
Composite	GIC	-2.3588	0.189	[-5.572, 0.855]
	RMGI	1.4765	0.512	[-1.737, 4.690]

Std error = 1.3287
*The mean difference is significant at the 0.05 level.

Table 3. Failure Modes within Restorative Material.

	Adhesive	Cohesive	Mixed
GIC	9 (53%)	0	8 (47%)
RMGI	17 (100%)	0	0
Resin composite	17 (100%)	0	0

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