Flowable Glass Ionomer Cement Layer Bonding to Sound and Carious Primary Dentin

Tathiane Larissa Lenzi, DDS, MSc, PhD
Clarissa Calil Bonifácio, DDS, MSc, PhD
Marcelo Bönecker, DDS, MSc, PhD
W. Evert van Amerongen, DDS, MSc, PhD
Fernando Neves Nogueira, DDS, MSc, PhD
Daniela Prócida Raggio, DDS, MSc, PhD

ABSTRACT

Purpose: The purpose of this study was to evaluate the effect of a flowable glass ionomer cement (GIC) layer application on bond strength to sound (SD) and carious primary dentin (CD).
Methods: Flat dentin surfaces from primary molars were randomly assigned to 4 groups (N=5) according to substrate (SD or CD; pH-cycling for 14 days); and layers of GIC (1 layer/control [regular powder/liquid ratio] or 2 layers [first a flowable GIC layer and second a regular powder/liquid ratio layer of GIC]). After 24 hours of water storage, specimens were prepared to be evaluated with the microtensile test (1 mm/min). The fracture pattern was evaluated at 400X magnification (stereomicroscope).
Results: The bond strength to SD was higher than to CD when GIC was inserted in 2 layers (P=.02). No significant difference was observed between 1 or 2 layers of GIC insertion (P>.05). For all groups, adhesive/mixed fracture prevailed.
Conclusion: The effect of applying the flowable GIC layer on bond strength to dentin is dependent on substrate and results in an increase in adhesion for sound primary dentin. (J Dent Child 2013;80(1):20-4)
Received October 18, 2011; Last Revision January 12, 2012; Revision Accepted January 23, 2012.

KEYWORDS: ATRAUMATIC RESTORATIVE TREATMENT, BOND STRENGTH, GLASS IONOMER CEMENT, MICROTENSILE, DENTIN

Ultraconservative treatment approaches are recommended for treating cavitated dentin lesions.[1,2] Atraumatic Restorative Treatment (ART) is one of the existing possible treatment approaches. This technique is based on partial caries removal (using only hand instruments), filling the dental cavity, and sealing the adjacent pits and fissures with high viscosity glass ionomer cement (GIC), without requiring energy sources.[3]

GIC is the material of choice for ART because of its physical and chemical properties, such as fluoride release and uptake, biocompatibility, bonding to enamel and dentin, and chemical set reaction.[4] High viscosity GICs, which have better mechanical properties than conventional GICs, were developed specifically for this approach by increasing the powder/liquid ratio.[5,6] Nevertheless, this material presents a viscous consistency, with complex handling and insertion characteristics. The difficulty in handling high viscosity GIC may result in inadequate adaptation to the tooth surface. Furthermore, cervical gaps and open margins may contribute to ART proximal restoration failures.[7-9]

Despite similar clinical behavior of high viscosity GICs and amalgam in single-surface restorations,[10-12] the performance of GICs in proximal ART restorations is

Dr. Lenzi is a PhD student, Dr. Bönecker is professor and Dr. Raggio is associate professor, all in the Department of Orthodontics and Pediatric Dentistry, and Dr. Nogueira is assistant professor, Department of Biomaterials and Oral Biology, all in the School of Dentistry, University of São Paulo, São Paulo, Brazil; and Dr. Bonifácio is assistant professor and Dr. Amerongen is associate professor, both in the Department of Conservative and Preventive Dentistry, Academic Centre for Dentistry Amsterdam, Amsterdam, The Netherlands.
Correspond with Dr. Raggio at danielar@usp.br

far from ideal.[13-16] This performance is even poorer in primary teeth, with lower survival rates than observed in permanent teeth.[3]

The insertion of the GIC in the cavity must be performed when the consistency is not too thick and it is still shiny,[17,18] which shows that remaining polyacrilic ions are available for chemical bonding to the dental structure. A recent laboratory study[19] demonstrated that the insertion of a flowable GIC layer in proximal cavities of primary teeth before inserting a regular GIC layer improves the material adaptation to the tooth surface, reducing microleakage. Although the results are encouraging, the bond strength properties of the flowable GIC layer to dentin are still unknown. Therefore, the purpose of this study was to evaluate the effect of a flowable layer application of high viscosity GIC on the bond strength to sound dentin (**SD**) and carious primary dentin (**CD**).

METHODS

TEETH SELECTION AND PREPARATION

Twenty sound, naturally exfoliated second primary molars were selected after each patient's informed consent was obtained under protocol approved by the School of Dentistry, University of São Paulo research ethics committee. The teeth were disinfected in 0.5% chloramine and stored in distilled water at 4ºC until use.

The occlusal surfaces were removed with a water-cooled diamond disc in a cutting machine (Labcut 1010, Extec Co, Enfield, Connecticut) to obtain flat dentin surfaces. The surrounding enamel was also removed with a diamond bur in a high-speed handpiece using water spray (no. 3195, KG Sorensen, Barueri, Brazil). Exposed occlusal dentin surfaces were then polished with 600-grit silicon-carbide paper under running water for 30 seconds to create a standardized smear layer.[20]

ARTIFICIAL CARIES INDUCTION

Half of the previously prepared teeth (N=10) were subjected to pH-cycling to create artificial CD. The roots and cervical portions were sealed with epoxy resin (Araldite Hobby, Ciba Especialidades Químicas Ltda, São Paulo, Brazil) and received 2 layers of acid-resistant nail polish (Colorama Maybelline Ltda, São Paulo, Brazil).

The specimens were individually submitted to 14 cycles of immersion for 8 hours in 10 ml of demineralizing solution (2.2 mM $CaCl_2$, 2.2 mM NaH_2PO_4, and 50 mM of acetic acid adjusted to a pH of 4.8) and for 16 hours in the same volume in remineralizing solution (1.5 mM of $CaCl_2$, 0.9 mM of NaH_2PO_4, and 0.15 mM of KCl adjusted to a pH of 7.0).[21] The solutions were changed every cycle, and at each interval the teeth were rinsed with deionized water and dried with absorbent paper.

BONDING PROCEDURES

The dentinal surfaces for all teeth were conditioned with a cotton pellet containing diluted liquid of Fuji IX (GC Europe, Leuven, Belgium) for 10 seconds,[22] rinsed, and dried. A Teflon matrix was positioned surrounding the prepared surface for high viscosity GIC insertion, resulting in cylindrical specimens with a diameter of 4 mm and a height of 5 mm. Following these procedures, the specimens were randomly reassigned into 2 groups: (1) control group; and (2) 2-layer group.

In the control group, the high viscosity GIC (Fuji IX, GC Europe) was mixed according to the manufacturer's instructions: 1 powder scoop (3.6 g) and 1 liquid drop (1 g; powder/liquid ratio=1:1) hand-mixed until a homogeneous consistency was achieved. The GIC was inserted with the Centrix syringe to avoid including air bubbles into the material. A finger pressure technique was applied for 10 seconds with a gloved index finger coated with petroleum jelly.

In the 2-layer group, the high viscosity GIC was hand-mixed with 1 powder scoop (3.6 g) and 2 liquid drops (2 g; powder liquid ratio=1:2) for the first layer. A flowable consistency mix was achieved. The first layer was inserted with the Centrix syringe, and the second layer was hand-mixed according to the manufacturer's instructions (powder/liquid ratio=1:1) and applied before the first layer hardened. A finger pressure technique was applied for 10 seconds with a gloved index finger coated with petroleum jelly.

After 6 minutes, the Teflon matrix was removed and petroleum jelly was applied on all specimen surfaces to avoid water uptake and loss.[23] Specimens were stored in distilled water at 37ºC for 24 hours.

MICROTENSILE TEST

Teeth were sectioned both in "X" and "Y" directions across the adhesive interface using a low-speed diamond disc in a cut machine (Labcut 1010, Extec Co, Enfield, Connecticut). This was done to produce bonded sticks with a cross-sectional area of approximately 0.65 mm^2, which was measured using a digital caliper (Absolute Digimatic, Mitutoyo, Tokyo, Japan).

Specimens were immediately attached to a testing apparatus with a cyanoacrylate glue on a universal testing machine (Kratos Dinamômetros, São Paulo, Brazil) and were submitted to a tensile test at a crosshead speed of 1mm/minute. Bond strength was expressed in MPa.

FRACTURE PATTERN

The fracture pattern was examined under 400X magnification using a stereomicroscope (HMV II, Shimadzu, Kyoto, Japan) and classified as adhesive/mixed fracture (presence of dentin or GIC adjacent to the interface) or cohesive (fracture in the dentin or GIC).

STATISTICAL ANALYSIS

The experimental unit in the current study was the tooth. Thus, the microtensile bond strength values of all sticks from the same tooth were averaged for statistical analysis. Since a high number of premature debonded specimens during the preparation phase means higher fragility of the bonding area, 4.0 MPa was assigned as the value for each stick and the specimens were considered in the statistical analysis.[24]

Normal distribution of data was confirmed using the Kolmogorov-Smirnov test. Data obtained were submitted to 2-way analysis of variance (**ANOVA**; group and substrate) and Tukey's post hoc at the 5% significance level. A chi-square test was applied to analyze the fracture pattern proportions among experimental groups. After calculating the effect size of our sample, the power reached was 0.72, which represent a reliable sample for detecting differences between groups.

RESULTS

Microtensile bond strength means (**MPa**) and standard deviations for all experimental groups are displayed in Table 1. ANOVA revealed that cross-product interaction (group x substrate) was statistically significant (P<.05).

When the flowable GIC layer was used, higher bond strength values were obtained when applied to SD (P=.02) vs CD, demonstrating a substrate-dependent result. No significant difference was observed in bond strength using 1 or 2 layers of GIC (P>.05).

The distribution of fracture pattern is summarized in Table 2. For all groups, adhesive/mixed fracture prevailed. No difference was observed in relation to the percentage of cohesive fracture in GICs among experimental groups. The percentage of cohesive fracture in dentin was higher in the 2-layer group, independent of the substrate. A lower percentage of premature fractures was observed for CD when a flowable GIC layer was applied.

DISCUSSION

High failure rates of proximal ART restorations have been widely reported in the literature.[10-13,25,26] Inserting a flowable GIC layer into proximal cavities before inserting a regular GIC layer may improve its adaptation to tooth structures.[19] The presence of a flowable GIC layer appears to promote better adhesion in proximal cavities, without compromising the mechanical properties of restorations.

Accepted adhesion principles suggest that fluid materials penetrate better in the substrate, thus enhancing the micromechanical adhesion.[27] It is not known, however, if the insertion of the flowable GIC layer will influence the bond strength to dentin. Thus, this study aimed to evaluate the high viscosity GIC bonding to SD and CD inserted in 2 layers.

No significant differences were found in bond strength values between the control and 2-layer groups. The bond strength to SD was higher than to CD, however, when flowable GIC layer was applied, suggesting a substrate-dependent behavior of this insertion.

Despite the fact that the GIC bonding mechanism to the tooth structure is not completely clear, chemical adhesion is attributed to ionic interaction between carboxylic groups from polyacids and the hydroxyapatite from the tooth surface, displacing calcium and phosphate ions from the latter.[28,29] As affected dentin demineralization is due to the carious process, the GIC bonding to this substrate may be reduced by comparing the bond to SD. Moreover, the lower powder/liquid ratio used for the flowable layer has important characteristics related to adhesion to the tooth. The higher polyacrilic acid available may be responsible for a higher number of cross-links, better wettability in SD, and consequently, higher bond strength values compared to CD.

Even though the CD showed a lower bond strength in the 2-layer group, the values were similar compared to CD in the control group. This indicates that the application of a flowable GIC layer does not necessarily decrease the adhesion in CD, but it does increase the bonding to SD.

Previous studies[20,30] that evaluated the microtensile bond strength of high viscosity GIC (Fuji IX) to SD found mean values between 9.7 to 12.4 MPa. Considering that the bond strength values to CD obtained in this study for the control group and the 2-layer group were, respectively, 8.55 and 9.14 MPa, they seem to be close to the threshold for bonding, demonstrating acceptable adhesion. Moreover, clinically, CD and SD coexist in cavity preparations and a proper adhesion can be expected.

Smaller specimens from microtests allow for a more uniform stress distribution along the adhesive interface. A high number of cohesive fractures were observed in this study, however, especially in cement, which seems to be a typical finding for GIC,[31] some remnants of which attached to the substrate. This fracture pattern has often been interpreted as indicating that the bond to the dentin is stronger than the cohesive strength of the cement. Bond rupture, is far more complex than this.

Table 1. Microtensile bond strength means (MPa) and standard deviations for all experimental groups

Substrate group	Sound dentin Mean±(SD)*	Carious dentin Mean±(SD)*
Control	13.12±3.28 A,a	8.55±2.45 A,a
2 layers	17.57±4.19 A,a	9.14±1.16 B,a

** Different capital letters indicate significant difference between the main factor "substrate"; equal lower case letters indicate no difference between the main factor "group."*

Table 2. Fracture pattern for all experimental groups (chi-square test results of the fracture pattern proportions among groups)*

Fracture pattern	1 layer (control group)		2-layer group		P-value
	SD	CAD	SD	CAD	
Adhesive/mixed	34	38	46	22	
Cohesive in GIC	17	7	15	11	0.18
Cohesive in dentin	1	1	9	5	0.03
Premature	15	17	3	19	<0.001

** SD= sound dentin; CD= carious dentin; GIC= glass ionomer cement.*

There are also inherent problems with bond strength tests, since there are several layers of material bonded together, including GIC, the hybrid-like layer, dentin, and demineralized dentin, all of which have rather different elastic moduli. In addition to that, GIC may contain air bubbles that can act as stress points, thus increasing the likelihood of cohesive fracture within the cement.[20] Since a large number of cohesive fractures occured, they were included in the statistical analysis, although the true bond strength is represented by fractures in the adhesive interface.

We speculated that a greater number of cohesive fractures in GIC would be observed in the 2-layer group, which did not occur. Although it was not possible to evaluate if cohesive fractures occurred within the 2 layers, no difference was found compared to the control group. By contrast, cohesive fractures in dentin were more prevalent in the 2-layer group, probably due to the presence of fewer voids in the 2-layered GIC,[19] which could improve the strength properties of the material. Likewise, premature fractures were less prevalent when the flowable GIC layer was applied to SD (approximately 5% compared to other groups), indicating a better adhesion.

Long-term studies should be conducted to confirm the bonding success of the 2-layered GIC to dentin clinically and to encourage the use of flowable GIC as a liner to enhance the longevity of proximal ART restorations in primary teeth.

CONCLUSION

Based on this study's results, it can be concluded that the effect of the application of the flowable GIC layer on bond strength to dentin is dependent on substrate and results in an increase in adhesion for SD.

REFERENCES

1. Mickenautsch S. An introduction to minimum intervention dentistry. Singapore Dent J 2005;27:1-6.
2. Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry: A review. FDI Commission Project 1-97. Int Dent J 2000;50:1-12.
3. Frencken JE, Songpaisan Y, Phantumvanit P, Pilot T. An atraumatic restorative treatment (ART) technique: Evaluation after one year. Int Dent J 1994; 44:460-4.
4. Frencken JE, Holmgren CJ. Atraumatic Restorative Treatment (ART) for Dental Caries. 1st ed. Nijmegen: STI Book; 1999(1):14.
5. van Duinen RN, Kleverlaan CJ, de Gee AJ, Werner A, Feilzer AJ. Early and long-term wear of "fast-set" conventional glass ionomer cements. Dent Mater 2005;21:716-70.
6. Bonifácio CC, Kleverlaan CJ, Raggio DP, Werner A, de Carvalho RC, van Amerongen WE. Physical-mechanical properties of glass ionomer cements indicated for atraumatic restorative treatment. Aus Dent J 2009;54:233-7.
7. Frencken JE, van´t Hof MA, van Amerongen WE, Holmgren CJ. Effectiveness of single-surface ART restorations in the permanent dentition: A meta-analysis. J Dent Res 2004;83:120-3.
8. van ‘t Hof MA, Frencken JE, van Palenstein Helderman WH, Holmgren CJ. The atraumatic restorative treatment (ART) approach for managing dental caries: A meta-analysis. Int Dent J 2006; 56:345-51.
9. Frencken JE, Taifour D, van ‘t Hof MA. Survival of ART and amalgam restorations in permanent teeth of children after 6.3 years. J Dent Res 2006;85: 622-6.
10. Yu C, Gao XJ, Deng DM, Yip HK, Smales RJ. Survival of glass ionomer restorations placed in primary molars using atraumatic restorative treatment (ART) and conventional cavity preparations: 2-year results. Int Dent J 2004;54:42-6.
11. Ersin NK, Candan U, Aykut A, Onçağ O, Eronat C, Kose T. A clinical evaluation of resin-based composite and glass ionomer cement restorations placed in primary teeth using the ART approach: results at 24 months. J Am Dent Assoc 2006; 137: 1529-36.
12. Cefaly DF, Barata TJ, Bresciani E, Fagundes TC, Lauris JR, Navarro MF. Clinical evaluation of multiple-surface ART restorations: 12 month follow-up. J Dent Child 2007; 74: 203-8.
13. Zanata RL, Fagundes TC, Freitas MC, Lauris JR, Navarro MF. Ten-year survival of ART restorations in permanent posterior teeth. Clin Oral Investig 2011; 15: 265-71.
14. Salama FS, Riad MI, Abdel Megid FY. Microleakage and marginal gap formation of glass ionomer resin restorations. J Clin Pediatr Dent 1995; 20: 31-6.
15. Roeleveld AC, van Amerongen WE, Mandari GJ. Influence of residual caries and cervical gaps on the survival rate of Class II glass ionomer restorations. Eur Arch Paediatr Dent 2006; 7: 85-91.
16. Mhaville RJ, Van Amerongen WE, Mandari GJ. Residual caries and marginal integrity in relation to Class II glass ionomer restorations in primary molars. Eur Arch Paediatr Dent 2006; 7: 81-4.
17. Wilson AD, Prosser HJ, Powis DM. Mechanism of adhesion of polyelectrolyte cements to hydroxyapatite. J Dent Res 1983; 62:590-2.
18. Kleverlaan CJ, van Duinen RN, Feilzer AJ. Mechanical properties of glass ionomer cements affected by curing methods. Dent Mater 2004; 20:45-50.
19. Bonifácio CC, van Amerongen WE, Meschini TG, Raggio DP, Bönecker M. Flowable glass ionomer cement as a liner: improving marginal adaptation of atraumatic restorative treatment restorations. J Dent Child 2010; 77:12-6.

20. Burrow MF, Nopnakeepong U, Phrukkanon S. A comparison of microtensile bond strengths of several dentin bonding systems to primary and permanent dentin. Dent Mater 2002;18:239-45.
21. Marquezan M, Corrêa FN, Sanabe ME, et al. Artificial methods of dentine caries induction: A hardness and morphological comparative study. Arch Oral Biol 2009;54:1111-7.
22. Raggio DP, Sônego FG, Camargo LB, Marquezan M, Imparato JC. Efficiency of different polyacrylic acid concentrations on the smear layer, after ART technique, by Scanning Electron Microscopy (SEM). Eur Arch Paediatr Dent 2010;11:232:5.
23. Brito CR, Velasco LG, Bonini GA, Imparato JC, Raggio DP. Glass ionomer cement hardness after different materials for surface protection. J Biomed Mater Res A 2010;93:243-6.
24. Reis A, Loguercio AD, Azevedo CL, de Carvalho RM, Singer JM, Grande RH. Moisture spectrum of demineralized dentin for adhesive systems with different solvent bases. J Adhes Dent 2003;5:183-92.
25. van de Hoef N, van Amerongen E. Influence of local anesthesia on the quality of Class II glass ionomer restorations. Int J Paediatr Dent 2007;17:239-47.
26. van Gemert-Schriks MC, van Amerongen WE, ten Cate JM, Aartman IH. Three-year survival of single- and 2-surface ART restorations in a high-caries child population. Clin Oral Investig 2007; 11:337-43.
27. Swift Jr EJ, Perdigao J, Heymann HO. Bonding to enamel and dentin: A brief history and state of the ART. Quintessence Int 1995;26:95-110.
28. Tanumiharja M, Burrow MF, Tyas MJ. Microtensile bond strengths of glass ionomer (polyalkenoate) cements to dentine using four conditioners. J Dent 2000;28:361-6.
29. Knight GM, McIntyre JM, Craig GG, Mulyani. Electron probe microanalysis of ion exchange of selected elements between dentine and adhesive restorative materials. Aust Dent J 2007;52:128-32.
30. Yip HK, Tay FR, Ngo HC, Smales RJ, Pashley DH. Bonding of contemporary glass ionomer cements to dentin. Dent Mater 2001;17:456-70.
31. Bonifácio CC, Shimaoka A, Andrade A, Raggio DP, van Amerongen WE, Carvalho R. Micro-mechanical bond strength tests for the assessment of the adhesion of GIC to dentine. Acta Odontol Scand 2012;70:555-63.