

Original Article

Comparative evaluation of the effect of a resin modified glass ionomer cement universal adhesive on the shear bond strength of glass ionomer cements

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Abstract The present study compared and evaluated the shear bond strength (SBS) of two types of glass ionomer cement (GIC), Riva Self Cure HV™ (SDI Ltd., Victoria, Australia) and GC Fuji IX GP EXTRA™ (GC America Inc., Alsip, USA) with and without the use of Riva Bond LC™ (SDI Ltd., Victoria, Australia), a lighted cured resin-modified glass ionomer cement (RMGIC) universal adhesive. Sixty extracted sound premolars with prepared exposure of the dentine on the occlusal surface were randomly assigned into four groups according to the tested restorative materials. Shear bond strength (SBS) tests were performed by using the Shimadzu Universal Testing Machine at a crosshead speed of 0.5 mm/minute, and the values obtained were statistically analysed using one-way ANOVA and Tukey tests. The inter-group comparison showed statistically significant differences in the SBS values between all the test groups ($p < 0.001$). A stereomicroscope was used to assess the modes of failure. Adhesive failures were predominant in adhesive groups (>80%) compared to higher cohesive failures found in the non-adhesive groups (>86%). A Spearman's rho correlation test performed to determine the association between SBS values and mode of failures had indicated positive correlations between the adhesive failure and SBS values in the adhesive groups ($r_s=0.86$, $p<0.001$; $r_s=0.85$, $p<0.001$) and the cohesive failure and SBS values in the non-adhesive groups ($r_s=0.87$, $p<0.001$). These findings support the improvement in adhesion of GICs to tooth structure with the use of RMGIC adhesive.

Keywords: Adhesion failure mode, adhesive failure, cohesive failure, de-bonding, resin-modified glass ionomer.

Introduction

A strong and durable bond between tooth structure and restorative material is important, not only from the mechanical viewpoint but also essential in fulfilling the biological and aesthetic needs. Excellent adhesion and adaptation of restorative material to tooth structure can reduce the occurrence of tooth staining, pulp irritation, micro-leakage and recurrent caries (Nakabayashi *et al.*, 1991). In the context of restorative dentistry, adhesion of the restorative material to the underlying tooth structure can be achieved through either macro-mechanical adhesion or micro-mechanical adhesion or interfacial chemical adhesion or true chemical adhesion.

Adhesion of glass ionomer cements (GIC) to tooth structure occurs via true

chemical reaction between the carboxylate groups of the polyacid molecules and calcium ions on the tooth surface that leads to ionic bonding. However, one of the chief disadvantages of GIC is its low bond strength when compared to other available restorative materials, despite improvements in its bond strength properties over the years (Manuja *et al.*, 2011; Nujella *et al.*, 2012). In 2011, SDI® Australia announced the launch of Riva Bond LC™, purported to be the resin-modified glass ionomer cement (RMGIC) universal adhesive for all types of direct restoration including GIC, composite and even amalgam. This bonding agent incorporates the bioactive proprietary of ion-glass technology with advanced glass ionomer resin technology. The manufacturer claimed that the chemical adhesion of Riva Bond LC™ would produce

higher bond strength. Besides, it also compensates for the polymerization shrinkage that might occur, which in turn improves the bonding strength of the material compared to the traditional adhesives. The contraction stress is eliminated by selective hygroscopic expansion/water absorption of the thin adhesive layer, which is not observed in purely resin bonds.

Most of the available studies have investigated the use of adhesive between GIC and composite for sandwich technique (Knight *et al.*, 2006; Kasraie *et al.*, 2013; Boruziniat and Gharaei, 2014). The present study intends to look at the matter from a different perspective by investigating the usage of RMGIC adhesive between the GIC and the dentine. The present study might provide insight into a way of improving GIC bond strength to dentine and at the same time testing the claim made by the manufacturer regarding the bond strength enhancement of the RMGIC adhesive.

The aim of the present study was twofold. First, the study aims to compare and evaluate the shear bond strength of two types of GICs with and without the use of Riva Bond LC universal adhesive. Secondly, to compare the correlation between the shear bond strength of the GICs with and without the use of the adhesive with the modes of failure observed. The first hypothesis of the present study is that there is no significant difference in the shear bond strength of both the GICs with or without the use of Riva Bond LC adhesive. The second hypothesis is that there is no correlation between the shear bond strength of the two types of GICs with and without the use of adhesive and the respective modes of failure.

Materials and methods

The National University of Malaysia (UKM) ethics committee granted the ethical approval for the present study [1.5.3.5/244/DD/2015/003(2)].

Sixty caries-free premolars teeth, both the maxillary and mandibular premolars, which were extracted previously for a clinical purpose were obtained for the present study and randomly assigned into

four groups of the same number (n=15). A critical review of the literature by Sirisha *et al.* (2014) stated that a universal sample size is yet to be established for bond strength studies. Previous studies that looked at shear bond strength testing of dental material to tooth used a sample size of 10 to 15 teeth per group (Yesilyurt *et al.*, 2008; Chandak *et al.*, 2012; Shashirekha *et al.*, 2012; Vashisth *et al.*, 2014). Based on Shashirekha *et al.* (2012) study, a sample size of 15 teeth per group was calculated using the following sample size formula:

$$N = \frac{[(Z_{1-\alpha/2} + Z_{1-\beta}) S_d]^2}{\delta^2}$$

N = Number of tooth

Z = Standard normal deviate for a one or two sided

α = Type I error

β = Type II error

S_d = Standard deviation

δ = A clinically acceptable margin

Only sound permanent premolar teeth with no fracture lines were used in the present study. Teeth with caries, restorations, sealant, fluorosis and other anomalies were excluded. Following extraction, the teeth were cleaned and stored in a labelled disposable plastic container containing saline solution until further use. These teeth were randomly divided into four groups of equal numbers (15 teeth in each group) as shown in Table 1. The composition of the main materials used in the present study is shown in Table 2.

Each tooth was sectioned at the level of cemento-enamel junction (CEJ) and embedded in self-cure acrylic resin with the help of aluminium moulds of 7 mm in height and 15 mm in diameter to produce a standardized disk (Fig. 1). The occlusal surface of the teeth was parallel to the acrylic resin block surface. The occlusal surface was flattened with a diamond saw until a clean dentinal surface was exposed. The prepared dentine was then polished with 180, 320, and 600 grit wet silicon carbide paper. The prepared specimens were stored in distilled water for 24 hours at 37°C.

The placement of GIC with/without adhesives was carried out according to the manufacturers' instruction for all groups. For the non-adhesive groups, Group 1 (Riva Self Cure HVTM) and Group 3 (GC Fuji IX ExtraTM), Riva conditioner and GC

dentine conditioner were applied respectively on the prepared dentine surfaces for 20 seconds and rinsed thoroughly with water. The dentine surfaces were kept slightly moist. Thereafter, respective GICs were placed into the prepared aluminium moulds. As for the adhesive groups, Group 2 (Riva Self Cure HV™ with Riva Bond LC™) and Group 4 (GC Fuji IX Extra™ with Riva Bond LC™), the prepared dentine surfaces were etched with Super Etch™ 37% phosphoric acid for 5 seconds and rinsed thoroughly with water and kept slightly moist. Thereafter, the respective GICs were placed into the prepared aluminium moulds. The aluminium moulds were used to prepare a standardize GIC cylinder of 4 mm height and 3 mm diameter on each tooth (Fig. 1).

After placement of GIC, the samples were stored in a container filled with distilled water for 24 hours at 37°C before they were subjected to thermocycling. The samples were thermocycled at 5°C and 55°C water baths for 500 cycles, with a dwell time of 20 seconds and transfer time of 2 seconds between baths. Thermocycling was done using a custom-engineered instrument that intends to simulate the condition in a human mouth in its hot and cold, body temperature with a ball screw transporting system. Then all the teeth were rinsed with an air-water syringe and dried with compressed air.

The mounted samples were subjected to shear bond strength (SBS) test using a Universal Testing Machine (Shimadzu Corporation, Japan), where a notch chisel was used, running at a cross-head speed of 0.5 mm/min to break the specimen. The results were recorded in mega Pascal (MPa) units.

Mode of failure assessment was done using Olympus SZX7 Zoom® Stereo Microscope, which utilizes a Galilean optical system to provide superior image accuracy at high resolutions. The specimens of all groups were examined at 10x magnification to define the location of the failure. The failures were categorized into three types (Kasraie *et al.*, 2013):

1. Adhesive failure: Occurring exclusively at the GIC-dentine interface.
2. Cohesive failure: Occurring exclusively

within the GIC or exclusively within the dentine.

3. Mixed failure: Combination of both the adhesive and any of the cohesive failures.

The results were analysed using the IBM SPSS Data Editor Version 23. Shapiro-Wilk test was used to assess the distribution normality of the obtained data. Intergroup comparisons were made using the one-way ANOVA and Tukey's post hoc statistical tests with the level of significance set at $p < 0.05$. Spearman's rho correlation test was done to determine any association between SBS values and modes of failure.

Results

The mean values of shear bond strength (SBS) for the GICs used in the study are presented in Table 3 and Fig. 2. The results showed that the adhesive groups produced higher mean SBS values compared to the non-adhesive groups.

The mean SBS values obtained were used for inter-group comparison using the one-way ANOVA and Tukey's post hoc test. The inter-group comparison showed that there were statistically significant differences in SBS values between all the groups tested with $p < 0.001$ (Table 3).

Microscopic examination of interfacial de-bonding revealed that when the adhesive was used, most of the failures were due to the adhesive failure. On the other hand, cohesive failure was the most common findings in groups without the adhesives. The least mode of failure is the mixed failure type (Fig. 3, Table 4).

The Spearman's rho correlation test between the mean SBS value and mode of failure indicated strong positive correlations between adhesive failure and SBS values in Group 2 and 4 ($r_s = 0.86$, $p < 0.001$; $r_s = 0.85$, $p < 0.001$) respectively. Similarly, positive correlations were noted for cohesive failure and mean SBS values in Group 1 and 3 ($r_s = 0.87$, $p < 0.001$). However, there was no correlation between mean SBS values and mixed failure observed in Group 2 and 4 ($r_s = 0.63$, $p = 0.333$; $r_s = 0.54$, $p = 0.333$) as shown in Table 5.

Table 1 Distribution of the study groups

Group	Number (n)	GIC Used	Adhesive Used
1	15	Riva Self Cure HV™	-
2	15	Riva Self Cure HV™	Riva Bond LC™
3	15	GC Fuji IX GP EXTRA™	-
4	15	GC Fuji IX GP EXTRA™	Riva Bond LC™

Table 2 Composition of the materials used in the study

Material	Manufacturer	Composition
Riva Self Cure HV™	SDI® Limited	Polyacrylic Acid Tartaric acid Fluoro Aluminosilicate glass
GC Fuji IX GP EXTRA™	GC® America Inc.	Alumino silicate glass Polyacrylic acid powder Polybasic carboxylic acid
Riva Bond LC™	SDI® Limited	Polyacrylic Acid Tartaric Acid 2-Hydroxyethyl Methacrylate Dimethacrylate Cross-linker Acidic Monomer Fluoroaluminosilicate glass powder

Table 3 Mean values of the shear bond strength (MPa) of GIC with and without RMGIC universal adhesive and pairwise comparison between groups using post-hoc Tukey test

Group (n = 15)	Min (MPa)	Max (MPa)	Mean (MPa) ^a	P-value ^b
1	6.01	6.61	6.27 (0.16)	<0.001 ^c
2	7.50	8.20	7.86 (0.24)	
3	6.12	7.01	6.57 (0.27)	
4	8.67	9.55	9.02 (0.21)	

Min = minimum, Max = maximum, ^a Mean (SD), ^b One-way ANOVA, ^c Post-hoc analysis with Tukey test with *p* is statistically significant at $\alpha = 0.05$

Table 4 Failure modes of the study groups

Group	Adhesive n (%)	Cohesive n (%)	Mixed n (%)
1	2 (13.3)	13 (86.7)	0
2	12 (80.0)	1 (6.7)	2 (13.3)
3	1 (6.7)	14 (93.3)	0
4	13 (86.7)	1 (6.7)	1 (6.7)

Table 5 Correlation between Shear Bond Strength value and mode of failure

Mode of Failure	Adhesive r_s (p -value)	Cohesive r_s (p -value)	Mixed r_s (p -value)
Group 1	0.63 ($p=0.333$)	0.87 ($p<0.001$)	-
Group 2	0.86 ($p<0.001$)	0.54 ($p=0.333$)	0.63 ($p=0.333$)
Group 3	0.54 ($p=0.333$)	0.87 ($p<0.001$)	-
Group 4	0.85 ($p<0.001$)	0.54 ($p=0.333$)	0.54 ($p=0.333$)

* Spearman's rho correlation test with *p* is statistically significant at $\alpha = 0.05$

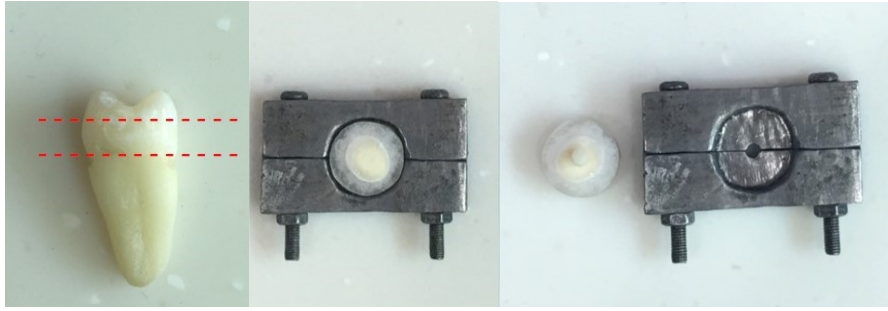


Fig. 1 Standardized tooth section disk of 7mm in height and 15mm in diameter of each tooth, embedded in self-cure acrylic resin and an Aluminium mould was used to prepare a standardize GIC cylinder of 4mm in height and 3mm in diameter on each tooth.

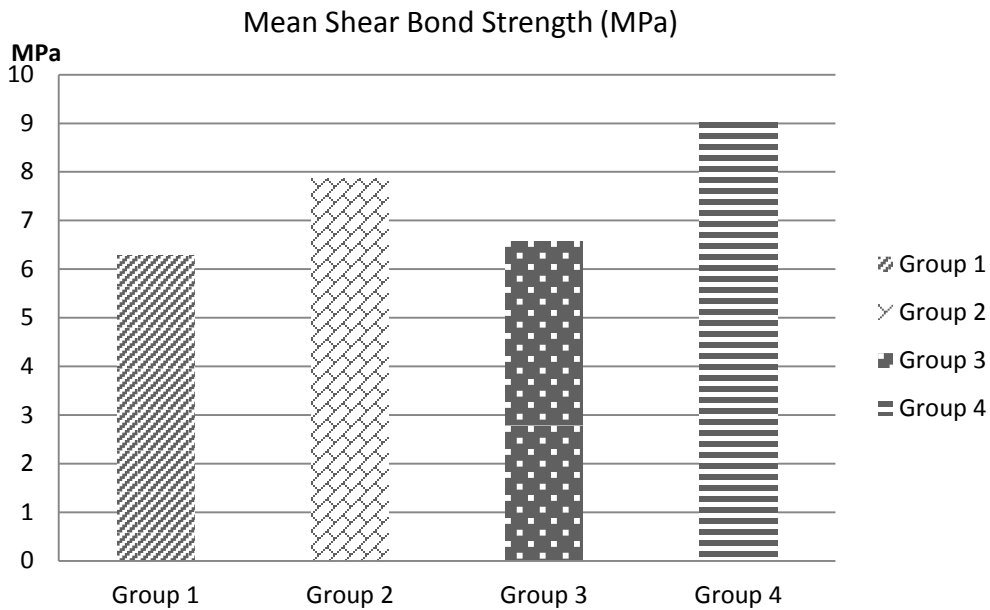


Fig. 2 Mean Shear Bond Strength (MPa) for all groups of GICs.

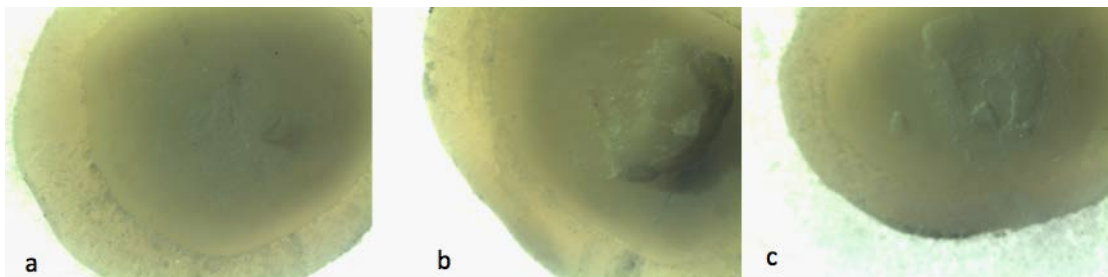


Fig. 3 Mode of failure examined under stereomicroscope: a) Adhesive failure: occurring purely at restoration – dentine interface, b) Cohesive failure: occurring purely within the material or purely within dentine, c) Mixed failure: combination of both the adhesive and any of the cohesive failures.

Discussion

Adhesive ability of a restoration can predict its longevity. Bond strength testing often measures the adhesive ability of a restorative material. An ideal bond strength test should be accurate, clinically reliable, and less technique-sensitive. In a shear bond testing, shearing load is applied to the two materials connected by adhesive until a fracture occurs. It is the most widely used test (Burke *et al.*, 2008) due to its simplicity as no further specimen processing was required after the bonding procedure (van Meerbeek *et al.*, 2003). In the present study, the shear bond strength test was used to evaluate the effect of using adhesive on the bond strength of GICs.

Intergroup comparison between Riva Self Cure HV™ or GC Fuji IX GP EXTRA™ with and without Riva Bond LC adhesive showed that there were significant increases in SBS values in the adhesive groups. These findings suggest that Riva Bond LC™ adhesive served as an interface, which adhered firmly to both GIC and dentine, as compared to a direct bonding between GIC and dentine.

One of the reasons for the enhanced adhesion as observed is probably due to the existence of the light-activated hydroxyethyl methacrylate (HEMA) in the Riva Bond LC™ adhesive. HEMA has an excellent wetting ability on tooth surface (McLean, 1996). HEMA acts as a hydrophilic primer, which improves the infiltration of adhesive monomer into demineralized dentine. It also maintained the collagen network in an expanded state by stiffening the collagen fibres (Iványi *et al.*, 1999; Iványi *et al.*, 2002). The presence of resin in Riva Bond LC™ adhesive suggests that bonding analogous to resin composite may occur, i.e. the establishment of a hybrid layer with mechanical interlocking into dentine by the carboxylic acid (McLean, 1996).

Due to the hybrid nature of RMGIC, Riva Bond LC™ adhesive has a polymerizable side chain and a carboxyl group. The polymerizable side chain, which is characteristic to a resin, can form cross-link with other methacrylate-terminated resins through photopolymerization. On the

other hand, the carboxyl group, which is characteristic to GIC, undergo acid-base reaction to form salt with metal ions and water (Hse *et al.*, 1999). The resin component is responsible for establishing a strong polymer that will infiltrate into the demineralized dentine and form a hybrid layer (McLean, 1996). Whereas the carboxyl component was able to react with GICs used in the present study to form salt bridges between the polyacid chain and result in the formation of silica hydrogel (Fritz *et al.*, 1996).

At the same time, the carboxyl group in the adhesive will adhere chemically to the dentine, through an ion exchange process between them (Cho and Cheng, 1999). As a result, we will have an adhesive with a dual mechanism of adhesion; on one end, it adheres mechanically and chemically to the dentine, and on the other end, it adheres chemically to the GICs. This combination resulted in a significantly higher SBS as compared to GICs without adhesive.

Furthermore, as per manufacturer instructions, dentine was conditioned using Super Etch 37% phosphoric acid for five seconds before application of Riva Bond LC™ adhesive. Conditioning of dentine with phosphoric acid helps to improve the adhesion of RMGIC to dentine (Cortes *et al.*, 1993; Silverman *et al.*, 1995; Bishara *et al.*, 2000; Valente *et al.*, 2002; Coutinho *et al.*, 2006). The conditioning effectively removes the smear layer, exposes the collagen fibrils and opens up the dentinal tubules. This allowed better penetration of HEMA within the underlying dentine surface to form a hybrid layer. The presence of this hybrid layer increases the surface energy that provides better wetting of the dentine surface by creating an inter-diffusion zone between the cement and dentine matrix. This inter-diffusion zone adds to the micromechanical retention of the GICs, in addition to the chemical adhesion to dentine (Nakanuma *et al.*, 1998; Pereira *et al.*, 1998; Wassell *et al.*, 2002).

The significant increase in SBS values of GC Fuji IX GP EXTRA™ showed that the improvement in adhesion brought about by Riva Bond LC is not only limited to

a single brand of GIC and this justified its use as a universal RMGIC adhesive as claimed by its manufacturer.

The result of the present study showed that Riva Bond LC™ universal adhesive has significantly increased the bond strength of conventional GICs to dentine. These findings rejected the first null hypothesis of the present study that there are no significant differences in shear bond strength of Riva Self Cure HV™ and Fuji IX GP EXTRA™ with and without the use of Riva Bond LC™ adhesive.

In the present study, without the use of RIVA Bond LC, the mean SBS values were lower compared to that with the adhesive used. Studies by Almuammar *et al.*, 2001, Iazzetti *et al.*, 2001, and Passi *et al.*, 2007 have shown inferior bonding performance of GICs to dentine. Glass ionomer cements are the only material that is self-adhesive to tooth tissue and does not require any prior tooth treatment (van Meerbeek *et al.*, 2003). The chemical bond that forms at the interface between the glass ionomer and tooth tissue is rather a weak bond compared to a micro-mechanical bond. Furthermore, preconditioning of dentine with a weak polyacrylic acid only helps to remove smear layer on the dentine surface and it does not remove smear plugs from the dentinal tubules. Although the mechanism of adhesion of glass ionomer to tooth surface is still not clear, it is believed that wetting of the tooth surface by the glass ionomer cement allows ionic exchange to take place (Miyazaki *et al.*, 1998).

Unexpectedly, SBS comparison between the two conventional GICs without the use of adhesive showed a significant difference. The findings could be due to the difference in the powder to liquid ratio (P/L) of these GICs. According to the respective manufacturers' data, the P/L ratio for Riva Self Cure HV™ is 3.85 (0.5/0.13) and Fuji IX GP Extra™ is 3.33 (0.4/0.12). GIC with lower ratio will produce lower bond strength because there will be a decrease in the ion release to form the ion exchange layer (Shebl *et al.*, 2015). However, the present study showed that Fuji IX GP EXTRA™, the GIC with lower P/L ratio, has a higher mean SBS value. A possible explanation for this

observation is that at high P/L ratio, there are more unreacted particles within the GIC, which can act as stress concentration points (Yap *et al.*, 2001). Presence of these stress concentration points might have reduced the SBS value recorded for Riva Self Cure HV™.

Another possible cause for the difference in the SBS values is the presence of porosities within the GIC microstructure. Strength of a material can be significantly affected by many factors such as porosity within the material and material particle size (Guggenberger *et al.*, 1998; Xie *et al.*, 2000). Riva Self Cure HV™, which has a higher P/L ratio could have had more porosities within its microstructure; hence the lower SBS value was observed.

In line with the bond strength results, examinations of the mode of failure of the tested materials showed that the adhesive failures were predominant in the groups where Riva Bond LC™ adhesive were used. Adhesive failure means the failure had occurred between GICs and the adhesive instead of within the GICs. The presence of Riva Bond LC™ adhesive as an interface between GICs and dentine had caused a significant increase in the mean SBS values, and as a result, there was more adhesive failure observed. Adhesive failure showed that there is a stronger bond between dentine and the adhesive as opposed to the bond between GICs and the adhesive. Similar findings were observed in studies which had previously used RMGIC and adhesives (Friedl *et al.*, 1995; Wang *et al.*, 2006). Clinically, adhesive restorations can reinforce weakened tooth tissues by transferring and disbursing the functional stresses across the bonded interface effectively. At the same, good adhesion also prevents formation of marginal gaps, which can lead to micro-leakage and restorative failure.

On the other hand, cohesive failures are predominant in the groups without the adhesives. The GICs fail cohesively in the cement rather than at its interface with the tooth structure (ionic-exchange layer). This cohesive type of failure complicates the interpretation of the bond strength testing in the laboratory (Tyas and Burrow, 2004).

The present results were in agreement with some previous studies which hitherto failed to measure the actual bond strength of the ion-exchange layer (Suwatviroj *et al.*, 2004; Choi *et al.*, 2006; Knight *et al.*, 2006; Lenzi *et al.*, 2011). The presence of cohesive failures for GICs means that the SBS values represent only the tensile bond strength of the cement rather than the strength of the tooth-cement interface which may indicate that the interfacial strength of the bond is higher than the inherent strength of the material (Fritz *et al.*, 1996).

Concerning the mixed mode of failure of the tested GICs, it might be due to the low resistance of GIC to early wear and the formation of glass ionomer matrix. Therefore, part of the glass ionomer remained adhered to the tooth structures, while part of it broke at the interface of GIC and the tooth structure.

Spearman's rho correlation indicated a strong positive correlation between SBS values and the adhesive and cohesive failures for groups with and without the use of universal RMGIC adhesive respectively. Greater SBS values in the adhesive groups indicated that the use of Riva Bond LC had enhanced the adhesion of the material to the tooth surface. Presence of more adhesive failures with the Riva Bond LC groups showed that the SBS values measured were a reflection of the actual bond strength rather than a measure of the tensile strength of the GICs.

Clinical relevance/application

The present study proved that the application of universal RMGIC adhesive (Riva Bond LC™) had improved the mean SBS of GICs. These findings showed that the use of Riva Bond LC could enhance the adhesion of GICs to tooth structure. Clinically, the use of this universal RMGIC adhesive allows better adherence of GIC as a restorative material especially at the areas subjected to a high occlusal load. This will help in preventing easy dislodgement of GIC restorations. The use of RMGIC may be able to address some of the issues related to high failure rate seen in the GIC restorations.

However, the use of adhesive requires an extra clinical step and good

moisture control which might lead to many clinicians not buying into this idea. As clinicians, one has to evaluate the significance of applying the adhesive objectively rather than seeing it from the economic and practical perspectives.

Conclusion

The findings of this study showed that Riva Bond LC™ adhesive has significantly increased shear bond strength (SBS) values of the two types conventional glass ionomer cement used. This finding is supported further by the examination of different modes of failure. The used of Riva Bond LC™ adhesive resulted in more adhesive failure, which showed a strong positive correlation with the increase in the SBS values observed. Using Riva Bond LC™ as adhesive might help to increase the clinical retentiveness and durability for conventional GIC. A clinical study is further required to support this statement.

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