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Does caries-removal method affect the dentin bond strength of high-viscosity glass ionomer cements?

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Aim: The objective of this study was to evaluate the impact of manual and rotary instruments on the microtensile bond strength of high-viscosity glass ionomer cements (GICs) to caries-affected dentin. **Methods:** Twelve sound molars and 24 molars with dentin caries were sectioned perpendicular to the long axis at the mid-dentin region. Teeth were divided into six groups (n=6) according to the carious tissue removal method (E: excavator, B: rounded bur), and restorative material (EQ: Equia® Forte Fil, RIV: Riva Self-Cure). The control group was formed by sound teeth (S: sound) restored with both materials. After a 24-hour storage in distilled water at 37°C, the teeth were sectioned along the long axis to obtain 1 mm thick slices and the adhesive interface was reduced to 1.2 mm with a diamond bur. The specimens were subjected to microtensile bond strength tests at a 1.0 mm/min crosshead speed in a universal testing machine. Data were submitted to two-way ANOVA, followed by the Games-Howell test with a significance level of 5%. **Results:** No significant differences were found for caries removal technique and restorative material ($p \geq 0.05$), but the interaction between these variables was statistically significant ($p<0.05$). The EQ-S and RIV-E groups showed significantly higher microtensile bond strength than the other groups ($p<0.05$), except for the RIV-B, which exhibited no significant difference when compared to all the other groups ($p>0.05$). **Conclusion:** The caries removal method did not negatively affect the dentin bond strength of Riva Self-Cure, while Equia® Forte had higher bond strength to sound dentin.

Keywords: Glass ionomer cements. Dental caries. Dental cavity preparation. Tensile strength.

Introduction

Minimal Intervention Dentistry (MID) is a philosophy that attempts to ensure that teeth are kept functional for life based on preserving as much healthy tooth structure as possible while achieving optimal treatment outcomes in restorative dentistry[1]. The main strategies adopted involve early detection and evaluation of risk factor for caries, remineralization of enamel and dentin, caries prevention measures, minimal invasive interventions, and repair instead of total replacement of restorations[2].

Selecting the type of treatment is crucial to preserve dental structures and pulp vitality. In a carious cavity, the outer layer is formed by infected dentin, highly contaminated with cariogenic bacteria and structurally disorganized[3], while the internal layer is formed by affected dentin, which is partially demineralized and can be remineralized[4]. Conventional restorative treatment requires the complete removal of all carious tissue on all cavity walls until firm dentin is found[5]. However, this approach presents a high risk of pulpal exposure in deep caries lesions[6]. In such cases, the selective removal of carious tissue is a safe and conservative method based on the removal of the highly contaminated softened dentin, keeping the affected dentin on the pulpal floor to avoid exposure, and caries complete removal on the lateral walls, followed by restoration[7]. Therefore, only decomposed and infected dentin is removed, decreasing the number of viable microorganisms and preserving the potentially remineralizable dentin[8].

In deep carious lesions, dentin bond strength is significantly reduced due to lower calcium concentration[9], and even lower in affected dentin due to the presence of acids producing demineralization of mineral crystals and modifying the collagen fibers[10]. Glass ionomer cements are the choice materials for bonding with this type of substrate, since they promote chemical bond with calcium[11].

Glass ionomer cements (GICs) have undergone significant changes in recent years. The advent of nanotechnology led the industry to develop products that are easier to use and at the same time resistant and aesthetic. High-viscosity GICs, obtained by a higher content of fluorine-aluminum-silicate particles, in addition to a higher powder/liquid ratio[12], have become a viable alternative for restorations in posterior teeth, although evidence of lower wear resistance and higher risk of fractures had imposed some limitations[13]. However, due to the ease of use, less sensitivity to humidity and protective effect against caries, self-cured high-viscosity GICs have been widely used for the Atraumatic Restorative Technique[14]. With the introduction of a resin-based coating associated with high-viscosity GICs wear resistance had increased, making these materials promising for areas of high occlusal incidence[15]. Results of *in vitro* studies demonstrated that the mechanical properties of high-viscosity GICs with resin coating are superior to those of conventional and resin-modified glass ionomers[16-19].

The bond strength of glass ionomer cements to sound[20-22] and in caries-affected dentin[22,23] has been commonly investigated by means of microshear bond strength. Studies with microtensile bond strength tests are scarcer and used artificial caries models[24] and primary teeth[25,26] to evaluate the bond strength of conventional high-viscosity GICs compared to other types of cements.

The aim of the study was to evaluate the effect of manual and rotatory instruments on the microtensile bond strength of high-viscosity glass ionomer cements to caries-affected dentin. The null hypothesis is that there will be no differences in bond strength to dentin irrespective of the caries removal method and the glass ionomer cement.

Methodology

Selection of teeth and tooth preparation

Twelve sound molars and twenty-four molars with dentin caries were obtained from the Tooth Bank of PUCPR after project approval by the Institution's Research Ethics Committee (3,987,550). The teeth were stored in 0.5% chloramine solution at 4ºC in a refrigerator for a maximum of 3 months before being used in the study.

Teeth with caries underwent radiographic examination to confirm that the lesion depth was from 1/3 to the middle of the dentin and that the carious lesion was limited to the occlusal surface.

Sound and carious teeth were embedded in acrylic resin and placed in a precision cutter with a diamond disc (Isomet 1000, Buehler Group, Uzwil, Switzerland). The crowns of sound teeth were sectioned perpendicular to the long axis of the tooth at the center of the carious lesion, and the crowns of carious teeth were sectioned to expose the dentin of the middle third of the crown.

Experimental design

Table 1 shows the materials used in the study. The teeth were randomly divided into six groups (n=6). Table 2 describes the distribution of groups according to the substrate, caries removal technique, and restorative material. Figure 1 describes the experimental design and the specimens' preparation steps.

Table 1. Description and composition of the materials used in the study.

Manufacturer	Material	Composition
GC Corp., Tokyo, Japan	GC Dentin Conditioner	20% polyacrylic acid, water
	Equia® Forte Fil	Powder: Fluoroaluminosilicate glass, polyacrylic acid, iron oxide. Liquid: Carboxylic acid and water.
	Equia® Coat	TEGDMA, UDMA, camphorquinone, BHT, tetramethylaniline
SDI Ltd., Bayswater, Victoria, Australia	Riva Conditioner	26% Polyacrylic acid, water, brilliant blue (dye).
	Riva Self-cure	Powder: Fluoroaluminosilicate glass, polyacrylic acid, pigment. Liquid: Polyacrylic acid, tartaric acid, water.
	Riva Coat	TEGDMA, UDMA

TEGDMA: Triethylene glycol dimethacrylate; UDMA: Urethane dimethacrylate; BHT: Butylated hydroxytoluene

Table 2. Distribution of the study groups considering the type of dentin, caries removal method and restorative material.

Group	Type of Dentin	Caries Removal	Restorative Material
EQ-S	Sound	-	Equia® Forte Fil
RIV-S	Sound	-	Riva Self-Cure
EQ-E	Carious	Excavator	Equia® Forte Fil
RIV-E	Carious	Excavator	Riva Self-Cure
EQ-B	Carious	Bur	Equia® Forte Fil
RIV-B	Carious	Bur	Riva Self-Cure

The teeth from the sound control group were abraded with 600-grit SiC paper under water cooling on a polishing machine (Aropol 2V-PU, Arotec Ind e Com., Cotia, SP, Brazil), followed by a 20-second water rinse and gentle air drying.

The removal of caries from the EQ-E and RIV-E group specimens was performed using an excavator following the technique of selective removal of softened dentin, which means complete removal of softened and infected dentin with circular excavation movements directed until finding slightly firmer dentin that is not easily deformed by instrument pressure. After the removal of carious dentin from the lateral walls, the removal of softened dentin was performed with care.

The removal of caries from the EQ-B and RIV-B group specimens was carried out with rounded carbide burs (KG Sorensen, Serra, ES, Brazil) until firm and consistent dentin was achieved by checking with an explorer.

All specimens were conditioned with the dentin conditioners of each manufacturer for 20 seconds, followed by a 20-second water/air spray rinse and gentle air drying.

Equia® Forte Fil (GC Corp., Tokyo, Japan) and Riva Self-cure (SDI Ltd., Bayswater, Victoria, Australia) capsules were activated and placed in a mixer for 10 seconds (Ultrasmart 2, SDI Ltd., Bayswater, Victoria, Australia). The capsules were attached to the applicator, and the material was applied into the dentin surface using a steel matrix band around the crown, forming a block of approximately 4 mm in height. A waiting time of 2 minutes and 30 seconds was observed for the complete gelation of the material. Equia® Coat (GC Corp., Tokyo, Japan) and Riva Coat (SDI, Bayswater, Victoria, Australia) were applied to the restorations and light-cured for 20 seconds using a high-irradiance LED-based curing unit (Grand VALO, Ultradent Inc., South Jordan, UT).

The specimens were stored in distilled water at 37°C for 24 hours and sectioned using a low-speed precision cutting machine (Isomet 1000, Buehler, Lake Bluff, IL) to obtain 1 mm thick slices. Each restored tooth produced an average of 5 slices. The slices were prepared with a cylindrical diamond tip at the interface to obtain an adhesive interface width of 1.2 mm. Measurements were verified using a digital caliper (Absolute Digimatic Caliper, Mitutoyo Corp., Tokyo, Japan). The samples were kept moist during the preparation procedures until testing.

Microtensile bond strength testing

The specimens were subjected to microtensile bond strength testing using a universal testing machine (EMIC DL2000, Instron Corp., São José dos Pinhais, PR, Brazil). For this purpose, each specimen was bonded to a metallic microtensile testing device using a cyanoacrylate adhesive (Slo-Zap, Super Glue Corp., Ontario, CA). The assembly was attached to the machine and subjected to tensile force at a speed of 1 mm/min until failure. The maximum failure load was recorded and converted to Megapascals (MPa) based on the adhesive interface area, which was measured using a digital caliper. Specimens that fractured or exhibited failures prior to the tensile test were recorded as "pre-testing failures" for each group. Figure 1 depicts the experimental design and the steps of the specimens' preparation.

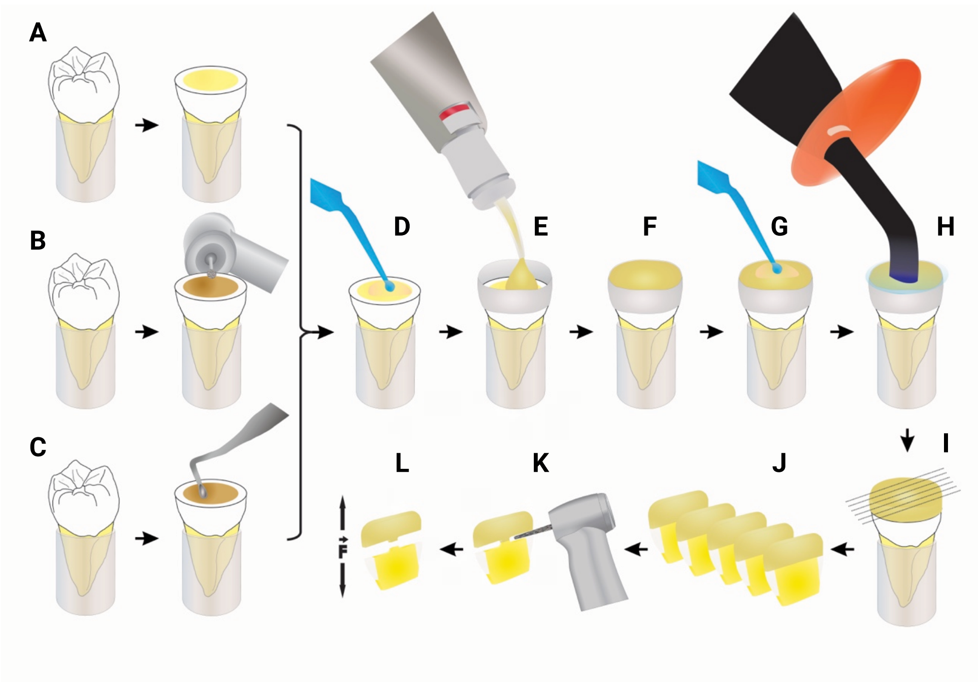

Figure 1. Schematic description of the study design. A- Sound dentin (control group); B- Bur-treated carious dentin; C- Excavated carious dentin; D- dentin conditioning for 20 s; E- Restorative material application into the dentin surface using a steel matrix band around the crown; F- Restoration block; G-H- Application of resin coat and light-curing for 20 s; I-J- Parallel sections of the specimens to obtain 1 mm thick slices; K- Diamond bur preparation at the interface (1.2 mm thick); L- Microtensile bond strength testing at the universal testing machine.

Statistical Analysis

The data were submitted to Kolmogorov-Smirnov and Lèvene's tests for normality of distribution and homogeneity of variances. Two-way analysis of variance (ANOVA) was performed, followed by Games-Howell post hoc test for multiple comparisons. All the tests were conducted at a significance level of 5% using SPSS 26.0 statistical package (IBM Inc., Chicago, IL, USA).

Results

According to the two-way ANOVA results, there was no significant difference for the variables “restorative material” (p=0.732) and “caries removal” (p=0.123). However, a significant interaction was found between both factors ($p=2.279^{-07}$).

Table 3 depicts the mean bond strength of EQ-S and RIV-E groups was significantly higher than the other groups, but not statistically different from the RIV-B group, which showed no significant differences with the other groups (p>0.05). The EQ-S group exhibited a higher mean than RIV-S (p<0.05).

Among the groups using Equia® Forte glass ionomer cement, the EQ-S group had significantly higher mean values than the EQ-E and EQ-B groups (p<0.05). The RIV-E group showed no significant difference compared to the RIV-B group (p>0.05), but it was significantly superior to the RIV-S group (p<0.05).

Table 3. Mean (SD) of microtensile bond strength (MPa) and number of pre-testing failures (PTF) for each group.

Group	n	PTF	Mean (SD)	Sig.
EQ-S	34	2	9.45 (5.16)	a
EQ-E	35	3	5.68 (2.42)	b
EQ-B	33	2	5.75 (2.65)	b
RIV-S	32	4	5.39 (2.49)	b
RIV-E	32	2	9.29 (5.23)	a
RIV-B	34	2	6.77 (3.48)	ab

Discussion

This study evaluated the microtensile bond strength of two resin-modified glass ionomer cements to both normal and caries-affected dentin after manual and mechanical caries removal. Our findings revealed no significant differences for each of the independent variables “caries removal method” and “type of restorative material”. However, there was a significant interaction between these variables, which means that one variable has a different effect on the outcome depending on the values of the other variable.

The EQ-S and RIV-E groups demonstrated superior bond strength compared to other groups, with comparable results to the RIV-B group. This outcome suggests that the choice between manual and mechanical caries removal methods may not significantly impact the bond strength of these materials.

The bond strength of conventional glass ionomer cements to caries-affected dentin reported means ranging from 1 to 7 MPa[27-29]. Some studies comparing the bond strength to caries-affected and normal dentin did not find significant differences between the two substrates using different types of GICs[30]. The results of the present study demonstrate a material-dependent relationship of bond strength according to the dentin substrate. Our results align with previous research indicating higher bond strength in sound dentin for Equia® Forte and similar high-viscosity glass ionomer cements[24,26,28]. The lower bond strength of glass ionomer cements to caries-affected dentin may be caused by the lower amount of calcium ions in the caries-affected dentin, reducing the opportunity for bonding between calcium ions and carboxyl groups[24]. This observation underscores the importance of considering the specific characteristics of dental substrates when selecting restorative materials.

Glass ionomer cements bond to dentin by chemical interaction and ion exchange at the tooth/restoration interface[11]. This interaction is formed during the setting reaction of the material, in which carboxylic radicals of the polyalkenoic acid chelate with calcium ions present in the dental structure, producing a layer composed of calcium salts and aluminum polyacrylate[31]. When polyacrylic acid is applied to dentin, the exposed calcium elements in hydroxyapatite become available for this chemical bond with carboxyl groups of the glass ionomer cement[32].

Differences in the concentrations of acid conditioners used in the materials may have influenced bond strength outcomes. Equia® Forte exhibited better interaction with sound dentin, possibly due to its lower acid concentration. On the other hand, Riva Self-Cure's higher acid concentration may have contributed to reduced bond strength in sound dentin but increased strength in caries-affected dentin across both caries removal methods.

There is no significant formation of smear layer when manual instruments are used for caries removal, which could result in better interaction of the material with calcium in dentin[33]. On the other hand, during caries removal with burs, there is a micromorphological alteration of the dentin surface and the formation of a thick smear layer[34]. This layer can affect the contact between the restorative material and the dentin structure, hindering proper adhesion[35]. However, the results of the present study demonstrated similar dentin bond strength for both GICs, regardless of whether excavation or bur was used.

Future investigations should explore variations in acid conditioner types and concentrations to optimize bond strength of high-viscosity GICs to caries-affected dentin. Additionally, more randomized clinical trials must be conducted to evaluate the clinical performance of high-viscosity glass ionomer cements associated with selective caries removal techniques.

In conclusion, the caries removal method did not negatively affect the dentin bond strength of Riva Self-Cure, while Equia® Forte had higher bond strength to sound dentin.

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Conflict of interest

None.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

Author Contribution

The authors **Vera Fernanda Gutierrez Alvarez** and **Luana Aparecida Jendik** performed the laboratorial procedures and wrote the initial draft of the manuscript. The author **Rodrigo Nunes Rached** designed the study and reviewed the manuscript. The author **Evelise Machado de Souza** designed the study, supervised the students, and reviewed the manuscript. All authors actively participated in discussing the manuscript's findings and have revised and approved the final version of the manuscript.

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