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Microleakage of Lithium Disilicate Crown Margins Finished on Direct Restorative Materials

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Clinical Relevance

Finishing lithium disilicate all-ceramic crowns on flowable resin composite materials in the esthetic zone should be used with caution. If necessary, finishing lithium disilicate all-ceramic crowns on nanofilled resin composite or resin-modified glass ionomer materials seems to provide the least amount of dye penetration.

SUMMARY

Objective: For some esthetic clinical situations, it is necessary to finish crown margins on direct restorative materials to preserve tissue integrity, bonding integrity, and biological width. The purpose of this research was to investigate microleakage at the interface between bonded lithium disilicate crowns and various direct restorative materials in a class III and class V position.

Methods and Materials: Class III or class V restorations were prepared on one side of extracted incisors with either Tetric EvoCeram, Tetric Evoceram Bulk, Fuji II LC, or Tetric Evoflow. The teeth were prepared for and received a lithium disilicate crown. After load fatiguing, the specimens were thermo-cycled with a fuchsin dye and sectioned. The depth and area of dye penetration were measured with a dimensional grid in micrometers using stereomicroscopy and reported as mean dye depth and area (μm) ± SD. The comparison of multiple categorical independent variables with ratio scale dependent variables was evaluated with an analysis of variance and Tukey's post hoc analysis.

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Results: A statistically significant higher dye penetration was noted for all treatment groups compared with the positive control (side opposite the restoration after sagittal sectioning was used as positive control) regardless of material or placement area ($p<0.05$). In comparing treatment groups, the Tetric EvoFlow experienced a statistically higher dye penetration than did the other treatment groups regardless of material or placement area ($p<0.05$). There was no statistically significant difference between the Tetric EvoCeram, Tetric Evoceram Bulk, and Fuji II LC materials regardless of placement area ($p>0.05$).

Conclusions: Within the limitations of this study, it can be concluded that flowable composite materials as finish lines that interact with resin cements could lead to exacerbated interfacial degradation. Finishing lithium disilicate all-ceramic crowns on flowable resin composite materials in the esthetic zone should be used with caution. If necessary, finishing lithium disilicate all-ceramic crowns on nanofilled resin composite or resin-modified glass ionomer materials seems to provide the least dye penetration depth and area.

INTRODUCTION

In some instances, the clinical situation dictates the necessity to finish crown margins on direct restorative materials in the esthetic zone. Typically class III and V restorations exist that may be above, at, or below the cemento-enamel junction (CEJ). To crown lengthen below existing restorations may compromise tissue integrity, bonding integrity, and biological width on highly esthetic cases. The current published literature does not contain any information for clinicians to provide evidenced-based decisions as to which direct restorative materials would function best in the aforementioned situation, if any. A recent clinical case report in the current literature described the treatment of a maxillary central incisor with class III invasive cervical resorption and a compromised ferrule with resin-modified glass ionomer (RMGI) and a full-coverage zirconia crown.[1] Optimal bond strength is the goal for long-term clinical success of all ceramic restorations. Optimizing bond strength to ceramic, enamel, and direct restorative materials will minimize microleakage associated with water sorption, dentin hypersensitivity, marginal staining, and caries formation.

Resin composite adhesive bonding is well documented within the current literature. Adhesive bonding of resin composite to enamel is very predictable and produces the highest bond strength using the total etch technique.[2] The high mineral content and low water content of enamel allows optimal adhesive bonding while reducing microleakage.[2] Adhesive bonding of a resin composite to dentin and cementum is less predictable due to the higher water content and increased technique sensitivity.[3] The current literature shows that dentin bonding is lower than enamel bonding due to the need for a hybrid layer within the dentinal collagen.[3] Clinical requirements to maintain a moist dentin while preventing water dilution of the adhesive material are difficult at best.[3] The hydrophilic portion of the primer needs to allow the formation of the hybrid layer within the dentinal collagen and tubules to minimize microleakage and sensitivity. The current literature suggests that long-term hydrolysis and proteolysis of the adhesive bond occurs naturally by innate defense mechanisms.[4,5] Additionally, conditioning and bonding to the existing resin composite has been published in the literature with varying results.[6,7] The consensus seems to be a decrease in bond strength across the repaired area in vitro.[6,7] A decrease in bond strength could lead to increased microleakage and a compromised long-term clinical survival of that restoration.[6,7]

RMGI restorative materials are also well documented in the current literature. These materials are advantageous in that they do not require adhesive bonding or mechanical retention within the preparation design.[8] The formulation of a “true” glass ionomer must have water, ion leachable glass, and polyacrylic acid for the acid-base reaction to occur.[8] The additional polyacrylic acid conditioner used as a separate step with this material allows chemical bonding to enamel, dentin, and cementum.[9] The acid-base setting reaction of the RMGI chemically bonds to calcium on the hydroxyapatite crystals and releases fluoride over time.[9] The resin monomer incorporation into the glass ionomer material provides improved esthetics and command light cure.[9] The final set glass can be conditioned with phosphoric acid and adhesively bonded also, as performed in the class II sandwich technique.[10] The current literature suggests that conditioning and adhesively bonding resin composite to a RMGI material yields a clinically acceptable interface.[8-10]

Flowable nano-hybrid resin composite materials have a lower filler content compared with traditional resin composites to improve fluid contact and reduce surface tension on tooth structures, especially at internal line angles.[11] Flowable bulk fill resin composites have been introduced recently to alleviate the need for small incremental placement. These restorative materials have been shown *in vitro* to experience dye microleakage around class II restorations.[12] There are no studies specifically evaluating the bonding of resin cement to either flowable or bulk fill resin composite materials. Therefore, through association, conditioning and bonding to existing resin composite could lead to a decrease in bond strength across the repaired area *in vitro* as with the nano-filled resin composite.[6,7] A decrease in bond strength could lead to increased microleakage and a compromised long-term clinical survival of that restoration.[6,7]

According to Wolfart,[13] there was no difference in clinical performance of bonded versus cemented lithium disilicate crowns after eight years. There are reported advantages to using a bonded technique versus a cemented technique. Simon and others[14] measured the tensile bond strength of the self-adhesive resin cements and a bonded resin cement for crowns bonded to extracted teeth with preparations having a total taper greater than 30°. It was concluded that some of the new self-etching resin cements can create bonds to nonretentive crown preparations that are stronger than the strength of a ceramic crown. Rojpaibool and Leevailoj[15] investigated the influence of cement film thickness, cement type, and substrate (enamel or dentin) on ceramic compressive fracture resistance. It was concluded that higher fracture loads were related to thinner cement film thickness and RelyX Ultimate resin cement (3M Corporation, St. Paul, MN). Bonding to dentin resulted in lower fracture loads than bonding to enamel.

Dye penetration for marginal sealing has been used for years as an acceptable surrogate to understand fluid flow and marginal integrity of the composites' cohesive and adhesive natures *in vitro*.[16-21] Therefore, the purpose of this research was to investigate the effects of interfacial microleakage when finishing pressed lithium disilicate ceramic crowns on various direct restorative materials in class III and class V positions. Of particular interest was the interface created between the resin cement and various direct restorative materials. The research questions for this evaluation were as follows:

1) Is there a difference in microleakage group means, measured as infiltration depth and area in micrometers, when comparing finish lines placed on class III and class V restorations made with different direct restorative materials (Tetric Evoceram, Ivoclar Vivadent Corp.,Amherst, NY; Tetric Evoceram Bulk, Ivoclar Vivadent Corp., Amherst, NY; Tetric EvoFlow, Ivoclar Vivadent Corp. Amherst, NY; and Fuji II LC, GC America, Alsip, IL) against a positive control for adhesively bonded lithium disilicate crowns in the esthetic zone? The null hypothesis for the first research question was that there will be no difference in microleakage depth or area in comparing treatment groups to the positive control.
2) Is there a difference in microleakage group means, measured as infiltration depth and area in micrometers, when comparing finish lines placed on class III and class V restorations made with different direct restorative materials (Tetric Evoceram, Tetric Evoceram Bulk, Tetric EvoFlow, and Fuji II LC) against treatment groups for adhesively bonded lithium disilicate crowns in the esthetic zone? The null hypothesis for the second research question was that there will be no difference in microleakage depth or area in comparing among treatment groups.

METHODS AND MATERIALS

Eighty newly extracted maxillary incisors were collected, mounted in acrylic, and stored in 1% thymol solution to prevent bacterial growth. Inclusion criteria required that all specimens be free of dental caries and existing direct or indirect restoration. Each specimen was randomly placed in one of four groups that received either a class III (n=10) or class V (n=10) restoration using the following: group 1, a nano-hybrid resin composite (Tetric EvoCeram); group 2, a nano-hybrid bulk fill resin composite (Tetric EvoCeram Bulk Fill); group 3, a nano-hybrid flowable resin composite (Tetric Evoflow); and group 4, an RMGI (Fuji II LC). Ten random specimens from the side opposite the restoration after sagittal sectioning were used as positive controls.

All groups received either a class III preparation or class V preparation as described above. The class III preparations were 8 (Incisal-Gingival) × 8 (Buccal-Lingual) × 2 mm (axially). The preparations were 4.0 mm (50%) above the CEJ and 4.0 mm (50%) below the CEJ (Figure 1). The class V preparations were 8 (Incisal-Gingival) × 8 (Mesial-Distal) × 2 mm (axially). The preparations were 4.0 mm (50%) above the CEJ and 4.0 mm (50%) below the CEJ (Figure 2). All preparations received incisal and gingival retention with a 1/2 round bur (Brasseler Corp., Savannah, GA, USA). All preparations were completed by two calibrated operative dentistry clinicians (one board certified) using the aforementioned prepara-

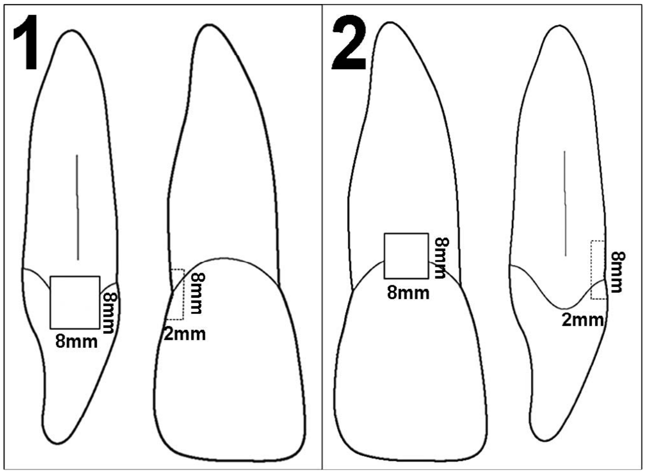

Figure 1. *Dimensional representation of the class III restoration placement.*
Figure 2. *Dimensional representation of the class V restoration placement.*

tion guidelines. Each specimen preparation was completed with a 245 carbide bur (Brasseler Corp.) under copious amounts of water coolant.

Group 1 was restored with a nano-hybrid resin composite restorative material in a crosshatch technique. The preparations were conditioned with 37% phosphoric acid (Total Etch, Ivoclar Vivadent, Amherst, NY) according to the manufacturer's recommendations and bonded with a fifth-generation single bottle bonding agent according to the manufacturer's recommendations (ExciTE F VivaPen, Ivoclar Vivadent). The bonding agent and resin composite restorative material were visibly light cured (VLC) with a calibrated (light intensity of 1200 mW/cm^2) light emitting diode (LED) curing unit (BluePhase and BluePhase Meter, Ivoclar Vivadent Corp) according to the manufacturer's recommendations. Restorations were polished with a serial composite finishing kit until highly polished (Astropol, Ivoclar Vivadent).

Group 2 was restored with a nano-hybrid bulk fill resin composite restorative material in a single application. Group 3 was restored with a nano-hybrid flowable resin composite restorative material in a crosshatch technique. Groups 2 and 3 were restored in the same sequence with the same products as group 1.

Group 4 was restored with an RMGI restorative material in a single application. The preparations were conditioned with 20% polyacrylic acid (GC Cavity Conditioner, GC America Corp., Tokyo, Japan). The RMGI material was placed in bulk according to the manufacturer's recommendations and VLC light cured with a calibrated (light intensity of 1200 mW/cm^2) LED curing unit (BluePhase and BluePhase Meter, Ivoclar Vivadent). Restorations remained hydrated and were polished with a serial composite finishing kit until highly polished (Astropol, Ivoclar Vivadent).

All 80 specimens (groups 1-4) were prepared to receive pressed lithium disilicate full-coverage indirect prostheses with a diamond bur (FG Medium Round End Taper Diamond, Brasseler Corp). All finish margins were a 90° shoulder performed by two calibrated faculty members within the authorship of this publication. The finish lines were placed 2 mm above the CEJ, with an axial reduction of 2 mm (Figure 3). All specimens had 8 mm of finished margin on the direct restorative material at the treatment side. Following preparation of all 80 specimens, a polyvinylsiloxane (PVS) impression (Virtual XD, Ivoclar Vivadent) of each specimen group was taken and labeled according to group and specimen. The PVS impressions were poured with a vacuum-mixed gypsum stone (Jade Stone, Whip Mix Corp., Louisville, KY, USA) to create laboratory analogs and were labeled. Full contour wax crowns were made on the stone analogs and pressed to full contour lithium disilicate ceramic crowns (IPS e.max, Ivoclar Vivadent) at a local dental laboratory. Original specimens were stored in individually labeled containers of 10% thymol at 37°C during the ceramic crown fabrication process.

On return from the local dental laboratory, all 80 ceramic crowns (intaglio pre-etched from the laboratory; 5% hydrofluoric acid) were evaluated for marginal integrity and delivered using a self-etching dual-cured resin adhesive luting system. Monobond Plus primer (Ivoclar Vivadent Corp) was placed on the intaglio of the crowns and let dry for 20 seconds. Multilink Primer A and B were mixed and scrubbed into the preparations for 20 seconds and air dried. A thin layer of the self-etch resin luting agent was placed in the intaglio of the crown and delivered (Multilink Automix, Ivoclar Vivadent). After hand pressure seating and removal of excess marginal material, all crown margins were VLC light cured with a calibrated (light intensity of 1200 mW/cm^2) LED curing unit (BluePhase and BluePhase Meter, Ivoclar Vivadent). All crown margins were polished with a serial composite finishing kit until highly polished (Astropol, Ivoclar Vivadent). Please see Table 1 for experimental design.

All specimens were exposed to cyclic uniaxial loading and thermocycled to measure possible variation in microleakage within experimental

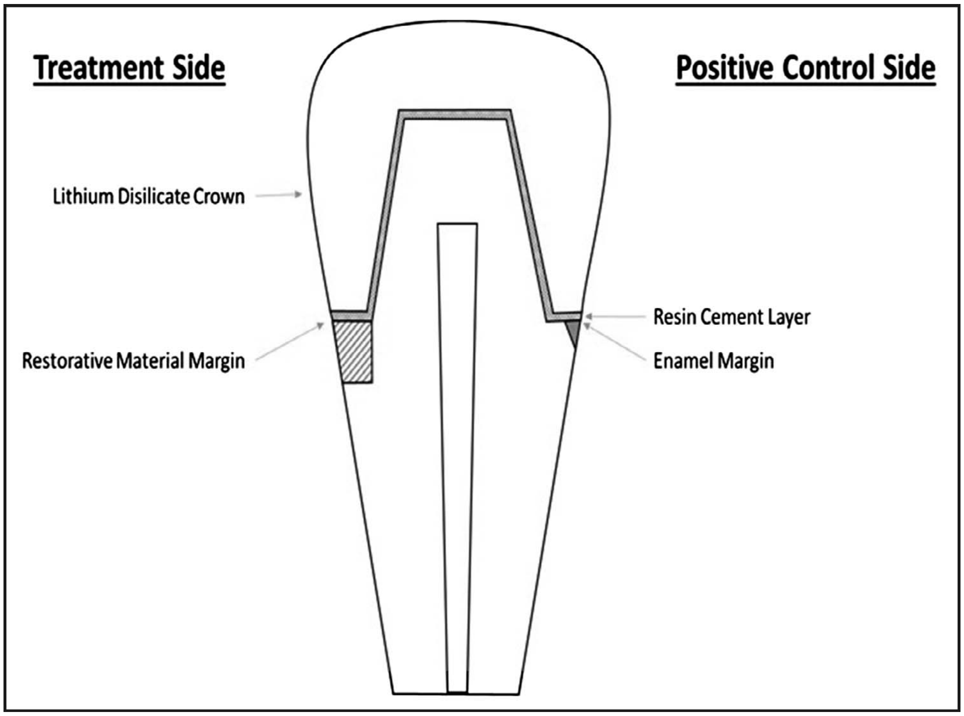

Figure 3. *Pictorial representation of the finish lines for the study of lithium disilicate crowns. Positive control side finished on enamel and treatment side finished on various restorative materials.*

groups and against the controls. All specimens were subjected to dry uniaxial compressive cyclic loading in an Instron (Instron USA, Norwood, MA) testing machine at 12 Hz for 10,000 cycles. A variable compressive load (40-400 N) was applied in the central fossa at an angle of 15° (buccal-lingual) to the long axis of the specimens to mimic shear forces possible experienced clinically. All specimens were then thermocycled with a red 0.5% basic fuchsin dye tracer (0.5 g basic fuchsin dye in 20 mL 95% ethanol diluted to 100 mL with distilled water) from 6°C to 60°C (five-minute dwell time) for 48 hours and immediately sagittal sectioned with a water-cooled diamond saw through the middle of the restorative material in three 2-mm sections. Each section was evaluated immediately for depth and area of dye penetration (micrometers) under stereomicroscopy (50×) on both the treatment side and the control side using a 1-μm boxed dimensional grid. The three sagittal-sectioned specimens were measured and averaged for an overall average dye penetration value.

The depth and area of dye penetration were measured with a dimensional grid in micrometers using stereomicroscopy and reported as mean dye depth and area (micrometers) ± standard deviation. The dimensional grid was boxed with 1-μm squares for easy measurement. The depth of the dye was measured from the cavosurface margin axially to the end of dye penetration in micrometers. The area of dye penetration was measured from the cavosurface margin axially as depth × width in micrometers. Four experimental dental materials were compared with positive control and within-treatment groups regarding mean depth and area of dye penetration in micrometers using analysis of variance (ANOVA) and Tukey post hoc analysis. The significance level was set at $p<0.05$ for these evaluations.

RESULTS

Class III Restoration Dye Penetration

Class III Depth—The descriptive statistics for the class III depth evaluation of all four treatment groups and the positive control are listed in Table 2. Different lowercase letters in Table 2 represent statistically significant differences in group dye depth penetration means. According to the ANOVA, a statistically significant difference exists among the control and four treatment groups (df=4,45; observed $F=92.7$; $p=0.012$, $p<0.05$). A Tukey's post hoc analysis was performed and determined that all four treatment groups were statistically significantly higher in dye penetration depth compared with the control ($p=0.022$, $p<0.05$). The Tetric EvoFlow treatment group was statistically significantly higher in dye penetration depth compared with the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p=0.024$, $p<0.05$). There was no statistically significant difference in dye depth

Table 1: *Sampling Methodology and Study Design*[a]

Tetric EvoCeram (TEC) (N=20)	Tetric EvoCeram Bulk (TEB) (N=20)	Tetric EvoFlow (TEF) (N=20)	Fuji II LC (FLC) (N=20)	Positive control (opposite side of tooth)
Class III (n=10)	Class III (n=10)	Class III (n=10)	Class III (n=10)	10 random samples from 40 specimens (n=10)
Class V (n=10)	Class V (n=10)	Class V (n=10)	Class V (n=10)	10 random samples from 40 specimens (n=10)
37% phosphoric acid conditioner Adhesive restoration bonding: ExciTE F (N=60)			20% polyacrylic acid conditioner (N=20)	
IPS e.Max All Ceramic Crown Press Luting- Multilink Automix Resin Adhesive Luting System (N=80)				

[a] All materials used according to the manufacturer recommendations.

penetration when comparing the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p>0.05$).

Class III Area—The descriptive statistics for the class III area evaluation of all four treatment groups and the positive control are listed in Table 3. Different lowercase letters in Table 4 represent statistically significant differences in group dye area penetration means. According to the ANOVA, a statistically significant difference exists among the control and four treatment groups (df=4,45; observed $F=270.6$; $p=0.022$, $p<0.05$). A Tukey's post hoc analysis was performed and determined that all four treatment groups had statistically significantly higher in dye penetration area compared with the control ($p=0.032$, $p<0.05$). The Tetric EvoFlow treatment group was statistically significantly higher compared with the Tetric EvoCeram, Tetric EvoCeram Bulk Fill and Fuji II LC treatment groups ($p=0.012$, $p<0.05$). There was no statistically significant difference in dye area penetration when comparing the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p\geq0.05$).

Class V Restoration Dye Penetration

Class V Depth—The descriptive statistics for the class V depth evaluation on all four treatment groups and the positive control are listed in Table 4. Different lowercase letters in Table 3 represent statistically significant differences in group dye depth penetration means. According to the ANOVA, a statistically significant difference exists among the control and four treatment groups (df=4,45; observed $F=106.2$; $p=0.011$, $p<0.05$). A Tukey's post hoc analysis was performed and determined that all four treatment groups were statistically significantly higher in dye penetration depth compared with the control ($p=0.023$, $p<0.05$). The Tetric EvoFlow treatment group was statistically significantly higher in dye penetration depth compared with the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p=0.025$; $p<0.05$). There was no statistically significant difference in dye depth penetration when comparing the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p>0.05$).

Class V Area—The descriptive statistics for the class V area evaluation on all four treatment groups and the positive control are listed in Table 5. Different lowercase letters in Table 5 represent statistically significant differences in group dye area penetration means. According to the ANOVA, a statistically significant difference exists among the control and four treatment groups (df=4,45; observed $F=271.4$; $p=0.017$, $p<0.05$). A Tukey's post hoc analysis was performed and determined that all four treatment groups were statistically significantly higher in dye penetration area compared with the control ($p=0.019$, $p<0.05$). The Tetric EvoFlow

Table 2: *Class III Depth Descriptive Statistics*[a]

	Class III depth: Descriptive statistics		
	Group mean	Group standard deviations	Sample size
Positive control	190.4[a]	±11.6	N=10 × 3 sections
Tetric EvoCeram (TEC)	249.2[b]	±16.3	N=10 × 3 sections
Tetric EvoCeram Bulk (TEB)	270.0[b]	±17.4	N=10 × 3 sections
Tetric EvoFlow (TEF)	358.6[c]	±28.0	N=10 × 3 sections
Fuji II LC (FLC)	245.2[b]	±23.0	N=10 × 3 sections

[a] Different lowercase letters represent a statistical significant difference in group means.

Table 3: *Class III Area Descriptive Statistics*[a]

	Class III area: Descriptive statistics		
	Group mean	Group standard deviations	Sample size
Positive control	10,702.1[a]	±1018.7	N=10 × 3 sections
Tetric EvoCeram (TEC)	22,701.7[b]	±1446.7	N=10 × 3 sections
Tetric EvoCeram Bulk (TEB)	24,742.9[b]	±2512.4	N=10 × 3 sections
Tetric EvoFlow (TEF)	36,884.2[c]	±2272.5	N=10 × 3 sections
Fuji II LC (FLC)	23,341.5[b]	±8801.9	N=10 × 3 sections

[a] Different lower case letters represent a statistical significant difference in group means.

treatment group was statistically significantly higher compared with the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups (p=0.022, $p<0.05$). There was no statistically significant difference in dye area penetration when comparing the Tetric EvoCeram, Tetric EvoCeram Bulk Fill, and Fuji II LC treatment groups ($p \geq 0.05$).

DISCUSSION

Dye penetration for marginal sealing has been used for years as a surrogate to understand fluid flow and marginal integrity of composites cohesive and adhesive natures in vitro.[16-21] Therefore, the purpose of this research was to investigate the effects of interfacial microleakage when finishing pressed lithium disilicate ceramic crowns on various direct restorative materials in class III and class V positions. Of particular interest was the interface between resin cement and direct restorative materials in the esthetic zone. The research questions for this evaluation were as follows:

1) Is there a difference in microleakage group means, measured as infiltration depth and area in micrometers, when comparing finish lines placed on class III and class V restorations made with different direct restorative materials (Tetric EvoCeram, Tetric EvoCeram Bulk Fill, Tetric EvoFlow, and Fuji II LC) against a positive control for adhesively bonded lithium disilicate crowns in the esthetic zone? According to the results of this study, the null hypothesis has been rejected with a statistically significant difference in microleakage depth and area between the treatment groups and the positive control for both class III and V restorations.
2) Is there a difference in microleakage group means, measured as infiltration depth and area in micrometers, when comparing finish lines placed on class III and class V restorations made with different direct restorative materials (Tetric Evoceram, Tetric EvoCeram Bulk Fill, Tetric EvoFlow, and Fuji II LC) against treatment groups for adhesively bonded lithium disilicate crowns in the esthetic zone? According to the results of this study, the null hypothesis has been rejected with a statistically significant difference in microleakage depth and area of the Tetric EvoFlow compared with the other treatment groups for both class III and V restorations. All other treatment groups were not statistically different.

Although there are no set standards for dye penetration evaluations, the ISO standard on testing the adhesion to tooth structure describes a microleakage test in the cavities of third molars with a diameter of 3 mm, a depth of at least 1 mm, and a sample size of at least 10.[19] It has been suggested in the literature that multiple sectional averages of specimens on dye tracer penetration yields more accurate results than single sections alone.[20]

Table 4: *Class V Depth Descriptive Statistics*[a]

	Class V depth: Descriptive statistics		
	Group mean	Group standard deviations	Sample size
Positive control	187.6[a]	±12.3	N=10 × 3 sections
Tetric EvoCeram (TEC)	251.7[b]	±17.2	N=10 × 3 sections
Tetric EvoCeram Bulk (TEB)	250.1[b]	±16.9	N=10 × 3 sections
Tetric EvoFlow (TEF)	348.6[c]	±21.1	N=10 × 3 sections
Fuji II LC (FLC)	254.5[b]	±18.7	N=10 × 3 sections

[a] Different lowercase letters represent a statistical significant difference in group means.

Table 5: *Class V Area Descriptive Statistics*[a]

	Class V area: Descriptive statistics		
	Group mean	Group standard deviations	Sample size
Positive control	11,502.3 (a)	±1052.2	N=10 × 3 sections
Tetric EvoCeram (TEC)	20,905.7 (b)	±1605.4	N=10 × 3 sections
Tetric EvoCeram Bulk (TEB)	22,695.1 (b)	±2460.6	N=10 × 3 sections
Tetric EvoFlow (TEF)	36,874.4 (c)	±2173.8	N=10 × 3 sections
Fuji II LC (FLC)	21,671.3 (b)	±1521.7	N=10 × 3 sections

[a] Different lowercase letters represent a statistical significant difference in group means.

Due to the fuchsin dye being water based, it is not unreasonable to consider its diffusion similar to water diffusion within marginal interfaces of resin cement approximating various restorative materials. The 0.5% basic fuchsin dye tracer is a water-based solution that represents the diffusion of that dye through the set chemical interfacial composition. Water diffusion and sorption has been evaluated within the set bis-acrylic matrices and the bis-acrylic/filler interface.[21-23] Water sorption and solubility have been evaluated on resin cements in the current literature as well.[24-26] Water sorption and diffusion has been shown to affect the interface between self-etch resin cement and silanated ceramics.[27] Conclusions on water sorption and diffusion claim a reduction in physical properties, mechanical properties, and optical properties *via* accelerated degradation of the set material. Missing from the current literature is the evaluation of microleakage at a resin cement/restorative material interface. Additionally, due to the variability in methodology across studies, a systematic review to correlate dye penetration to clinical ramifications (material properties, hypersensitivity, retention, marginal staining, or marginal caries) is lacking in the current published literature.[28]

In evaluating the control side of the specimens, dye penetration occurred within the resin cement matrix between the ceramic substrate and the enamel substrate. In using the surface opposite of the treatment side, it was postulated that both surfaces would undergo similar shear force movement and thermocycling of the resin cement layer. One limitation of the specimen comparisons is that the control and experimental side of the teeth in the class V group experienced different loading forces due to the 15° off-axis loading. The dye penetration started at the cavosurface area and worked itself axially. Most of the dye penetration occurred at the resin cement/enamel interface compared with the resin cement/ceramic interface. The control sides of the specimens groups experienced some dye penetration. Therefore, in terms of fluid flow and water diffusion, some microleakage is occurring at the resin cement/ceramic interface and the enamel/resin cement interface, with deeper penetration at the resin cement/enamel interface as viewed in the stereomicroscope (50×).

In evaluating the Tetric EvoCeram (TEC) group in the class III and V positions, the dye penetration for depth and area was significant higher than the control. Most of the dye penetration occurred at the resin cement/TEC interface as viewed under the stereomicroscope (50×). In evaluating the Tetric EvoCeram Bulk Fill (TEB) group in the class III and V positions, the dye penetration for depth and area was significant higher than the control. Most of the dye penetration occurred at the resin cement/TEB interface as viewed under the stereomicroscope (50×). In evaluating the Tetric EvoFlow (TEF) group in the class III and V positions, the dye penetration for depth and area was significant higher than the control. Most of the dye penetration occurred at the resin cement/TEF interface as viewed under the stereomicroscope (50×). The conditioning, bonding, and placement of resin cement to an existing composite restoration yielded an interface more susceptible to dye penetration compared with the control.[6,7]

In evaluating the Fuji II LC (FLC) group in the class III and V positions, the dye penetration for depth and area was significant higher than the control. Most of the dye penetration occurred at the resin cement/FLC interface as viewed under the stereomicroscope (50×). The final set glass can be conditioned with phosphoric acid and adhesively bonded also as performed in the class II sandwich technique.[10] Conditioning and adhesively bonding resin composite to a RMGI material yield a clinically acceptable interface.[8-10] The micromechanical locking of the resin cement to the existing FLC restoration could have been improved if the total etch technique was utilized. The self-etching resin cement used could have prevented the integration needed to create a less permeable interface.

In comparing the treatment groups, the TEF class III and V experienced a significantly higher dye penetration depth and area than did the TEC, TEB, and the FLC. The TEF group created a poor interface with the resin cement. The interface created was very permeable to fluid flow and the dye penetrated much deeper into the resin cement layer and into the set flowable composite itself. The dye penetrated in the set TEF material more easily in a greater volume exhibiting some inherent diffusion characteristics that are noteworthy for further investigation. One can theorize that the limited filler in the TEF composite with high matrix lends itself vulnerable to water diffusion characteristics not experienced in TEC, TEB, and FLC materials.

A systematic review on dye penetration and bond strength to tooth structure determined that there is no correlation between the two.[29] However, there are no studies containing any information on dye penetration at the interface between resin cement and direct restorative materials or what that might mean. Additionally, cause and effect relationships between dye microleakage and restoration failure were reported in the current literature without providing adequate correlation coefficients, coefficient of determinations, linear regression, multiple regression, or percentage of common variance that any variables may have shared.[28-30] The results from this study determined that in comparing the control and experimental groups, the interface created by a self-etching resin luting agent was significantly better to enamel. The significant fluid flow and diffusion of the water-based dye at the interface layer suggests a weaker interaction of resin cement and direct restorative materials. The correlation between dye penetration and marginal gaps analysis with a scanning electron microscope was reviewed and determined that a marginal correlation existed. Again, this dye penetration study measured the restorative material/tooth structure interface.[29] In terms of clinical implications, there exists no studies in the current *in vitro* and *in situ* literature that demonstrate a correlation between microleakage and hypersensitivity and/or secondary caries formation.[31,32]

According to the results of this study, there is higher dye penetration depth and area when finishing pressed lithium disilicate crowns on all the examined existing class III and V restorative materials compared with the control. In terms of microleakage and fluid diffusion, increased fluid flow within these materials could have a detrimental effect on the long-term success of clinical indirect all-ceramic restorations. As shown with the flowable resin composite (TEF), high polymerization stress shrinkage and limited filler may lend itself to deeper dye penetration and possible exacerbated degradation. The authors are cognizant not to draw clinical implications from this *in vitro* evaluation as there is no set accepted standard for dye penetration depth within restorative materials or proven clinical implications.[30] It is important, however, for clinicians to be aware of the possibility of interfacial degradation and limited performance of flowable resin composite materials interacting with resin cement as finish lines for lithium disilicate all-ceramic crowns.

CONCLUSION

Within the limitations of this study, it can be concluded that flowable composite materials as finish lines that interact with resin cements could lead to exacerbated interfacial degradation. Finishing lithium disilicate all-ceramic crowns on flowable resin composite materials in the esthetic zone should be used with caution. If necessary, finishing lithium disilicate all-ceramic crowns on nanofilled resin composite, nanofilled bulk fill composite, or RMGI materials seems to provide the least dye penetration depth and area.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subject's oversight committee guidelines and policies of: University of Louisville. The approval code for this study is: 14.0995.

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.

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