Operative Dentistry, 2006, **31-6**, 719-727

Microleakage in the Proximal Walls of Direct and Indirect Posterior Resin Slot Restorations

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Clinical Relevance

Evaluation of microleakage in proximal resin restorations in relation to factors such as the type of dentin bonding system and the location of gingival margins may provide information that can aid clinicians in their attempt to reduce the occurrence of microleakage.

SUMMARY

This study compared the degree of microleakage in the proximal walls of direct and indirect resin slot restorations in relation to the types of dentin bonding systems and the location of gingival margins. Two Class II slot preparations were prepared and restored in each of 60 extracted human molars using direct (Filtek Supreme) and indirect (Tescera ATL) restorative resin materials. Various types of dentin bonding systems, including self-etching (OneStep Plus/Tyrian SPE, iBond, Xeno III) and etch and rinse systems (All-Bond 2, Prime & Bond NT) were used to restore the prepared teeth. The gingival proximal wall was placed apical to the cementoenamel junction (CEJ) in 1 proximal box and coronal to the CEJ in the other. The specimens were stained and evaluated for microleakage using a digital imaging and analysis system. Significant differences were found in the degree of microleakage observed in the various restorative groups. In general, the group restored with indirect resin had less microleakage than the direct resin groups. Factors, such as type of dentin bonding system and location of gingival margins, exert a substantial influence on the degree of microleakage that occurred along the walls of proximal resin restorations.

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DOI: 10.2341/05-148

INTRODUCTION

As the demand for esthetic tooth-colored restorations increases, resin composite restorations are being utilized in more clinical situations. In the past, these restorations were considered for use in only non-stress bearing areas due to deficiencies in their wear and fracture resistance,[1] which were considered poor compared to those of amalgam restorations.[2-3] The physical properties of these resin restorative materials have improved over the years, especially in regard to their wear and fracture resistance,[4-6] and their use in stress-bearing posterior restorations has increased dramatically. Although these resin restorative materials have improved, they still exhibit characteristics that can have a major impact on their clinical success, especially on their ability to seal the interface between the tooth and restoration.

Despite their improvements, microleakage at the interface of the resin composite and tooth is still considered to be a major problem.[7-8] Resin composite materials rely on adhesive bonding to produce a seal between the restoration and the tooth structure and, if not adequate, restoration failure can occur due to secondary caries.[9] Adding to this problem is the consideration that these materials have no antimicrobial effect on the pathogenic bacteria of the oral environment.[10-11] In light of all of these factors, creating an effective seal between the resin composite and tooth structure remains a critical factor in the longevity of resin composite restorations.

One reason microleakage occurs in resin composite restorations is due to stress created between the restorative material and the cavity walls during the polymerization process.[12-13] If stress created by the polymerization shrinkage of the restorative material is greater than the bond of the resin to the tooth structure, gap formation may occur and lead to microleakage.[14] Attempts to reduce the adverse effects of polymerization stress on resin composite restorations have led clinicians to use various types of adhesive systems, preparation techniques and curing regimens. One technique employed to minimize polymerization shrinkage is indirect resin composite restorations. These restorations are adapted to a die of the cavity preparation and are subsequently cured. The finished restoration is then bonded to the cavity preparation utilizing a thin film of resin luting cement. Theoretically, this should eliminate much of the stress placed on the bonded resin adhesive and tooth interface due to a decreased amount of polymerization shrinkage. However, some clinical studies indicate that there is no significant difference in the clinical success rate of indirect versus direct resin restorations.[15-17]

Another characteristic of resin composite restorations, which can affect their clinical success, is decreased bond strengths to dentin when compared to their bond strengths to enamel. Earlier microleakage studies have indicated that a resin adhesive bond to enamel margins exhibits less microleakage than those in non-enamel margins.[18-20] There is evidence that the absence of enamel tooth structure in cavity margins located apical to the CEJ make them more difficult to seal.[21] Because of this decreased ability to bond to dentin tooth structure, improvements in bonding systems have been primarily directed toward enhancing the ability to create a strong, effective bond between resin and dentin.

Dentin bonding systems that use a variety of approaches to achieve a bonded interface between the restoration and tooth structure are currently available. Dentin bonding systems that utilize a separate acid-conditioning (etch and rinse) approach have been widely used for many years. More recently, dentin bonding systems that do not require a separate acid-conditioning step (self-etching) have been developed. Although some of these materials are less time-consuming and less technique-sensitive than earlier dentin bonding systems, there has been some question as to whether they are able to achieve the excellent bond to enamel that earlier systems exhibited. Studies have suggested that some newer self-etching dentin bonding systems may not bond to enamel as well as the more traditional etch and rinse systems.[22-27]

This study compared the degree of microleakage in proximal facial, gingival and lingual walls of direct and indirect resin slot restorations in relation to the type of dentin bonding system and the location of gingival margins.

METHODS AND MATERIALS

Sixty non-carious extracted human molars were stored in deionized water at room temperature. The molars were randomly divided into 6 experimental groups consisting of 10 teeth each. The specimens in 5 of the groups were restored with direct resin composite restorations; whereas, the specimens in the remaining group were restored with indirect resin restorations.

Cavity Preparation for Direct Resin Composite Restorations

Slot cavity preparations were prepared in the mesial and distal surfaces of each of 50 teeth as follows: all preparations were cut with a #1157L high-speed carbide bur (Brasseler USA, Savannah, GA, USA) under air/water coolant. Both slot preparations in each tooth were 4 mm wide buccolingually and 2 mm wide mesiodistally at the gingival wall. They were prepared with rounded internal line angles and no retentive grooves. On each tooth, one of the slot preparations had

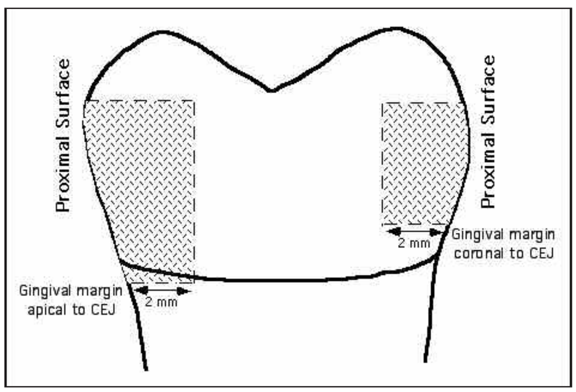

Figure 1. *Diagram of cavity preparations.*

the gingival wall placed in enamel coronal to the CEJ (0.5 mm to 1.0 mm width of enamel remaining in the gingival wall), and the other had the gingival wall placed in cementum just apical to the CEJ (no enamel remaining in the gingival wall) as shown in Figure 1.

Cavity Preparation for Indirect Resin Composite Restorations

Slot cavity preparations were prepared as described above with one modification: the walls were divergent to allow for insertion of the indirect restoration. Ten of the slot preparations had gingival walls apical to the CEJ and 10 had gingival walls located coronal to the CEJ as described above.

Restorative Procedure for Direct Resin Composite Restorations

Proximal preparations in teeth assigned to each individual group were restored in an identical fashion utilizing the same dentin bonding system. The cavity preparations were cleaned with medium pumice slurry, and a stainless steel Tofflemire matrix was placed around the tooth. After applying 1 of the 5 dentin bonding systems as per manufacturers' instructions (Table 1), all preparations in the direct restorative groups were restored with shade A1 Filtek Supreme resin composite (3M ESPE, St Paul, MN, USA) in increments no thicker than 2 mm. The cavity preparations were restored in approximately 3-4 increments, depending on the depth of the gingival wall. Each increment was cured for 20 seconds with a halogen light source (Spectrum 800, Dentsply Caulk, Milford, DE, USA) at a power density of 550 mW/cm^2. After the Tofflemire matrix was removed, the restorations were cured from the facial and lingual portion of the tooth to assure adequate curing, simulating clinical protocol. The restorations were finished with high speed finishing burs and abrasive discs (Sof-Lex, 3M ESPE). They were then stored in deionized water until thermocycling, which consisted of 500 cycles with 30-second dwell times (5°–23°-47°C).

Restorative Procedure for Indirect Resin Composite Restorations

Polyvinylsiloxane (Reprosil, Dentsply Caulk) impressions were made of the inlay slot preparations. Dies were fabricated using die stone (Silky Rock, Whip Mix Corp, Louisville, KY, USA). The indirect inlays were fabricated using Tescera ATL resin composite (BISCO, Inc, Schaumburg, IL, USA) according to the manufacturer's instructions (Table 2). The restoration was fabricated and initially cured on the die using pressure and light after each increment was placed. The restoration was removed from the die and the final curing was done in a Tescera ATL polymerization unit (BISCO, Inc) under water in the presence of heat, pressure and light.

The restorations were trial fitted onto the teeth, and the margins were adjusted as needed. Prior to cementation, the internal surfaces of the restorations were air abraded with 50 µm aluminum oxide particles for 1-2 seconds and treated with 2 coats of silane primer. Following air-drying, 1 coat of One-Step Plus bonding resin (BISCO, Inc) was applied to the restoration, air-dried and cured. The teeth were dried and Tyrian SPE self-priming etchant (BISCO, Inc) was applied to the surfaces of the teeth in 2 coats and agitated for 10 seconds. Excess primer was removed from the tooth surfaces and 2 coats of One-Step Plus dentin bonding resin were applied, air-dried and light-cured. The restoration was cemented into place using Illusion dual cure resin cement (BISCO, Inc). Excess cement was removed, and the resin cement was light-cured for at least 40 seconds. The margins were finished and polished with abrasive discs and rubber points. The specimens were stored for at least 24 hours prior to thermocycling.

Staining

Areas of microleakage were identified using a 50% aqueous solution of $AgNO_3$ as described by Wu and others.[28] Prior to staining, the root apices were sealed with Vitrebond resin-modified glass ionomer (3M ESPE). The entire tooth surface was sealed to within 1 mm of the cavosurface margins using fingernail polish to allow staining to occur only at the tooth-restoration interface. The specimens were then immersed in the $AgNO_3$ solution for 2 hours at room temperature in the absence of light, rinsed for 1 minute in running water and immersed in radiographic developing solution for 6 hours, while exposed to florescent lighting. Following a 10-minute water rinse, the specimens were dried, then mounted in acrylic bases in preparation for incremental facing.[28]

Sectioning and Measurement of Microleakage

The sectioning and measurements were accomplished using the following protocol, as shown in Figure 2: The acrylic base of the specimens fit into a custom-mounting device that was secured to the table of a precision sectioning instrument (Micromech MFG Corp, Rahway, NJ, USA). A 240-grit diamond-impregnated resin cup grinder (#11-2740, Buehler Ltd, Lake Bluff, IL, USA) was mounted in the sectioning instrument. The specimen was aligned and locked into place to allow the face of the abrasive grinding wheel to parallel the proximal surface of the restoration. The table of the sectioning instrument could be moved accurately for removal of 0.25 mm increments of the outer surface of the specimen. The diagram in Figure 3 summarizes the distribution of specimens in each experimental group. A digital photograph was taken using a stereo-optical microscope (Model SZX12, Olympus America, Inc, Melville, NY, USA) and camera (Spot 2, Diagnostics, Inc, Sterling Heights, MI, USA) to record an image of the tooth-restoration interface at each facing increment (Figure 4). Any microleakage present was indicated by

Table 1: *Summary of Dentin Bonding Systems for Direct Resin Restorative Groups*

Bonding System	System Components	Number of Steps	Composition	Lot #
(AB) All-Bond 2 3 step etch & rinse BISCO, Inc Schaumburg, IL, USA	Separate etch	**Step 1** UNI-ETCH–15 seconds Rinse with water	32% H_3PO_4, Benzalkonium chloride	#030004518
	2-bottle primer	**Step 2** Primer A	Acetone, Ethanol, Na-N-tolylglycine glycidylmethacrylate	#0300005598
		Primer B	Acetone, Ethanol, Biphenyl dimethacrylate	#0300006107
		Mix and apply 5 coats, air dry		
	1-bottle bond resin	**Step 3** D/E Resin Apply thin coat, light cure	Bisphenol A diglycidylmethacrylate, Urethane dimethacrylate, Hydroxyethyl methacrylate	#0300006501
(IB) iBond 1 step self-etch Heraeus Kulzer Armonk, NY, USA	1 bottle self-etching Primer/Bond resin	**Step 1** Bond resin Apply 3 coats, agitate for 30 seconds, light cure	Acetone, 4-Methacryloxyethyltrimellitanhydrid, Diurethandimethacrylate, glutaral, 2-hydroxyethyl methacrylate, 2-(n-Butoxy)ethyl-4-dimethylaminobenzoat, 2,3 Bornandion, Butyl-hydroxy-toluol	#010027
(PB) Prime & Bond NT 3 step etch & rinse Dentsply Caulk Milford, DE, USA	Separate etch	**Step 1** UNI-ETCH—15 seconds Rinse with water	32% H_3PO_4, Benzalkonium chloride	#030004518
	1 bottle Primer/Bond resin	**Step 2** Prime & Bond NT resin Apply for 20 seconds, air dry, light cure	Di- and Trimethacrylate, PENTA (dipentaerythritol penta acrylate monphosphate), Silicon dioxide fillers, Cetylamine hydrofluoride, photoinitiators	#021220
(OS) One-Step Plus/ Tyrian SPE 2 step self-etch BISCO, Inc Schaumburg, IL, USA	2 bottle self-priming etchant	**Step 1** Tyrian Self-Priming Etchant Part A Part B	Ethanol 2-Acrylamido-2-methyl propanesuflonic acid	#0300006390
	1 bottle bond resin	**Step 2** One-Step Plus bond resin Apply 2 coats for 15-20 seconds, blot excess Mix, apply 2 coats, agitate 20 seconds, air dry, light cure	Biphenyl dimethacrylate, Hydroxyethyl methacrylate, Acetone Bis (2-(methacryloyloxy)ethyl) phosphate, Ethanol	#0300006240
(XN) Xeno III 1 step self-etch Dentsply Caulk Milford, DE, USA	2 bottle self-etching Primer/Bond resin	**Step 1** Xeno III resin Liquid A	Hydroxyethyl methacrylate, Ethyl alcohol	#0302000573
		Liquid B Mix, apply for 20 seconds, air dry, light cure	Phosphoric acid modified methacrylate, Fluoride releasing polyfunctional methacrylate resin, Urethane dimethacrylate	

All 5 direct resin restorative groups were restored with Filtek Supreme (FS) resin composite (3M ESPE, St Paul, MN, USA) Lot #3AL 2006-04

Table 2: *Summary of Steps for Fabrication of Indirect Resin Restorations*

Restorative System	Fabrication and Insertion	Composition	Lot #
(TS) Indirect Inlay BISCO, Inc Schaumburg, IL, USA	Fabrication: Tescera Dentin (87% filled by wt) Tescera Body (72% filled by wt) • Fabricated on die • Initial layers cured with pressure and light on die • Final cure in water bath with heat, pressure and light	• Ethoxylated Bisphenol A dimethacrylate • BisPhenol diglycidylmethacrylate Glass Frit, Amorphous Silica	#0100012673 #0100013111
	Inlay surface preparation: • Air abrade internal surface of inlay • Apply Composite Activator to inlay • air-dry • Apply One-Step dentin bond resin • air-dry • light cure	• 50 micron aluminum oxide particles • Methyl methacrylate, Isobutyl methacrylate • Biphenyl dimethacrylate, Hydroxyethyl methacrylate, Acetone	#0200001858 #0300006240
	Tooth surface preparation: • Dry • TyrianSelf-Priming Etchant Part A Part B • Blot dry • Apply 2 coats of One-step dentin bonding resin • Air dry • Light cure	• Ethanol • 2-Acrylamido-2-methyl propanesuflonic acid, Bis (2-(methacryloyloxy)ethyl) phosphate, Ethanol	#0300006390 #0300006391
	Cementation: • Illusion resin cement • Equal parts: Catalyst and Base • Apply to Inlay and tooth preparation • Seat inlay • Remove excess cement • Light cure	• Bisphenol A diglycidylmethacrylate, Triethyleneglycol dimethacryate, 70% Glass filled by wt	#200008620 #200008621

the black $AgNO_3$ stain. The lengths of the lingual, facial and gingival walls were measured using IPLab software (Scanalytics, Inc, Fairfax, VA, USA) along with the corresponding lengths of microleakage occurring along each wall.

The percent of microleakage for the gingival wall ($M_{G\%}$) was defined as the measured length of the microleakage observed (M_G) divided by the measured length of the gingival wall (L_G).

$$M_{G\%} = \frac{M_G}{L_G} \text{x } 100\%$$

The total percent microleakage ($M_{T\%}$) was defined as the percentage of the sum of the measured lengths of microleakage for the lingual (M_L), gingival (M_G) and facial (M_F) walls divided by the sum of the measured lengths of the lingual (L_L), gingival (L_G) and facial (L_F) walls (Figure 4) as shown in the equation below.

$$M_{T\%} = \frac{M_L + M_G + M_F}{L_L + L_G + L_F} \text{x } 100\%$$

A statistical comparison of the percent of microleakage values calculated for the experimental groups was performed using 2-factor Repeated Measures Analysis

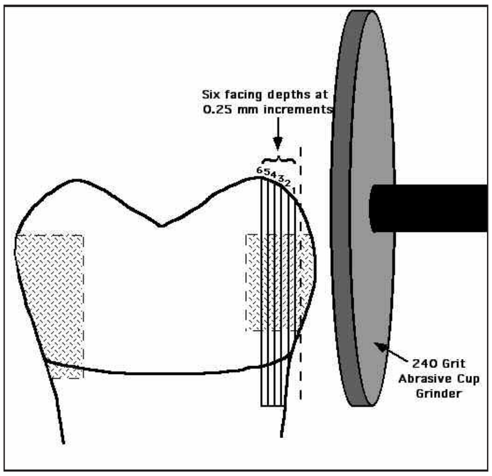

Figure 2. *Diagram of sectioning procedure.*

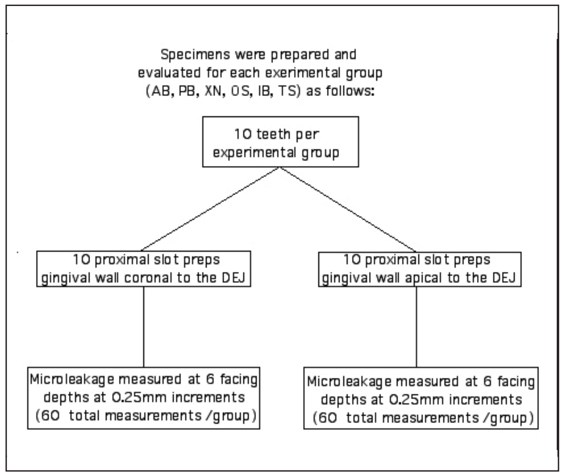

Figure 3. *Distribution of specimens per experimental group.*

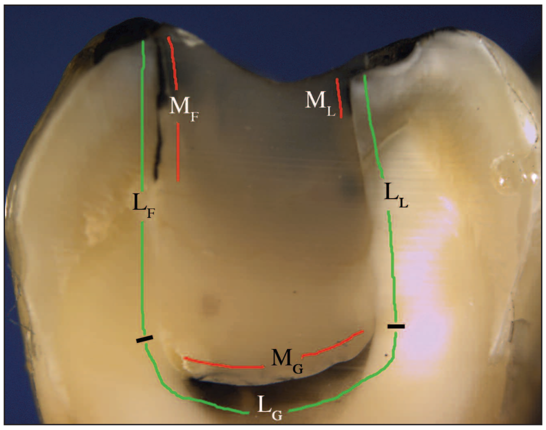

Figure 4. *Specimen showing microleakage determination.*

of Variance and post hoc Student-Neuman-Keuls tests (p=0.05).

RESULTS

Mean Percent Microleakage in Gingival Walls

For the experimental groups in which the gingival margin was apical to the CEJ (Table 3), the indirect restorations exhibited significantly less microleakage than the direct groups (1.57% versus > 30.59%). Within the direct groups, there was no statistically significant difference among the percent of microleakage. For the experimental groups in which the gingival margin was coronal to the CEJ, the indirect restorations again exhibited significantly less microleakage than the direct groups, although within the direct groups, significant differences were noted.

Mean Total Percent Microleakage

With respect to the mean total percent of microleakage, the indirect resin composite (TS) again exhibited the least amount of microleakage but was not statistically different from product AB (Table 3). However, the groups using etch and rinse products AB and PB were also not significantly different from each other. The remainder of the experimental groups, which all utilized self-etching systems, were not statistically different from one another.

DISCUSSION

This *in vitro* study was designed to specifically provide an accurate evaluation of the degree of microleakage occurring in the proximal walls of direct and indirect

Table 3: *Mean Total % Microleakage and Mean Gingival % Microleakage Values*

	Total % Microleakage		% Microleakage in Gingival Walls Apical to the CEJ		% Microleakage in Gingival Walls Coronal to the CEJ	
Group	Mean % Microleakage (STD)	SNK Groups	Mean % Microleakage (STD)	SNK Groups	Mean % Microleakage (STD)	SNK Groups
TS	9.36 (excess4.33)	A	1.57 (± 1.76)	A	2.02 (± 3.17)	A
AB	17.64 (± 15.77)	A/B	56.27 (± 33.00)	B	7.09 (± 9.02)	B
PB	24.55 (± 14.90)	B	60.45 (± 22.01)	B	19.54 (± 29.37)	B
OS	38.15 (± 18.73)	C	54.22 (± 36.99)	B	27.89 (± 28.54)	B
IB	38.08 (± 13.46)	C	30.59 (± 33.66)	B	32.51 (± 17.18)	C
XN	48.20 (± 17.00)	C	54.69 (± 44.91)	B	55.16 (± 26.60)	D

p=*0.05*

resin composite slot restorations. Specifically of interest was the effect of placement of the gingival wall with respect to the CEJ on microleakage.

Microleakage in Gingival Margins Located Coronal to the CEJ

Since the development of self-etching adhesive resin systems, concern has been expressed that these systems could not bond to enamel as effectively as the more traditional adhesives that used a separate etch step. Past studies have presented mixed results on the efficacy of self-etching adhesive systems on enamel in regard to bond strength and microleakage. Comparisons of self-etch and etch and rinse adhesives by Hashimoto and others (2003) and Kelsey and others (2005) found no significant difference in bond strengths to enamel.[29-30] Lopes and others (2004) found that some self-etch systems had comparable bond strengths to etch and rinse systems, while others were significantly lower.[31] DeMunck and others (2003) found that the 3-step etch and rinse adhesive they studied had significantly better bond strengths than the self-etch adhesives studied.[27] Studies by Kerby and others (2005) and Goracci and others (2004) found the etch and rinse material they tested produced stronger bonds to enamel than the self-etch materials tested.[24-25] A study by Kiremitci and others (2004) found that the self-etch systems that they studied produced better bond strengths to enamel than etch and rinse systems.[32] Koliniotou-Koumpia and others (2004) found that etch and rinse adhesives exhibited less microleakage than self-etch adhesives.[33] Studies by Santini and others (2005) suggested that there was no significant difference seen in the amount of microleakage in restorations using etch and rinse or self-etch adhesives.[34-35]

In regard to proximal preparations with gingival margins located in enamel, this study indicated that the indirect restoration, along with the 2 direct resin restorative groups using the etch and rinse adhesive systems, exhibited less microleakage than the direct resin restorative groups using self-etching dentin bonding systems. In respect to the direct resin restoration groups, the 2 groups using an etch and rinse adhesive along with 1 of the self-etching groups statistically exhibited significantly less microleakage than the remaining self-etching groups. This could indicate a decreased ability to create an effectively bonded or sealed enamel-resin interface by some self-etching dentin bonding systems.

Microleakage in Gingival Margins Located Apical to the CEJ

Due to its physical properties, dentin has proven to present special problems for adhesive bonding.[36-37] The evaluation of mean percent microleakage occurring in gingival margins located apical to the cemenotenamel junction is very pertinent to problems faced in clinical situations involving proximal preparations with caries extending apical to the CEJ. The indirect resin restoration exhibited substantially lower amounts of microleakage in preparations with gingival margins located apical to the CEJ. For groups restored with direct resin composite restorations, there was not a statistically significant difference found in mean percent microleakage in gingival margins located in cementum. In general, groups restored with direct resin restorations showed more microleakage in preparations with gingival margins located apical to the CEJ when compared with their performance in gingival margins located in enamel. The 2 materials (AB and PB) that utilized an etch and rinse adhesive exhibited a significant increase in the amount of microleakage observed when comparing the amount of mean percent microleakage in gingival margins located in enamel with the amount observed in gingival margins located apical to the CEJ. It was interesting to note that the 2 groups restored with dentin bonding systems utilizing a 1-step self-etching application (IB and XN) showed very little difference between microleakage observed in the gingival walls with enamel margins compared with that observed in gingival walls located apical to the CEJ. The other 3 direct restorative groups employed multiple steps and exhibited a significant increase in microleakage observed in the gingival margins apical to the CEJ compared to microleakage observed in enamel gingival margins.

Mean Total Percent Microleakage

The mean total percent microleakage was represented in this study by measurement of the combined percent microleakage observed at the resin-tooth interface in the facial, lingual and gingival walls of slot restorations. As was reported in the Results section, the group restored with indirect resin composite material (TS) performed very well with regard to microleakage. This can logically be attributed to decreased stress from polymerization shrinkage, since the restoration is polymerized outside the preparation, then cemented into place with resin cement. Polymerization shrinkage has been related to marginal gap formation in resin composite restorations.[38] Utilization of an indirect resin composite inlay effectively reduces the thickness of resin material that polymerizes within the cavity preparation to the width of the resin cement's thickness.[14] In an attempt to assure that the dentin bonding agent used in conjunction with the cementation process was not the causative factor for the reduced microleakage, the same self-etching dentin bonding agent (OS) was used in one of the direct restorative groups for comparison. There are many factors that may enter into the selection of a posterior resin restorative material, but the performance of this indirect resin restoration in regard to microleakage would suggest that it be highly considered. The indirect resin restoration performed especially well compared to direct resin restorations in preparations with gingival margins located apical to the CEJ.

Of the groups using direct resin restorations, the 2 materials that utilized an etch and rinse adhesive system exhibited the least total mean percent microleakage. A review of the Results section shows that breakdown of microleakage observed in the different walls of the preparation suggest that these materials exhibited less total microleakage than groups using self-etching dentin bonding systems, possibly due to their better performance in sealing the enamel proximal walls.

CONCLUSIONS

1. Indirect resin composite restorations exhibited significantly less mean percent microleakage at the gingival walls than the 5 direct resin composite restorative groups, regardless of placement of the gingival wall with regard to the CEJ.
2. The direct resin composite restorative groups using an etch and rinse adhesive in their dentin bonding systems exhibited less mean total percent microleakage when compared to the groups restored with a direct resin composite using a self-etching dentin bonding system.

Acknowledgements

The authors thank Dr Leon Bragg, Dr Manville Duncanson Jr and Dr Ray Laverdiere for their contributions to this research. We also thank the University of Oklahoma Native American Center of Excellence for its financial support of this project.

(Received 3 November 2005)

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