Effect of Aging on Coronal Microleakage in Access Cavities through Metal Ceramic Crowns Restored with Resin Composites

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Abstract

Purpose: The purpose of this in vitro study was to determine if packable resin composite with/without flowable resin composite has the ability to prevent coronal leakage in restored endodontic access openings following aging.
Materials and Methods: Eighty simulated standardized access cavities of metal-ceramic crowns were fabricated and fixed on Vitrebond cavities filled with an epoxy resin. The specimens were randomly divided into two main groups: (1) Group A—Access cavities filled with only packable composite (Filtek P60); (2) Group B—Access cavities filled with Filtek P60 and a flowable composite (Filtek Z350) as liner. Each main group was further subdivided randomly into four subgroups according to water storage and thermocycling periods. All specimens were immersed in blue ink solution for 24 hours and then sectioned into quadrants. The extension of blue ink along the metal-ceramic crown/composite resin interface was measured linearly using image analyzer and then analyzed by three-way ANOVA and independent *t*-test with a Mann-Whitney test. The level of significance was set at $p < 0.05$.
Results: All tested subgroups demonstrated different levels of microleakage. There was no significant difference related to restorative technique; however, there was a significant difference related to water storage and thermocycling.
Conclusions: All tested techniques and materials in this study showed microleakage. Packable composite while a flowable liner showed a marginally better result than packable composite alone. Excessive thermocycling resulted in significant differences among the test groups.

Metal-ceramic crowns are a good treatment option for teeth with large or defective restorations;[1] however, more than 50% of teeth with such metal-ceramic crowns or bridge retainers require nonsurgical root canal treatment.[2] A common practice in dentistry is to cut endodontic access cavities through existing crowns to treat diseased pulps[3-6] and subsequently permanently repair the openings.[1,3,7,8] The restoration of the access opening, however, can be challenged by coronal leakage, exposing the root-filled tooth and periradicular tissue to bacterial invasion and subsequent failure of the nonsurgical root canal therapy.[9] Advantages of restoring such endodontic access cavities through existing crowns include avoiding remake, which can be costly, problematic, and time consuming. It is therefore more practical for function and for economic considerations[7,8] to retain a good crown for continued serviceability.

Unfortunately, no evidence-based research suggests the best materials for these access repairs.[9,10] Clinicians routinely use either amalgam, composite resin, or glass ionomer. Trautmann et al[1] presented the results of a survey by endodontists, prosthodontists, and general practitioners as to the material of choice for a direct repair. The preferred and most frequently used material to restore a metal crown was a bonded silver amalgam restoration, whereas composite resin was the material of choice for the metal-ceramic crowns.

Recently, several improvements in resin composite formulations have been developed.[11-13] Two clinical characteristics are now well defined: (1) high-viscosity "condensable" resins presenting a structure that allows compression and consequent filler particle accommodation[14,15] and (2) low-viscosity resin composites that are fluid and injectable.[16,17] Use of flowable composites in conjunction with the very high viscosity, high-modulus packable composites is a common clinical technique.[16,18] The main rationale behind the use of flowable composites is the formation of an elastic layer that may compensate

for the polymerization shrinkage stresses;[17,19] however, there are very few studies evaluating the sealability of packable composite with/without flowable composite resins in repair of endodontic access cavities, especially after aging by water storage and thermocycling.[20,21]

Coronal microleakage appears to be of equal or greater clinical relevance as a factor in endodontic failure than apical leakage.[7–9,22–26] Although apical microleakage has been studied extensively, only a few reports have been published on coronal microleakage in restored endodontic access openings in permanently fixed crowns. The techniques used to assess microleakage had considerably variable results.[8,25,26] The use of organic dyes as tracers is one of the oldest and most common methods of detecting microleakage in vitro,[8,26,27] because it is generally simple and fast to perform. Water storage and thermocycling in vitro are also common for testing dental materials to establish their suitability for in vivo use.[28,29] So far, it seems there is no evidence-based research regarding the best technique and how aging affects restorative materials in endodontic access openings when metal-ceramic crowns are to be retained following root canal treatment.

The purpose of this in vitro study was to determine if packable composite with/without flowable composite resin as a liner has the ability to prevent coronal leakage in endodontic access openings following aging. First, the null hypothesis of this in vitro study stated that there was no statistically significant difference between packable composite restorations with/without flowable composite resin as a liner in reducing coronal leakage. Secondly, the null hypothesis also stated that storage of the specimens in distilled water (1 day, 7 days) and thermal cycling (after 1 day and within 7 days) would have no effect on the metal ceramic-composite resin interface.

Materials and methods

Eighty specimens of simulated metal-ceramic crowns with access openings were fabricated. A standardized custom washer (19 mm in diameter) with a standardized centered hole (5 mm in diameter) was used to manufacture the specimens from calibrated 0.4-mm thick green sheet wax (Batch No. 117-040-00, Dentaurum, Pforzheim, Germany) standardized from metal disks (Collon Buim Type I, Lot No. 61004; High-Dental-Japan, Tokyo, Japan). Debubblizer (Lot No. 3-1323; Kerr, Romulus, MI) was applied to every 10 sprued wax disk patterns that were then invested using phosphate-bonded investment powder and liquid (Powder, Lot No. 03151-11, Liquid, Lot No. 0901511, Jelenko, NY) in a size C casting ring lined with asbestos-free ring liner (Kera-Vlies, Dentaurum). After wax burnout in an electric furnace (acc-thermII, XL-M, Jelenko), the disks were cast in an induction casting machine (Bego, Bremen, Germany) using a nickel-chromium alloy (Ni 58.7%, Cr 22.0%, Mo 10.0%, Be 0%, others 8.3%; Collon Bium Type I, High-Dental-Japan).

The sprue from each completed casting was removed by using a thin carborundum disc (Dentaurum) mounted on a low-speed handpiece controlled at 30,000 rpm (NM-4000, Nouvag AG, Goldach, Switzerland), and each metal disk was checked for any bending or deformity and then finished by using a coarse ceramic abrasive (Dentaurum). A porcelain-bearing surface was achieved with fine ceramic stone followed by white aluminum oxide stone bur (Dentaurum) moving in one direction. Each bur was used for five specimens only. After finishing, the metal specimens were sandblasted with 50 μm nonrecycled pure aluminum oxide particles (Dentaurum) at a maximum pressure of three bars for 10 seconds to remove the excess oxide layer, steam-cleaned (Triton, Bego) for 30 seconds to remove any debris, and then heat treated in a porcelain furnace (Vita Vacumat 40 T, Vivdent, Bad Säckingen, Germany) to degas for 5 minutes at 1000°C under vacuum.

Vita VKM 68 feldspathic porcelain opaque (Lot No. P533) body (Lot No. 544) and enamel (Lot No. 530) (shade B2) (VITA Zahnfabrik, Bad Säckingen, Germany), Vita opaque liquid (Lot No. 6728), and modeling liquid (Lot No. 4756) were used to fabricate the metal-ceramic restorations. The opaque layer around each access opening was determined to be 0.3 ± 0.1 mm in thickness as measured by a metal caliper device from four random positions. The total thickness of both body and enamel porcelain layers was 1.5 ± 0.2 mm. Adjusting and finishing were carried out by using a sintered diamond bur (Dentaurum) mounted on a controlled low-speed micromotor handpiece and finally, a thin layer of glaze was applied and fired according to the manufacturer's instructions. All 80 specimens were fabricated by one operator according to procedures in the actual construction of metal-ceramic crowns and were standardized as much as possible (ISO/6872, 1999). The inner walls of the access cavities were lightly ground using standardized diamond burs (ISO No: 806 314 546 016, FG 546G016, Horico, Berlin, Germany) with a 300,000 rpm turbine handpiece (No.TS1–14771, Semince, Berlin, Germany) under heavy water spray mounted on a dental surveyor (AF30, Nouvag AG) in a unidirectional circular motion for 10 seconds for each specimen. Every five specimens were treated with one bur. After wet grinding using a diamond disk (Buehler 41, Lake Bluff, IL) and grinder/polisher under water coolant (Metaserver 2000, Buehler) the thickness of each specimen was determined by a digimatic micrometer (Mitutoyo, Tokyo, Japan). All specimens were examined with a laboratory light-microscope (7× magnification) to ensure they were free from porcelain cracking or chipping.

The specimens with fine access openings of 5 mm (Fig 1) and 2 ± 0.5 mm thickness (Fig 2) were then placed in a container of normal physiological saline (0.9% w/v Sodium Chloride solution, Batch No. 5275A101, B. Braun, Melsungen, Germany) inside an incubator (Memmert B-400, Schwabach, Germany) at 37°C for 1 week. After that, 20 specimens were randomly selected and measured at five areas in various locations on the internal access cavity surfaces using a profilometer (Surftester, Mitutoyo) to show an average surface roughness value of Ra = 1.11 μm.

Eighty standardized, clear, cold-curing epoxy resin molds (Mirapox 950–230 A, Batch No. 5118–3 and Mirapox 150–230 B, Batch No. 5114–11, Miracon, Balakong, Malyasia) were filled with resin-modified glass ionomer liner/base (Vitrebond liner/base, Lot No. 20060429, 3M ESPE Dental Products, St, Paul, MN) according to the manufacturer's recommendations to simulate lining over root fillings and were ground using 180-grit silicon carbide paper (Buehler 41) on a grinder and polisher (Metaserver 2000) to ensure that all surfaces were smooth and flat. After this, each dried metal-ceramic specimen was fixed

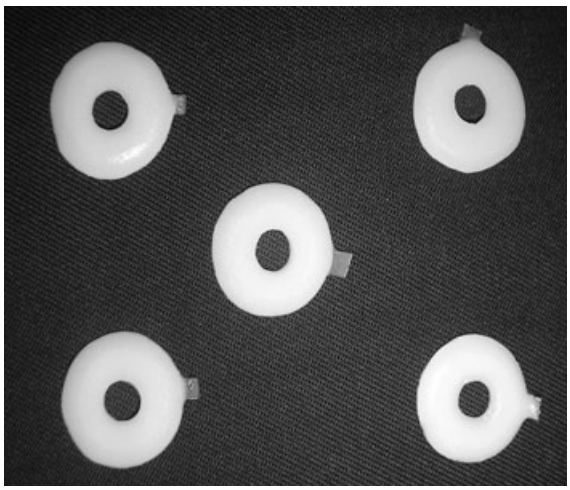

Figure 1 Simulated metal-ceramic specimens.

to the Vitrebond-filled epoxy cavities by carefully adding a thin layer of a cyanoacrylate (Supa Glue, Selleys, Batch No. 38-383, Padstow, Australia) on the clean lower metal surface under gentle pressure for 10 seconds to ensure the access cavity surface was not contaminated by the glue. It was then allowed to set for 12 hours, and then a thin layer of mixed epoxy resin was added all around the outer borders of each metal-ceramic specimen and the epoxy cavity (Fig 3) and left for 24 hours to completely polymerize to prevent any penetration around the borders during immersion.

The 80 standardized metal-ceramic/epoxy molds were randomly divided into two main groups according to the filling materials used, and the specimens in each group were further divided into four subgroups according to water storage periods and thermocycling and then coded numerically using a permanent pen.

Group A: The access cavities were restored with packable composite (Filtek P60, Shade B2, 3M ESPE) after Adper Scotchbond Multi-Purpose Plus Adhesive system (3M ESPE) was applied (Table 1). Following the manufacturer's recommendations: (1) the walls of the access cavities were treated with Scotchbond Etchant (35% phosphoric acid, 3M ESPE) using a disposable brush (Microbrush, 3M ESPE) for 15 seconds, rinsed with a copious amount of water for 5 seconds; and then dried with oil-free air spray for 2 seconds; (2) Rely X ceramic primer (silane primer) (3M ESPE) was next applied to the walls using a fully saturated disposable brush and gently air dried for 5 seconds to leave a shiny surface. Adper Scotchbond Multi-Purpose Plus Adhesive was applied to the treated walls using a fully saturated 3M disposable brush by gentle brushing for 10 seconds, then thinning by using oil-free air spray until movement of the liquid was no longer visible, and light-cured for 10 seconds by using a light-curing unit with a light intensity of 400 mW/cm^2 (Spectrum 800, Dentsply Caulk, Milford, DE); (3) Filtek P60 was applied incrementally into the access cavities and adapted using plastic instruments (Ash No. 6 and 49). A Mylar strip (3M ESPE) was placed on the restored cavity with gentle passive digital pressure and finally adapted by a 5-kg static load for 5 minutes using a custom-made loading device; and (4) excess at the margins was carefully removed using a surgical blade #11 in the direction from restoration to cavity margin, then covered with another Mylar strip, and light cured for 20 seconds by holding the light emission window as close as possible to the Mylar strip.

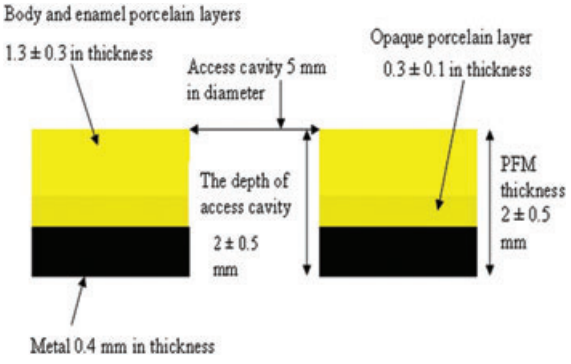

Figure 2 Dimensions of simulated metal-ceramic specimens.

Figure 3 Specimens and epoxy-filled cavity fixed using glue and epoxy resin.

Group B: The access cavities of this group had flowable nanocomposite (Filtek Z350, Shade B2, 3M ESPE) (Table 1) as a liner under the Filtek P60. After etching and application of Rely X ceramic primer, Adper Scotchbond Multi-Purpose Plus Adhesive was applied to the walls of the access cavities as in group A. Filtek Z350 was applied by lining the base of the access cavities by using a needle syringe to approximately 0.5 mm thickness at the level of the metal-opaque porcelain

Table 1 Restorative materials used

Product	Compositions*	Manufacturer's recommendations	Lot and exp.
Filtek P60	Bis-GMA, UDMA, Bis-EMA, (61, 83%) inorganic fillers	1-2.5-mm thickness in increments, need 20 sec curing with 400 mW/cm^2	5RG-8100B2
Filtek Z350	Bis-GMA, TEGDMA, Bis-EMA, (55, 65%) inorganic fillers	0.5-2.00-mm thickness need 20-sec curing with 400 mW/cm^2	6AH-6031B2
Scotchbond Etchant	Aqueous solution of 35% Phosphoric acid (H_3PO_4)	15-sec etching, 15-sec rinsing, 2-sec drying	6KG-2009-01
RelyX ceramic primer	HEMA, light-cured polymer	5-sec ceramic priming with 5-sec drying	5BB-2008-12
Adper Scotchbond	Bis-GMA (60-70%), HEMA (30-40%), Camphoroquinone	10-sec curing of adhesive layer with 400 mW/cm^2	6PK-2008-12

*As reported by manufacturer (3M ESPE Dental Products).

Bis-GMA = Bisphenol-A glycidyl dimethacrylate; UDMA = Urethane dimethacrylate; TEGDMA = triethylene glycol dimethacrylate; Bis-EMA = ethoxylated bisphenol-A polyethylene dimethacrylate; HEMA = 2-Hydroxyethyl methacrylate.

junction and light cured for 20 seconds. In all light-curing procedures, for every five restorations, the intensity of the light-curing source was confirmed to be 400 mW/cm^2 by using a radiometer, and all the procedures were performed at 23 ± 2°C.

The finishing and polishing of all restored access cavities were carried out after 24 hours of distilled water storage; they were first finished on #600 silicon carbide paper, and then polished with Sof-Lex polishing discs (3M ESPE), one disc for one specimen, by using a low-speed handpiece at 15,000 rpm (No.T140-05905, Simence, Berlin, Germany) mounted on a dental surveyor under water spray. Polishing was carried out with a series of Sof-Lex flexible disks from coarse-(150), medium-(360), fine-(600), to superfine-grit (1200) under uniform light pressure in a circular motion for 10 seconds for each abrasive disk.

Subgroup 1: after 1-day distilled water storage (ISO/11405, 2003), the specimens were removed and allowed to dry for 2 hours at room temperature. After that, two coats of fingernail varnish were painted 1 mm from the interfaces of the restored access openings to prevent dye penetration from anywhere other than at the metal-ceramic/filling material interfaces. After allowing 15 minutes for each coating of fingernail varnish to set and air dry, the 10 specimens of subgroup 1 were completely immersed in a container of blue ink (Parker Quink, Newhaven, UK) at 37°C for 24 hours. The pH of the blue ink was 7.4 as tested by a pH meter (HANNA Instruments, Kallay Way, Singapore).

Subgroup 2: following 1-day distilled water storage, the specimens were placed in separate mesh bags and thermocycled between 5 ± 2°C and 55 ± 2°C for 30 seconds in cold and 30 seconds in hot baths with a transfer time between baths of 10 seconds for 500 cycles. After thermocycling, the 10 specimens were removed and similarly treated as subgroup 1.

Subgroup 3: after 7 days of distilled water storage, the specimens were removed and treated as for subgroup 1.

Subgroup 4: within the 7 days of distilled water storage, the specimens were thermocycled between 5 ± 2°C and 55 ± 2°C for 30 seconds in the cold and 30 seconds in the hot baths with a transfer time between baths of 10 seconds for 72 cycles per day over 7 days, giving a total of 504 cycles. After that, the 10 specimens were treated as subgroup 1.

Once dye immersion was complete, all specimens were rinsed in tap water for 1 minute to remove excess dye, cleaned with a toothbrush, and blot-dried to remove any excess water. The nail varnish was removed using a scalpel with #11 blades. The specimens were then embedded completely in clear epoxy resin; when hardened, each specimen was sectioned into four equal quadrants using a 0.5-mm thick diamond blade (High-speed-2000, Isomet-Buehler) with water coolant. The first section of two equal halves was across the midline of the restored access cavities of the specimens, followed by a second section on the first half of the specimen across its center to produce two equal quadrants and a third section on the second half to produce another two equal quadrants. Each specimen with four equal quadrants and each quadrant having two sides produced (Fig 4) a total of eight sides per specimen for evaluation of the dye penetration. All eight sides of each specimen were air-dried and coded numerically using a permanent pen and then stored in coded containers.

The coded sectioned specimens were first viewed under a stereomicroscope (Nikon, Tokyo, Japan) at ×15 magnification to ensure no evidence of leakage between the metal-ceramic and epoxy resin interface. Then digital images of the dye penetration along the metal-ceramic/composite restoration interface

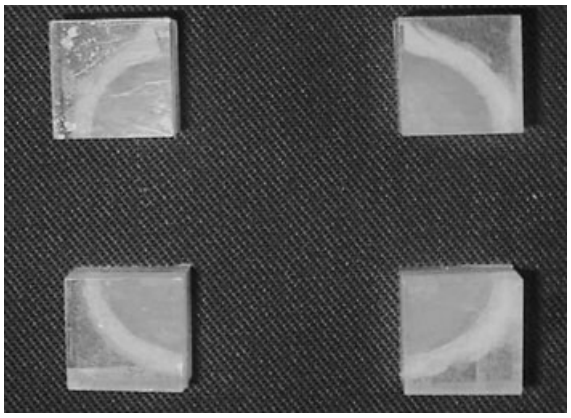

Figure 4 Specimen was sectioned into 4 quadrants.

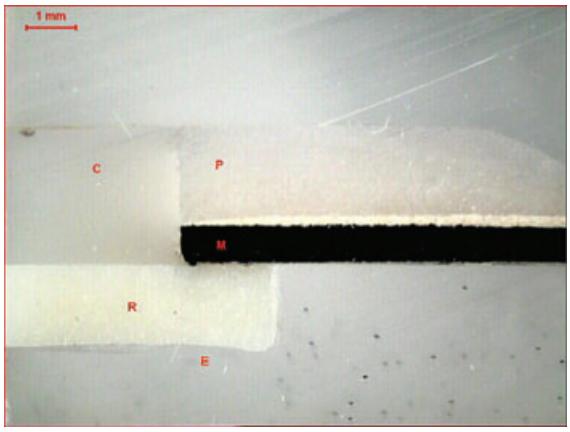

Figure 5 No dye leakage at metal-ceramic/composite interface. P = Porcelain; M = Metal; C = Packable Composite; R = Vitrebond; E = Epoxy resin mold. Red Bar = measurement of dye extension by millimeter (1 mm).

for all the sections were evaluated with an image-analyzing system. Digital images were obtained with a JVC camera (Tk. C1380-Colour Video Camera, optics, Video Lens-VSH300-39708, Tokyo, Japan) with attached computer-image analyzer software (Leica Qwin Lite T2-8, Serial No.: 3154, Leica Microsystems imaging solutions Ltd., London, UK) (Figs 5-8) and illumination using a Schott 1500 KL fiber optic unit at 75× on-screen magnification (1 pixel = 0.0109 mm) to the nearest 0.01 mm by a line drawn along the extension of the ink penetration at the metal-ceramic/composite interfaces. All eight interfaces of each specimen were examined, and then a mean measure was obtained with a single-blind technique. Three measurements for the eight interfaces of each specimen were taken at three times with a 3-day interval between each evaluation without reference to the previous measurements to eliminate evaluator bias. All data were subsequently transferred to a computer following breaking of the randomization code, and statistical analysis was performed using SPSS for Windows statistical software (Version 14.0, SPSS Inc, Chicago, IL) in several stages. The intra-rater reliability between the three measurements was calculated to be 0.983 ($P < 0.001$) and was thus highly reliable.

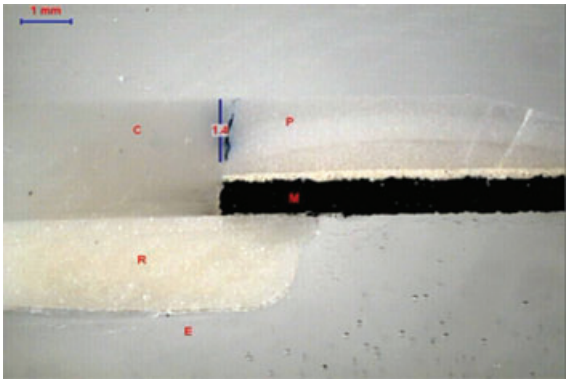

Figure 7 Dye leakage at metal-ceramic/composite interface. P = Porcelain; M = Metal; C = Packable Composite; R = Vitrebond; E = Epoxy resin mold. Blue Bar = measurement of dye extension by millimeter (1 mm).

Three-way ANOVA was used to determine the main effects and interaction of the restorative technique, water storage, and thermocycling. Two assumptions of concern are: (1) normality of the residuals using histogram and (2) homogeneity of variance (Levene's test) between independent variables ($P < 0.05$). To compare the means of two groups of an independent variable, the independent *t*-test was used. Ideally, for this test, the subjects should be randomly assigned to two independent groups, so that any difference in response is due to the treatment (restorative technique, thermocycling, or water storage) or no difference in response due to lack of treatment. For all statistical tests, the level of significance was set at $P < 0.05$.

Results

Generally the respective mean dye penetration (mm) of all thermocycled specimens was higher than nonthermocycled

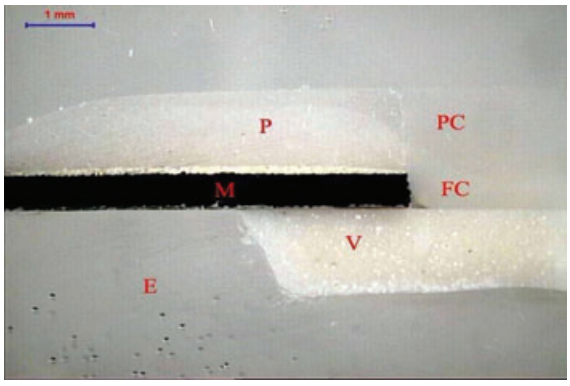

Figure 6 No dye leakage at metal-ceramic/composite interface. P = Porcelain; M = Metal; PC = Packable Composite; FC = Flowable Composite; V = Vitrebond; E = Epoxy resin mold. Blue Bar = measurement of dye extension by millimeter (1 mm).

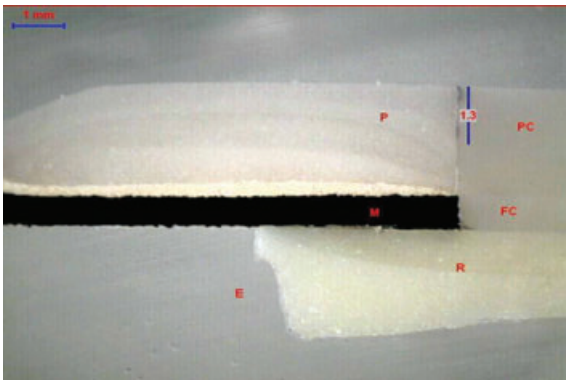

Figure 8 Dye leakage at metal-ceramic/composite interface. P = Porcelain; M = Metal; PC = Packable Composite; FC = Flowable Composite; R = Vitrebond; E = Epoxy resin mold. Blue Bar = measurement of dye extension by millimeter (1 mm).

Table 2 Mean dye penetration for coronal microleakage

Technique	Water storage	Thermocycling	Mean (SD) (mm)	N
Packable composite resin	1-day	No	0.41 (0.358)	10
		Yes	0.93 (0.353)	10
	7-day	No	0.23 (0.186)	10
		Yes	0.52 (0.305)	10
Packable/flowable Composite resins	1-day	No	0.26 (0.312)	10
		Yes	0.80 (0.346)	10
	7-day	No	0.29 (0.270)	10
		Yes	0.34 (0.213)	10

specimens (Table 2). Also, the mean of all thermocycled specimens after 1-day water storage was correspondingly higher than the thermocycled specimens carried out within 7 days of water storage. Thus, the greatest dye penetration was found in those specimens when thermocycling after 1-day water storage was carried out.

Three-way ANOVA was employed to determine the effects of the restorative technique, water storage, and thermocycling on coronal microleakage. Assumption of 3-way ANOVA was checked, and the normality test was also checked for each factor. Each factor showed either it was normally distributed or slightly skewed positively, which was in the accepted range of skewness. As the sample for each group is 40, which is more than 30, the Central Limit Theorem was applied. Homogeneity equality of variance was checked using Levene's test, and it was found that the equality of variance assumption was met ($p = 0.514$). Thus, it can be concluded that it had not violated the homogeneity of variance assumption for 3-way ANOVA.

The restorative techniques (packable composite without and packable composite with flowable liner) had no significant effect on the coronal microleakage ($p = 0.135$) (Table 3). Only the effects of water storage and thermocycling had a significant effect on the mean coronal microleakage ($p = 0.000$); however, when 2-way interaction effect between each study factor was checked, it was found that there was a significant interaction effect between thermocycling and water storage on the mean microleakage ($p = 0.009$) (Table 3). This indicates that the effect of thermocycling on coronal microleakage may differ between 1-day and 7-day water storage. Therefore, a separate analysis was done to locate the effect of thermocycling and water storage on coronal microleakage.

Table 3 Results of 3-way ANOVA

Source	Sum of squares	df	Mean square	F	*P*-Value
Restorative technique	0.201	1	0.201	2.278	0.135
Water storage	1.308	1	1.308	14.826	0.000
Thermocycling	2.419	1	2.419	27.411	0.000
Water storage * Thermocycling	0.643	1	0.643	7.283	0.009

The p-value of equality of variances is more than 0.05 ($p = 0.097$) for thermocycling (Table 4). Thus, the variances are similar. Based on the t-test, there is a significant difference between the mean dye penetration of nonthermocycled and thermocycled specimens.

For water storage, p-value of equality of variances is less than 0.05 ($p = 0.002$). Thus, the variances are not similar. Therefore, equality of variances was not assumed. Results indicated there was a significant difference in dye penetration between 1-day and 7-day water storage of the specimens. The mean score for the 7-day water storage was less than the mean score for 1-day water storage. Thus, it was concluded that the 7-day water storage specimens had lesser coronal microleakage than the 1-day water storage specimens.

Table 5 shows the effect of water storage (1-day and 7-day) on coronal microleakage in the thermocycled groups. Thermocycling showed more differences in the mean coronal microleakage for the 1-day than the 7-day water storage. Therefore, the independent t-test was used. The results showed there were significant differences in mean coronal microleakage between 1-day and 7-day water storage specimens with thermocycling ($p = 0.000$).

The normality test was checked for 1-day and 7-day water storage without thermocycling and was found to be not normally distributed. Therefore, Mann-Whitney U test was employed to compare between the 1-day and 7-day water storage without thermocycling. Without thermocycling, there was no significant difference between the 1-day and 7-day water storage (Table 6).

Discussion

In this study, the first hypothesis was not rejected, in that neither the packable composite restorations with/without flowable composite resin as a liner had reduced coronal leakage when restoring endodontic access openings in permanently fixed metal-ceramic crowns. The second hypothesis was rejected, in that the overall metal-ceramic/composite resin restoration interface was affected by water storage and by a change in temperature (thermocycling) after 1 day and within 7 days.

The wide variety of dye materials and different techniques used in in vitro tests make comparing the results of different studies difficult, as there is no generally accepted standard for experimental parameters. In addition, there is also a lack of correlation between in vitro and in vivo studies, and in vivo studies do present some conditions that could hardly be reproduced in vitro. In vitro testing is, however, essential for development purposes. Therefore, the standardization of such methods is necessary to obtain comparable results from different studies. In this study, to obtain reliable results, an in vitro standard model was chosen to standardize the quality of the ready-made access cavities through metal-ceramic crowns and the quantification of leakage to enhance reliability of the results. The materials were used according to the various manufacturers' recommendations, and ISO/TS guidelines for testing were followed precisely. All procedures were carried out by one evaluator to decrease the number of variables involved in obtaining the results. The depth of the access cavity was also standardized at 2 ± 0.5 mm, thereby obtaining composite resin restorations

Table 4 Effect of water storage and thermocycling on coronal microleakage

			t-test for quality of Means		
Variable	N	Mean (SD)	Mean differ (95% CI)	*T* statistic (*df*)[a,b]	*P* value
Thermocycling					
No	40	0.30 (0.286)	−0.348 (−0.497, −0.199)	−4.638 (78)[a]	0.000
Yes	40	0.65 (0.378)			
Water Storage					
1-Day	40	0.60 (0.430)	0.256 (0.097, 0.415)	3.214 (64.402)[b]	0.002
7-Day	40	0.34 (0.262)			

[a]Equality of variances assumed for thermocycling (Levene's test p-value = 0.097).

[b]Equality of variance did not assume for water storage (Levene's test p-value = 0.002).

of similar thickness. A limitation of this study was that natural teeth were not used; however, the specimens were symmetrical and standardized, unlike the variation and curvatures found in natural teeth. A total of 80 specimens were considered sufficient to cover most variables. Because two types of composites (packable, flowable) were the main focus of this investigation, all other variables, such as thickness of the metal-ceramic specimens, depth of access openings, roughness of the cavity wall, RMGIC, type of adhesive, and all laboratory procedures, were standardized to overcome experimental variation as much as possible.

In this study, Adper Scotchbond Multi-Purpose Plus adhesive was used, as it is a versatile system for bonding to composite resin, metal, and porcelain. Also, RelyX^{TM} ceramic primer was used for silaniziation of the ceramic and metal before composite restoration. The synergistic application of silane primer/adhesive resin blends appears to be a promising method when bonding resin composites to ceramic.[30,31] The main rationale behind the use of packable composites is to take advantage of their stiffer consistency with improved handling characteristics that made them easier to condense into the access cavities of metal-ceramic crowns, while the rationale behind use of flowable composite as a liner under the packable composite is flow capacity at the base of access cavities and the formation of an elastic layer that may compensate for polymerization shrinkage stresses. Even though several studies demonstrated that flowable composite did not influence the microleakage,[32,33] other studies show an improved marginal sealing.[34,35] This study showed that the flowable composite liner did not significantly reduce microleakage.

Microleakage is usually evaluated with in vitro models. Some of these techniques include bacterial, chemical, or radioactive tracer molecule infiltration; however, color dye penetration studies are the most commonly employed technique. Currently, no outstanding method is available to determine microleakage.[27] Despite the limitations, the dye leakage methodology remains a popular tool to investigate the sealing ability of restorative materials due to its low cost and very simple technique.[36] Dye particles are small enough to penetrate and color the surface where adhesion of restorative material and cavity wall is insufficient,[37] thereby making them appropriate for this research. In this study, Parker Quink blue ink was chosen due to good contrast between composite resin restorations and metal-ceramic specimens in digital images. Parker Quink blue ink is manufactured using dyes in a soluble dye-based ink[38] that can stain and is generally pretty stable. The activation energy of Quink blue ink is 15.6 kJ mol^{-1}, its density is 1.193 g/cm^{-3}, and its viscosity coefficient being smaller at 0.98 cp would result in an expected lower energy barrier for ink diffusion in water.[38] Parker blue ink has a closely guarded secret dye, and it does not contain aniline or Prussian blue dyes. Because it is not the same as dyes with carbon particles of known diameters, its leakage may likely be greater; however, it is an efficient tracer, as it can be detected immediately, since its color differs from that of metal-ceramic/composite materials. Parker blue ink is also a chemically nonreactive agent, unlike some other dyes like methylene blue dye, which in contact with reducing agents that exist in restorative materials may be reduced to a colorless substance.[39] Parker blue ink is a pH-neutral solution of dye-based ink and does not require buffering, while other dyes like methylene blue, silver nitrate, and basic fuchsin need to be neutralized before being used. Digital imaging microscopy had been used to record the actual length of dye penetration along the interface.[40]

Table 5 Effect of water storage on coronal microleakage with thermocycling

			t-test for quality of means		
Variable	N	Mean (SD)	Mean differ (95% CI)	*T* statistic (*df*)[a]	*P* value
Water storage					
1-Day	20	0.86 (0.347)	0.435 (0.236, 0.634)	4.416 (38)[a]	0.000
7-Day	20	0.43 (0.271)			

[a]Equality of variances assumed (Levene's test p-value = 0.214).

Table 6 Effect of water storage on coronal microleakage without thermocycling

Mean dye penetration	N	Median (IQR)	Z stat[a]	*P* value[a]
Water storage				
1-Day	20	0.24 (0.59)		
7-Day	20	0.17 (0.38)	−0.339	0.735
Total	40			

[a]Mann-Whitney U Test.

In this study, dye penetration along the metal-ceramic/composite interface was selected; however, 3D techniques revealed more accurate and more extensive dye penetration than sectioning techniques that provided a 2D view only,[41] but they are more time-consuming and expensive and also some do not allow good visualization of dentine tubule leakage.[42] When a sectioning technique is to be used for dye assessment, multiple sections should be used.[27] Thus, in this study, the metal-ceramic/composite interface of each specimen had eight equally sectioned sides for assessment of dye penetration. Also, the measurement was done by a single operator in a single-blind design and, to evaluate the effect of potential measurement errors, each independently coded section was measured three times. An intra-class correlation coefficient in excess of 0.98 was obtained in the analysis of intra-rater reliability, thus demonstrating a high reproducibility of results of the measurement system. The use of a similar measurement system had also been reported.[7]

Many investigators have assessed the sealing ability of restorative materials to prevent coronal microleakage[1,3–5,7–9,22–26] with different results. Ray and Trope[24] concluded that the technical quality of the coronal restoration was more important than the technical quality of the endodontic treatment; however, the findings of this study showed leakage in both packable as well as packable with flowable composite resin as a liner, though the latter restorative technique showed marginally better results. The results of this study are therefore in agreement with the literature[7,17,19,27–29] in which all specimens leaked; this could be explained by the initial shrinkage of composite resins due to polymerization shrinkage stress, which resulted in a pull back of the restoration toward the light source, pulling with it the adhesive bonding system with subsequent gap formation and consequent increased microleakage. The percentage of volumetric polymerization shrinkage for Filtek P60 is 2.1%,[15,43] while Filtek Z350 is 4%.[16,17] An inorganic nonsilanated filler content that interferes with the polymerization shrinkage process, is found in Filtek P60 as round zircon and silicon particles in proportions of 61% by volume or 83% by weight.

In this study, the results demonstrated that the restorative technique did not significantly affect the mean microleakage at the metal-ceramic/composite resin interface, although it was slightly decreased in group B compared to group A when subjected to the same conditions. This can be due to standardization of the model of this study and/or thickness of the flowable composite (0.5 mm). Consequently, the C-Factor was basically the same for all specimens. It has been reported that ideally the C-Factor should be lower than 1;[44] when the C-Factor is greater than 1 the results are unexpected.[43] Also, there was similarity between the chemical compositions in the matrix of P60 (61% vol, 83% wt) comprising mostly Bis-GMA monomers with Bis-EMA and UDMA resins (3M ESPE, Technical Profile, 1998) and Z350 (55% vol., 65% wt) comprising Bis-GMA with TEGDMA and Bis-EMA resins (3M ESPE, Technical Profile, 2005). Thus, there was no statistically significant difference between the two restorative techniques (packable composite without and packable with flowable composites), which is in agreement with other studies[32,33] that demonstrated that the use of flowable composite did not influence the microleakage, but in disagreement with studies that showed that the use of flowable composite resulted in an improved marginal sealing.[34,35]

In this study, the results demonstrated that water storage could significantly affect the mean coronal microleakage at the metal-ceramic/composite interface; there was a slight decrease in mean coronal microleakage in 7-day water storage compared to 1-day water storage. These slight differences could be explained by the slightly more water at 7 days than 1 day with more hygroscopic expansion, thereby agreeing with other studies that showed that the degree of hygroscopic expansion in resin-based composites had an inverse relationship between filler loading and water sorption,[45] thus compensating for resin composite shrinkage.

The results also demonstrated that thermocycling significantly increased the mean coronal microleakage at the metal-ceramic/composite interface. Exposing the specimens to thermocycling speeds up diffusion in between the composite resin and the metal or ceramic, creating stress at the interface of the materials because of their different coefficients of thermal expansion.[28] Large differences exist between the linear coefficients of thermal expansion of porcelain (14×10^{-6} pp/°C), nickel-chromium beryllium-free alloy (15.38×10^{-6} pp/°C), and composite resins (packable composite: $28\text{-}35 \times 10^{-6}$ pp/°C; flowable composite: $35\text{-}50 \times 10^{-6}$ pp/°C).[8,29,46] There was no standard for thermocycling methodology in microleakage studies, and this permitted contradictory discussions and results in various laboratory studies. Thus, in this study the temperature was standardized at 5 to 55 ± 2°C, and the dwell time was 30 seconds, as these variables seem able to be tolerated by oral tissues and should be suitable for clinical conditions. Also, in this study, a near constant number of cycles (500 cycles after 1-day water storage and 504 cycles within 7 days) were selected for evaluation to determine if there was a direct relation with the increase of microleakage in the restored access cavities.

The results also showed that there were significant differences in the coronal microleakage between 1-day and 7-day water storage with thermocycling ($p > 0.05$). Thus, it indicated that thermocycling for 500 cycles after 1 day was more pronounced than thermocycling for 504 cycles over 7 days of water storage. The increase in coronal microleakage of the thermocycled specimens following 500 cycles after 1 day of water storage could be due to thermal fatigue (stress) and mismatch of coefficient of thermal expansion and the thermal conductivity of metal; however, when thermocycled for 504 cycles over 7 days of water storage, the specimens had less coronal microleakage.

This was because they could not reach threshold fatigue with 72 cycles per day when thermal stress was less. Thus, 72 cycles per day did not cause as much fatigue as 500 cycles, which meant composite resins in the oral cavity, except for microleakage due to polymerization shrinkage, should be able to withstand coronal microleakage over time. A 30-second conductivity dwell time was observed in the study, as it had been found that the low thermal conductivity of resin composite suggested that a 15-second dwell time was not sufficient to transfer the temperature through resin composite restoration to stress the adhesive interface and rupture it.[47] Some studies have compared thermocycled and nonthermocycled groups[48] with different numbers of cycles[28] showing no statistically significant difference; however, in other studies,[49,50] there were significant differences in marginal microleakage of resin composite restorations between thermocycled and nonthermocycled groups.

An in vitro evaluation is the first step for testing any technique or material. Although the specimens and testing conditions of this study were designed to simulate the clinical use of restoring access cavities of metal-ceramic crowns, in vivo tests are needed to confirm the results. This study tested interfacial microleakage in restored access cavities of metal-ceramic crowns in relation to the composite material only. Other aspects of the metal-ceramic/composite interface, such as bond strength and the effect of different retention systems should also be investigated. Additionally, composite resin materials with reduced shrinkage, thermal expansion, and resistance to water sorption are needed. Also, an understanding of the choice of appropriate restorative materials and their placement technique is needed when restoring such access cavities.

Conclusions

Within the limitations of this study, it can be concluded that:

(1) There was no statistically significant difference related to restorative technique. Both tested groups presented different degrees of marginal leakage. Flowable composite as a liner under packable composite showed marginally better results than packable composite alone, but it did not prevent microleakage in restoring endodontic access cavities.
(2) There was a statistically significant difference related to water storage over time. Also, there was a statistically significant difference related to thermocycling with respect to the number of cycles over time.

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