Evaluation of marginal gap at the composite/enamel interface in Class II composite resin restoration by SEM after thermal and mechanical load cycling (An in vitro comparative study)

Mais Yaroub, B.D.S., M.Sc. [1]
Mohammed R. Hameed, B.D.S., M.Sc., Ph.D. [2]

ABSTRACT

Background: This study compared in vitro the marginal adaptation of three different, low shrink, direct posterior composites Filtek™ P60 (packable composite), Filtek™ P90 (Silorane-based composite) and Sonic fill™ (nanohybrid composite) at three different composite/enamel interface regions (occlusal, proximal and gingival regions) of a standardized Class II MO cavity after thermal changes and mechanical load cycling by scanning electron microscopy.

Materials and methods:Thirty six sound human maxillary first premolars of approximately comparable sizes were divided into three main groups of (12 teeth) in each according to the type of restorative material that was used: group (A) the teeth were restored with Filtek™ P60 and single bond™ Universal adhesive using horizontal incremental technique, group (B)the teeth were restored with Filtek™ P90 and P90 system adhesive using horizontal incremental technique and group (C) the teeth were restored with Sonic fill™ composite and single bond™ Universal adhesive using bulk technique.After specimens were stored in distilled water at 37°C for 7 days, all specimens were subjected to thermocycling at (5° to 55 °C), then submitted to mechanical load cycling (intermittent axial force of 49N and a total of 50.000 cycles). The specimens were observed under scanning electron microscope at (2000 X) to measure marginal gap width (the distance between the dental wall and the restoration) at occlusal, proximal and gingival regions in micrometer using Tescan software, version 3.5. Data were analyzed statistically by one way ANOVA test and least significant difference tests.

Results:The results showed that the silorane-based posterior composite (Filtek™ P90) showed significantly the least marginal gap width at the occlusal, proximal and gingival regions after the application of thermal changes and mechanical load cycling in comparison to the two methacrylate-based posterior composite Filtek™ P60 (packable) and the Sonic fill™ (nano-hybrid). Sonic fill™ bulk fill composite that relied on the vibration concept to lower the viscosity of high filler loaded composite material showed significantly lesser marginal gaps width at occlusal, proximal and gingival composite/enamel interface regions in comparison with Filtek™ P60 (packable composite) using horizontal incremental technique. The silorane-based composite (Filtek™ P90) showed non-significant difference in marginal gaps width at the three different regions. While, both methacrylate based Filtek™ P60 and Sonic fill™ composite showed significantly lesser marginal gap width at the occlusal region in comparison with gingival regions.

Conclusion: None of the low-shrinkage composite restorative materials tested in this study totally prevented micro-gap formation at composite/enamel interfaces of Class II MO cavity.

Key words: Scanning electron microscope, marginal gap, Filtek™P60, Filtek™P90, Sonic fill™. (J Bagh Coll Dentistry 2014; 26(4):63-70).

INTRODUCTION

The increasing demand for tooth colored restorations, cosmetic dental procedures, conservation of tooth structure together with dramatic advances in the field of adhesive technology has led to widespread placement of direct composite restorations[1]. The application of composite resin to posterior teeth, especially in class II restorations, may be compromised because of the inherent polymerization shrinkage and contraction stress that can cause de-bonding at the tooth-composite interface with an increased risk of gap formation, dentinal sensitivity and restoration failure [2]. Despite many new and innovative developments in the field of adhesives, a 100% perfect margin is not realistically achievable.

(1) Master Student. Department of Conservative Dentistry, College of Dentistry, University of Baghdad.
(2) Assistant Professor, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.

Composite materials undergo volumetric polymerization contraction of at least 2% which may result in gap formation as the composite pulls away from cavity margins during polymerization. A material's ability to seal a cavity preparation can be influenced by its composition, plastic deformation, flow, coefficient of thermal expansion, modulus of elasticity and the mechanical stresses caused by cavity shape [3].Therefore a tight marginal seal still has to be the primary goal for the clinician, because once happened; gap formation cannot be counteracted with restorative materials that prevent demineralization along with cavity margins [4].

In addition to stress shrinkage, the occlusal loads and alterations of the temperature of the oral behavior produce stress on the restoration and can also compromise the marginal sealing [5]. In an attempt to solve problems related to polymerization shrinkage, a low-shrinkage composite material (Filtek™ P90) based on a new resin chemistry with silorane monomers has been developed. Filtek™ P60 Packable composite introduced to market place as an alternative to amalgam. “Packable” composites have higher filler loadings (> 80% by weight); therefore, they tend to feel stiffer than traditional composites and handle more like amalgam. The high filler content reduces the polymerization shrinkage. Due to their packability, these composites help in restoring good contacts in posterior teeth. These stiffer materials may not adequately adapt to internal areas and cavosurface margins at the cervical joint [6].

A novel resin composite system, Sonic fill™ system (Kerr/Kavo), was recently introduced in the market. Is indicated for use as a bulk fill posterior composite restorations and can be bulk filled in layers up to 5 mm in depth due to reduced polymerization shrinkage. Sonic fill™ incorporates a highly-filled proprietary resin with special modifiers that react to sonic energy. As sonic energy is applied through the hand piece, the modifier causes the viscosity to drop (up to 87%), increasing the flow ability of the composite enabling quick placement and precise adaptation to the cavity walls. When the sonic energy is stopped, the composite returns to a more viscous, non-slumping state that is perfect for carving and contouring [7].

The high quality of modern composite materials has made it more difficult to see changes in the quality of restoration margins, which in turn, has increased the need for more sensitive methods to assess the early changes of the marginal adaptation. Scanning electron microscopy (SEM) is a method that can be used for closer examination of the restoration margins because of its ability to magnify and reveal details [8].

This study was conducted with aim of comparing in vitro the marginal adaptation performance of three different, low shrink, direct posterior composites.

MATERIALS AND METHODS

Teeth selection

Thirty six sound, human maxillary first premolar extracted as a part of an orthodontic treatment plan, were selected for use in this study. The teeth were cleaned with pumice and carefully rinsed with water to remove the residual debris. Then the teeth were examined using a magnifying lens and by transilluminating fiber optic from a light curing unit for the presence of cracks. Only intact teeth free of defects and of comparable size were selected and stored in distilled water at room temperature.

Cavity preparation

To simulate the clinical situation during restoration placement, a dental manikin (Maxilla) was used. Maxillary canine and maxillary 2nd premolarwere included in a manikin, with a space between them to place the tested tooth. The three teeth were positioned with crowns in proximal contacts and long axis parallel to each other [9].

All teeth received a standardized class II mesio-occlusal (MO) cavity preparation. All cavities were prepared above cemento-enamel junction in order for all the cavity margins to be within enamel. The dimensions of the occlusal isthmus of the cavities were: bucco-palatally width (3 mm), occlusal depth (2 mm) measured from the cavosurface margin of the palatal cusp and (1.6 mm) thickness of remaining tooth structure was left during the extensions into distal marginal ridge.

The dimensions of the proximal box were: buccao-palatally width (3 mm), height (2 mm) and (1.5 mm) depth axiallythe cavity preparation was made by using the parallel sided; flat- ended carbide fissure bur of 1 mm diameter with a high speed water-cooled hand piece that was fixed to the vertical arm of modified dental surveyor to standardize the cavity preparation.The width was checked using a point vernier caliper from different points of the prepared cavity while the depth was measured by graduated periodontal probe.A new bur was used for every four preparations to maintain cutting efficiency[10].

Samples grouping

The teeth were randomly divided into three main groups (12 teeth in each group) according to the type of restorative material that was used. For all samples, three different composite/enamel interface regions were measured; occlusal region (assigned 1), proximal region (assigned 2) and gingival region (assigned 3).

Group A: The teeth were restored with Filtek™ P60 (3M ESPE, USA) using horizontal incremental technique.

Group B: The teeth were restored with Filtek™ P90 (3M ESPE, USA) using horizontal incremental technique.

Group C: The teeth were restored with Sonic fill™ composite (Kerr, USA) using bulk technique.

Restorative procedure

Each composite system was used according to the manufacturer's instructions with their corresponding adhesive systems. Shade A3 was used for each composite type.After the cavity was prepared for each tooth, the cavity was dried using gentle air blast and a Palodent sectional matrix system was placed.For group A and C a self-etch Single bond™ Universal adhesive (3M ESPE, Germany) was used to bond the restorative material to the cavity walls. The bond was applied to the entire preparation's walls using a disposable applicator and rubbed in for 20 seconds, followed by gentle air thinning over the liquid for about 5 seconds until it no longer moves, indicating complete vaporization of the solvent then light cured of the adhesive for 10 seconds using LED light curing device. Then Filtek™ P60 composite resin was applied to the cavity of each tooth in group Ausing horizontal incremental technique. Two increments of 2 mm in thickness for each one were placed by the aid of plastic instrument for composite placement. Each increment was light-cured for 20 seconds using a LED light curing device. For group B, group, the teeth were restored with Silorane-based (FiltekTM P90). Filtek™P90 composite resin comes with a specially developed system adhesive (P90 system adhesive, 3M ESPE AG, Germany) which consists of a self-etch primer and a bond. Firstly, the self-etch primer was applied to the entire cavity for 15 seconds then dispersed with a stream of air and light-cured for 10 seconds by LED light curing device. Then, the bond was applied to the entire cavity, rubbed and light-cured for 10 seconds as for the primer. The restoration was built up using horizontal incremental technique with Filtek™ P90 (3M ESPE, USA). Two increments of 2 mm in thickness for each one were placed by the aid of plastic instrument for composite placement. Each increment was light-cured for 40 seconds using a LED light curing device. For group C,the Sonic fill™ composite was placed using Sonic fill™ handpiece (Kavo, Germany). The handpiece was attached to the multiflex coupling device (Kavo, Germany) that fit on air-water tube of dental chair. The Sonic fill™ composite unidose capsule (Kerr, USA) was screwed on the handpiece. The dispensing speed at the bottom of the handpiece was set at 3 (The medium speed). The unidose tip was placed at the deepest portion of the preparation to avoid trapping air. After the handpiece activation, Sonic fill™ composite was placed in the cavity in a single, bulk increment then cured for 20 seconds from the occlusal surface by LED light curing device. Additional curing from the buccal and palatal aspects for 10 seconds each was done.

Thermocycling procedure

Thermocycling was done to simulate the temperature changes that take place in the oral cavity that might result in changes in the microspace between the tooth and the restoration.The procedure done by cycling the teeth between two water baths: one of the water baths maintained at 5°± 0.5°C and the other at 55°± 0.5°C, with a dwell time of 15 seconds. The number of cycles was 500 cycles according to the International Organization for Standardization (ISO TR 11405) [11].

Teeth mounting

To simulate periodontal ligament, the root surfaces were dipped into molten wax (dipping wax) up to 2.0 mm below the cemento-enamel junction using dipping wax machine. The tooth was dipped, resulting in a wax layer of 0.2 to 0.3 mm thickness [12]. Then all teeth were embedded along their long axis using a dental surveyor in mixed cold cure acrylic (at dough stage) 2.0 mm apical the cemento-enamel junction using a custom-made split metal mold (20 mm× 20 mm× 25 mm).

After the first signs of polymerization, teeth were removed from the acrylic blocks and the wax was removed from root surfaces by using a surgical blade. A silicone-based light body impression material was injected into the acrylic resin blocks and the teeth were reinserted into the cubic acrylic blocks. A standardized silicone layer that simulated periodontal ligament was thus created taking the thickness of the wax layer [13].

Mechanical load cycling procedure

A custom made apparatus was used for the cycling load. The design of the apparatus was consisted of stainless steel piston (25 mm diameter) with cylindrical arm and spherical end (2 mm diameter). The surface area of the piston equaled 4.9 cm2. A compressor delivered compressed air with pressure that was fixed at 1 bar. In order to achieve an axial force of 49 N, an air pressure of about 1 bar delivered to the piston through tubes every mechanical load cycle and according to the following equations:

1 bar = 1.01971 kg/cm^2 (Pressure unit)

1.01971 kg/cm^2 $\times$ 4.9 cm^2 (surface area of the piston) = 4.996579 kg $\cong$ 5 kg

1 kg = 9.8 N (Newton unite)

5 kg $\times$ 9.8 m/s^2= 49 N

Five kg was required to obtain an axial force of 49 N; also the axial force was verified by using an electronic load cell. The tip of the device (spherical end) was placed in contact with the center of the occlusal surface of the restoration. The loading device delivered an intermittent axial force of 49 N at a frequency of 2.5 Hz. The samples were subjected to 50,000 cycles (corresponding to 5.5 hours in the machine) [14].

Specimens' preparation for SEM investigation

All the specimens were sectioned horizontally with the level of cemento-enamel junction with a water cooled diamond disc to separate the crowns from the roots and the crowns were kept for SEM examination. The samples were placed on aluminum stubs with the help of an adhesive material and a carbon paste was placed on a side of the sample to be act as an electrical conductor then the stubs were fixed on SEM standard specimen holder. The holder was placed on a stage in a sputtering coater device (SPC-12 Compact plasma sputtering coater, USA) for 10 sec. to coat the samples with gold. The holder was screwed on the specimen chamber mounting table of SEM.

Evaluation of marginal adaptation

All the samples were examined by Tescan SEM at 2000X magnification to detect marginal gaps along the composite/enamel interfaces at occlusal, proximal and gingival regions [13]. The measurement of marginal gap width (the distance between the dental wall and the restoration) in each sample were taken at: three points in the gingival region, six points at the proximal region (3 points in buccal side and 3 points in palatal side) and nine points at the occlusal region (3 points in buccal side, 3 points in palatal side and 3 points in distal side) (Figure 1).The largest marginal gap width from the three points in each side of the region was recorded in micrometers (µm) by Tescan image processing software (Atlas software, version 3.5, Germany) [5].

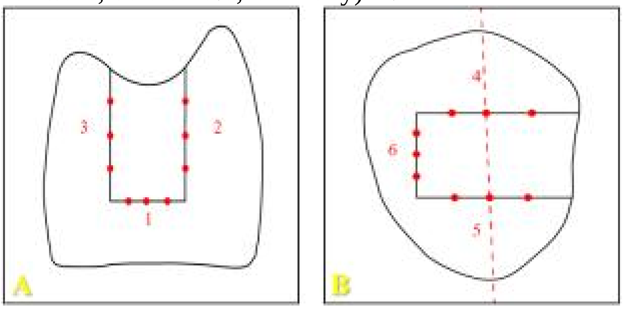

Figure 1: The location of the points (●) in each region.

RESULTS

The data were collected and analyzed using SPSS (version 20) for statistical analysis. For the occlusal region, the mean of three points from the buccal, palatal and distal sides that represent the largest marginal gaps width of occlusal region was taken, for the proximal region, the mean of two points from the buccal and palatal sides that represent the largest marginal gaps width of proximal region was taken and the point that represent the largest marginal gap width at the gingival region was taken for each sample (Figure 2).

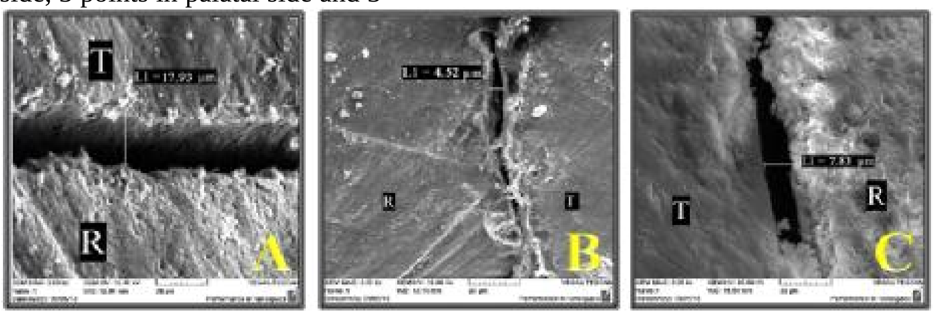

Figure 2: The largest tooth (T)/restoration (R) marginal gaps width at gingival region's point of sample restored with A- Filtek™P60. B- Filtek™P90. C- Sonic fill™.

The mean, standard deviation, minimum and maximum values (descriptive statistics) for marginal gaps width in (µm) at the occlusal, proximal and gingival regions for the three different composite materials are summarized in (Table 1).

The comparison between the three composite materials in marginal gaps width (µm) at each region by one-way ANOVA test revealed a statistically highly significant differences among all groups of this study ($P \leq 0.01$) as shown in (Table 2).

Table 1: Means, standard deviations, minimum and maximum values for marginal gaps width (μm) at the occlusal, proximal and gingival regions for all composite materials.

Materials groups	Regions	Descriptive statistics			
		Mean	±SD	Min.	Max.
Group (A)	A1	12.34	1.06	10.75	13.89
	A2	13.33	1.30	11.25	15.64
	A3	14.18	1.58	12.44	17.93
Group (B)	B1	3.24	0.66	1.92	3.96
	B2	3.01	0.68	1.99	3.98
	B3	3.54	0.63	2.3	4.52
Group (C)	C1	4.88	0.95	3.46	6
	C2	5.61	1.27	4.05	7.57
	C3	6.69	1.18	5.05	8.6

Table 2: ANOVA test for the marginal gaps width (μm) among the three composite materials at each region

Regions		ANOVA	Sum of squares	df	Mean square	F-test	P-value
(Occlusal)	A1	Between groups	564.539	2	282.270	345.409	0.000 HS
	B1	Within groups	26.968	33	0.817		
	C1	Total	591.507	35			
(Proximal)	A2	Between groups	691.547	2	345.774	275.289	0.000 HS
	B2	Within groups	41.449	33	1.256		
	C2	Total	732.996	35			
(Gingival)	A3	Between groups	715.750	2	357.875	249.300	0.000 HS
	B3	Within groups	47.372	33	1.436		
	C3	Total	763.122	35			

Further comparisons between groups by LSD test revealed a statistically highly significant difference in marginal gaps width when comparing group A with group B and C. While, group Bshowed statistically significant less marginal gap width than group C at occlusal, proximal and gingival regions (Table 3)

Table 3: LSD test for the marginal gaps width (μm) among the three composite materials at each region

Regions			Mean Difference	p-value
Occlusal	A1	B1	9.098	0.000 HS
		C1	7.462	0.000 HS
	B1	C1	-1.637	0.000 HS
Proximal	A2	B2	10.322	0.000 HS
		C2	7.718	0.000 HS
	B2	C2	-2.603	0.000 HS
Gingival	A3	B3	10.632	0.000 HS
		C3	7.483	0.000 HS
	B3	C3	-3.149	0.000 HS

The comparison of marginal gaps width (μm) at occlusal, proximal and gingival regions within each composite material by one-way ANOVA test revealed a statistically highly significant difference for groupsA and C. while, for group B there was no significant difference for the marginal gaps width (μm) among the three tested regions (Table 4).

Table 4: ANOVA test for marginal gaps width (µm) at three different regions within each composite material

Materials groups		ANOVA	Sum of squares	df	Mean square	F-test	P-value
(A)	**A1**	**Between groups**	20.319	2	10.159	5.745	0.007 **HS**
	A2	**Within groups**	58.362	33	1.769		
	A3	**Total**	78.681	35			
(B)	**B1**	**Between groups**	1.739	2	0.869	2.001	0.151 **NS**
	B2	**Within groups**	14.341	33	0.435		
	B3	**Total**	16.080	35			
(C)	**C1**	**Between groups**	20.061	2	10.031	7.683	0.002 **HS**
	C2	**Within groups**	43.086	33	1.306		
	C3	**Total**	63.147	35			

Further comparisons by LSD test was performed for the three different regions within each group A and group C and the result showed that, The group A1 has no statistical significant difference than group A2, while the group A1 has highly statistical significant difference as compared with group A3. Also the result showed that, the group A2 has no statistical significant difference as compared with group A3.LSD test for comparison between group C1, C2 and C3 showed that, the group C1 has highly statistical significant difference as compared with group C3 and no statistical significant difference as compared with group C2, while the result showed that the group C2 has statistical less significant difference as compared with group C3 (Table 5).

Table 5: LSD test for marginal gaps width (µm) at three different regions for group (A) and group (C)

Materials groups	Regions		Mean Difference	p-value
Group A	**A1**	**A2**	-0.992	0.077 **NS**
		A3	-1.838	0.002 **HS**
	A2	**A3**	-0.847	0.128 **NS**
Group C	**C1**	**C2**	-0.735	0.125 **NS**
		C3	-1.818	0.000 **HS**
	C2	**C3**	-1.083	0.027 **S**

DISCUSSION

The polymerization of composite resin results in a reduction in the intermolecular distance between the monomers and consequential shrinkage. Bonding the composite resin to the cavity walls impairs the material deformation and generates shrinkage stress on the bonding interfaces. If stress exceeds the bond strength between the dental substrate and the adhesive system, a contraction gap will be formed, jeopardizing the restoration's longevity [15,16]. In this study, Filtek™ P90 composite material that tested exhibited statistically the highly significant decrease in marginal gaps width along the composite/enamel interface at the occlusal, proximal and gingival regions after thermo-mechanical load cycling as compared with Sonicfill™ composite and Filtek™ P60 composite resins. This could be attributed to:

1-The difference in chemical composition of the matrix system, the inherent ring-opening polymerization of oxirane moieties in the silorane monomer of Filtek™ P90 composite resin starts with the cleavage and opening of the ring mechanism which helps in gaining space and counteracts the loss of volume which occurs in the subsequent step, when the chemical bonds are formed manifested as a reduction in polymerization shrinkage stress at the tooth/restoration interface as compared to the linear polymerization of the methacrylate-based Sonicfill™ and Filtek™ P60 composite resins[17].

2- It is also hypothesized that since silorane technology provides lower polymerization shrinkage and related polymerization stress than methacrylate-based composite resins. It should be able to withstand thermo-mechanical cycling fatigue at the tooth/restoration interface better than the methacrylate-based composite resins. This finding agrees with studies of Palin et al. [18]; Yamazaki et al. [19]; Bagis et al. 2009 [20] and Borges et al. [10]. They showed that the percentage of gaps in the siloranes samples did not increase significantly after thermal and mechanical cycling but in the methacrylates this difference was significant.

3-The type of adhesive system used plays an important role in reduction the shrinkage stress and avoiding initial marginal gaps. The two-step, self-etch Filtek™ P90 system adhesive (6th generation) used with Filtek™ P90 composite resin produce higher bond strengths to both enamel/dentin and exhibit better marginal sealing than one-step, self-etch Single bond™ Universal adhesive (7th generation) used with Filtek™ P60 and Sonic fill™ [21].

On the other hand, the Sonic fill™ composite resin exhibited the highly significant decrease in marginal gaps width along the composite/enamel interface at the occlusal, proximal and gingival regions as compared with Filtek™ P60 composite. This could be attributed to the increase in the amount of filler particles and a consequent increasing in the viscosity of the Filtek™ P60 composite resin, leading to an inadequate adaptation to the enamel walls. The packable composites have insufficient matrix available for wetting the cavity wall and melting of the subsequent layers leading to creation of voids within the restoration or at the cavo-surface margin [6,17].

The Sonic fill™ composite relied on the concept of sonic vibration which assumed that vibration lowers the viscosity of the composite resin, allowing the material to flow and possess a good wetting ability, which favors their adaptation to the cavity walls, and therefore expected to decrease the risk for air entrapment and void inclusion, in a similar way as a flowable composite, This finding agrees with study of (Yap and Powers in 2011)[22] who showed that although material consistency does not equal that of a flowable composite, vibration secures an adaptation to the cavity walls similar to that obtained with a composite flow.

From the result of this study, the marginal adaptation of Filtek™ P90 as tested by SEM along the composite/tooth interface was found that no statistical significant differences between occlusal, proximal and gingival regions. This is possibly related to the low-shrinking behavior of Silorane resin and the fact that at gingival margin, low polymerization contraction stress cannot overcome the bond strength [23].

While, in both methacrylate-based Filtek™ P60 and Sonic fill™ composite resins a highly significant increase marginal gap width at the gingival region as compared with occlusal region. The inadequate marginal adaptation at the gingival margin of both methacrylate-based composite resins may be due to:

1-The shrinkage of resin composite towards the light source because the composite closer to the light hardens first. This, in turn, pulls the softer composite resin from the gingival areas creating a gap. Contraction towards the light source causes the resin to shrink from margins of the preparation, even when resin is applied and cured in small increments [24].

2-Another possible explanation may be due to lesser thickness of enamel at the cavo-surface margin of the proximal aspect which requires adhesion of the restorative materials to greater proportion of dentin; a less reliable, more complex substrate than enamel [25].

3-The distance of light source from the material which is higher at the proximal box base as compared to occlusal surfaces. The distance from the light curing tip alters the irradiance of the light-cure device which reaches the composite resin, reducing the percentage of degree of conversion.Low degree of monomer conversion might cause unconverted double bonds, making the resin more susceptible to degradation by premature breakdown at the tooth-restoration interface [26].

As conclusions;

1. The silorane-based posterior composite (Filtek™ P90) showed the least marginal gap width at the occlusal, proximal and gingival regions in comparison to the two methacrylate-based posterior composite Filtek™ P60 and the Sonic fill™ . While, Sonic fill™ bulk fill composite that relied on the vibration concept to lower the viscosity of high filler loaded composite material showed lesser marginal gaps widthin comparison with Filtek™ P60 (packable composite) using horizontal incremental technique after the application of thermal changes and mechanical load cycling when the tooth/restoration interface is located in enamel.
2. The silorane-based composite (Filtek™ P90) showed non-significant difference in marginal gaps width at the three different regions. While, both methacrylate based Filtek™ P60 and Sonic fill™ composite showed significantly lesser marginal gap width at the occlusal regions in comparison with gingival regions of class II composite restorations.

REFERENCES

1. Nadig RR, Bugalia A, Usha G, Karthik J, Rao R, Vedhavathi B. Effect of four different placement techniques on marginal microleakage in class II composite restorations: An in vitro study. World J Dent 2011; 2(2): 111-6.
2. Goncalves FS, Castro C, De-Freitas A, Moreira AN, Magalhaes CS. The short-term clinical performance of a silorane-based resin composite in the proximal

contacts of class II restorations. J Contemp Dent Prac 2012; 13(3): 251-6.
3. Korkmaz Y, Ozel E, Attar N. Effect of flowable composite lining on microleakage and internal voids in class II composite restorations. J Adhes Dent 2007; 9: 189-94.
4. Matthias J, Roggendorf NK, Andreas A, Michael N, Roland F. Marginal quality of flowable 4-mm base vs. conventionally layered resin composite. J Dent 2011; 39: 643–7.
5. Casselli DSM, Faria-E-Silva AL, Casselli H, Martins LRM. Marginal adaptation of class V composite restorations submitted to thermal and mechanical cycling. J Appl Oral Sci 2013; 21(1): 184-9.
6. Radhika M, Sajjan GS, Kumaraswamy BN, Mittal N. Effect of different placement techniques on marginal microleakage of deep class II cavities restored with two composite resin formulations. J Conserv Dent 2010; 13: 9-15.
7. Eunice C, Margarida A, João CL, Filomena B, Anabela P, Pedro A, Miguel MC, Diana R, Joana M, Mário P, Marques FM. 99mTc in the evaluation of microleakage of composite resin restorations with SonicFill™. An in vitro experimental model. Oper Dent 2012; 2: 340-7.
8. Schmidt M, Horsted-Bindselv P, Poulsen S, Nyengaard JR. Marginal adaptation of a low-shrinkage silorane-based composite: A SEM-analysis. J Braz Oral Res 2012; 116(10): 736-42.
9. Sabah MK. Marginal Leakage of Amalgam and Modern Composite Materials Related to Restorative Techniques in Class II Cavity: A comparative study. A master thesis, College of Dentistry, University of Baghdad 2013.
10. Borges AS, Santos JD, Romos CM, Ishikiriama SK, Shinohara MS. Effect of thermo-mechanical load cycling on silorane-based composite restorations. Dent mater. 2012; 31(6): 1054-9.
11. Loguercio AD, Bauer JRD, Reis A, Grande RHM. In vitro microleakage of packable composites in Class II restorations. Restor Dent 2004; 35(1): 29-34.
12. Soares CJ, Pizi ECG, Fonseca RB, Martins LRM. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Braz Oral Res 2005; 19(1): 11-6.
13. Zarrati S, Mahboub F. Marginal adaptation of indirect composite, glass-ceramic inlays and direct composite: An in vitro evaluation. Tehran J Dent 2010; 7(2): 77-83.
14. Paula AB, Duque C, Correr-Sobrinho L, Puppin-Rontani RM. Effect of restorative technique and thermal/mechanical treatment on marginal adaptation and compressive strength of esthetic restorations. Oper Dent 2008; 33(4): 434-40.
15. Papadogiannis D, Kakaboura A, Palaghias G, Eliades G. Setting characteristics and cavity adaptation of low-shrinking resin composites. Dent Mater 2009; 25:1509-16.
16. Rodrigues SA Jr, Pin LF, Machado G, Della Bona A, Demarco FF. Influence of different restorative techniques on the marginal seal of class II composite restorations. J Appl Oral Sci 2010; 18: 37-43.
17. Majeed MA. Microleakage evaluation of silorane-based and methacrylate-based packable and nanofill posterior composites (in vitro comparative). J Tikrit Dent Sci 2012; 2(1): 19-26.
18. Palin WM, Fleming GJ, Nalhwani H, Burke FJ, Randall RC. In vitro cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. Dent Mater 2005; 21: 324-35.
19. Yamazaki PC, Bedran-Russo AK, Pereira PN, Wsift EJ Jr. Microleakage evaluation of a new low-shrinkage composite restorative material. Oper Dent 2006; 31:670-6.
20. Bagis YH, Baltacioglu IH, Kahyaogullari S. Comparing Microleakage and the Layering Methods of Silorane-based Resin Composite in Wide Class II MOD Cavities. Oper Dent 2009; 34(5): 578–85.
21. Ulker M, Ozcan M, Sengun A. Effect of artificial aging regimens on the performance of self-etching adhesives. J Biomed Mater Res Part B: Appl Biomater 2010; 93(1):175-84.
22. Yap P, Powers JM. Depth of cure of several composite restorative materials. Dent Advis Res Report 2011; 33: 1.
23. Ghulman MA. Effect of cavity configuration (C factor) on the marginal adaptation of low-shrinking composite: A comparative vivo study. Int J Dent 2011; 61-6.
24. Johar K. Fundamentals of laser dentistry. 1st ed. India: Jaypee Brothers, 2011; Ch5: 45-53.
25. Bogra P, S Gupta S, Kumar S. Comparative evaluation of microleakage in class II cavities restored with Ceram X and Filtek P-90: An in vitro study. Contemp Clin Dent 2012; 3(1): 9-14.
26. Coutinho M, Trevizam NC, Takayassu RN, Leme AA, Soares GP. Distance and protective barrier effects on the composite resin degree of conversion. J ContempClin Dent 2013; 4(2): 152–5.