A Comparative Evaluation of Microleakage around Class V Cavities Restored with Different Tooth Colored Restorative Materials

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Abstract

Objectives: To evaluate and compare microleakage around class V cavities restored with silorane and dimethacrylate-based composite resins.

Methods: Standard Class V cavities were prepared on the buccal surface of 60 non-carious human molars. Teeth were randomly divided into 3 groups (n=20) depending on the restorative materials used, Silorane-based composite resin (Filtek P90-SIL), dimethacrylate-based composite resin (Solare P-SOLP) and light-cure glass ionomer cement (GC Fuji II LC -LCGIC). The restored teeth with these tooth-coloured restorative materials were thermo-cycled and then immersed in 2% Rhodamine B dye under vacuum pressure for 48 hours. All teeth were bisected longitudinally in a bucco-lingual direction and observed under stereo-microscope at 30X magnification for the evidence of dye penetration. The data were analysed using one-way analysis of variance (ANOVA) and Tukey's Post Hoc tests (α=0.05).

Results: SIL composite resin showed the least microleakage in Class V cavity restorations with a statistically significant difference to SOLP and LCGIC. Sixty five percent of specimens in SIL group, 30% in SOLP group and 5% in LCGIC group showed dye penetration up to one-third of the cavity depth, while 5% in SIL group, 5% in SOLP group and 35% in LCGIC group showed dye penetration up to two-thirds of the cavity depth, and 30% in SIL group, 65% in SOLP group and 60% in LCGIC group showed dye penetration up to the axial wall.

Conclusions: Silorane-based composite exhibited least microleakage in restoring class V cavities compared to dimethacrylate-based composite resin and light-cured glass ionomer cement.

Key Words: Silorane Resins, Composite Resins, Glass Ionomer Cement, Dental Marginal Adaptation

Introduction

The demand for tooth-colored restorations has grown considerably during the last decade. Resin-based Composites (RBCs), ceramics, glass ionomer cements are tooth coloured restorative materials, to name a few. Resin-based composites are the most widely used aesthetic restorative materials in today's world [1]. Now a days, at least half of posterior direct restoration placements are done using resin-based composite restorative materials [2]. The reasons for their world-wide popularity are their excellent esthetic value, needing minimal tooth preparation, providing micro-mechanical bonding with the tooth structure and good retention. However, in spite of the many advantages; one of the major shortcomings of all Resin-based Composites (RBCs) is that they undergo polymerization shrinkage upon curing. The resulting volumetric contraction produces stress between the bonded restorations and tooth walls, resulting in gap formation and microleakage. Microleakage is defined as the marginal permeability to bacterial, chemical and molecular invasion at the interface between the teeth and restorations [3], leading to discoloration, recurrent caries and pulpal pathology, affecting longevity of composite resin restorations [4-6]. Thus, resistance to microleakage of bonded restorative materials plays a crucial role in clinical success of the restoration. Over the years, various strategies have been proposed to minimize the negative effects associated with polymerization shrinkage of RBCs [7,8]. Recently, to control polymerization shrinkage, a new RBC based on silorane chemistry has been introduced. Siloranes are a new class of ring-opening monomers obtained from the reaction of oxirane and siloxane molecules [9-11]. One of the commercially silorane-based RBCs is available as Filtek P90 (3M ESPE). It is a microhybrid composite, filled with fine quartz particles, and radio-opaque yttrium fluoride. Filtek P90 is used along with P90 system adhesive, a two-step self-etching bonding system. It consists of a P90 system adhesive self-etch primer which is hydrophilic and bonds to the tooth, and a P90 system adhesive bond which is hydrophobic and adheres to the resin. Although several studies have shown conflicting results with regards to the degree of microleakage using Total-Etch (TE) and Self-Etch (SE) adhesive systems [12-17]. However, recent studies have shown that the use of a total-etch system significantly reduces microleakage than a self-etch system and three-step etch-and-rinse adhesives still remains the gold standard in terms of durability [18-20]. Thus, this study was conducted to evaluate and compare microleakage around class V cavities restored with silorane and bis-GMA based composite resins using self-etch and total-etch adhesive systems.

Materials and Methods

Sixty non-carious freshly extracted human molars were collected and stored in 0.2% thymol solution at room temperature until use. Routine prophylactic procedure was carried out with rubber cup and pumice slurry for all teeth. The teeth with presence of fracture, crack or pigmentation were excluded. After autoclaving teeth samples were mounted in a semicircular fashion using dental plaster in a rubber mould and set at right angle to its long axis.

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Standard Class V cavities were prepared on the buccal surface of all 60 molars, using #245 carbide burs (D-Flex, Germany, CE8120) in a high speed hand-piece with copious amount of water coolant. Bur was changed after each cavity preparation. Dimensions of the cavity preparation were kept exactly to: mesio-distal width of 3 mm, occluso-gingival height of 3 mm and depth of 2 mm.All cavity margins were kept in enamel. The depth of cavities was millimetrically standardized using a periodontal probe.All the preparations were performed by the same operator.

The teeth were then randomly assigned into 3 groups (n=20) depending on the restorative material used (*Table 1*). The three groups of teeth were restored following all the steps of etching, bonding and curing with different materials according to the manufacturer's instructions. Each specimen was light-irradiated using a light-emitting diode curing unit (SmartLite™ PS, Dentsply DeTrey GmbH, Germany). The light guide tip has 8mm in diameter, which covers the entire cavity preparation, and light output of 1000 mW/cm^2 as measured with a specific radiometer. In Group I (SIL) FiltekP90 self-etch primer was applied and left undisturbed for 15 s. It was air blown for 5 s and light cured for 10 s. Filtek P90 Bond was applied, air blown, and light cured for 10 s. Filtek P90 was placed in increments using Teflon coated instrument and cured for 40s. In Group II (SOLP) the prepared surfaces of the teeth were etched first with 35% phosphoric acid for 15 seconds(s), rinsed for 30 s and excess water was removed leaving the dentin surface visibly moist (wet bonding). This was followed by application of two consecutive coats of total etch adhesive, dried with a gentle stream of air for 5 s, and light-cured for 10 s. Solare P was placed in increments using teflon coated instrument and cured for 40s. In Group III (LCGIC) light-cured glass ionomer cement cavity conditioner was applied for 10 s. It was rinsed thoroughly with water and preparation was gently dried with air syringe carefully without desiccating it. Required amount was mixed, placed into the cavity and light cured for 20 s. All the restored teeth were stored at 37°C in 100% relative humidity for 24 h before finishing and polishing with abrasive discs (Sof-Lex™, 3M ESPE, St. Paul, USA). Teeth were then carefully separated from the cast to avoid damage on restorations, washed and dried using gentle stream of air.

The restored teeth were subjected to thermo-cycling at 5°C and 55°C for 500 cycles, with 30 s dwell time at each bath. The teeth were covered with nail varnish leaving a window of 1 mm all around cavity margins and then they were immersed in 2% Rhodamine B dye under vacuum pressure of 75 torr, for 48 h. After exposure to the dye, the samples were rinsed with running water to remove the dye and the nail varnish was gently removed with a sterile #15 disposable scalpel blade (Lister, Chennai, TN, IN). All teeth were bisected longitudinally in a bucco-lingual direction using a diamond disc (Isomet, Buehler, IL, USA) at slow speed and observed under stereo-microscope (Labomed Inc, Los Angeles, CA, USA) at 30X magnification, for evidence of dye penetration. The maximum degree of dye penetration was recorded for each specimen and dye penetration was scored on a nonparametric scale from zero to four based on Alavi and Kianimanesh [20] criteria for microleakage analysis (*Table 2*). All the specimens were evaluated by two examiners. Three readings were taken, with two of the readings were to check for intra-examiner reliability.

Intra examiner reliability was obtained using STATA statistical software by computing weighted kappa. The value of weighted kappa was 0.74. This kappa was in an acceptable range that indicated an acceptable level of consistency. Kappa statistic showed acceptable intra examiner reliability. The data were entered using SPSS version 11.0 and analyzed using One-Way Analysis of Variance (ANOVA) and Tukey's Post Hoc tests (α=0.05).

Results

Microleakage was assessed as shown in *Figures 1-4*. A zero score was not observed in specimens from all groups. SIL composite resin showed the best results with lowest dye penetration and hence least microleakage in Class V cavity restorations. Further, it showed statistically significant difference with SOLP and LCGIC (*Tables 3 and 4*). Sixty five per cent of specimens in SIL group, 30% in SOLP group and 5% in LCGIC showed dye penetration up to one-third of the cavity depth, while 5% in SIL group, 5% in SOLP group and 35% in LCGIC group showed dye penetration up to two-thirds of the cavity depth, and 30% in SIL group, 65% in SOLP group and 60% in LCGIC group showed dye penetration up to the axial wall (*Graph 1*).

Discussion

Over the past several decades, RBCs are providing an increased array of options for clinicians to restore teeth in a minimally invasive manner. However, these esthetic materials have limitations that restrict their use as universal restorative materials. In the present study Filtek P 90 (SIL) has shown the least microleakage, statistically

Table 1. *Test materials, manufacturers and composition.*

Material		Manufacturer	Composition
Adhesives	P90 self-etch adhesive	3M/ESPE Dental Products, St Paul, MN, USA	*Primer:* Phosphorylated methacrylate, Vitrebond copolymer, BisGMA, HEMA, Water, Ethanol, Silane-treated silica filler, Initiator *Bond:* Hydrophobic Dimethacrylate, Phosphorylated methacrylates, TEGDMA, Silane-treated silica filler, Initiators, Stabilizers
	Solare total etch adhesive system	GC Corporation, Tokyo, Japan	BisGMA, HEMA, dimethacrylates, Polyalkenoic acid, Copolymer, Ethanol, Water
Resin composite	Filtek P 90 Silorane Microhybrid composite **(SIL)**	3M/ESPE Dental Products, St Paul, MN, USA	*Resin:* Silorane, Camphoroquinone, iodonium salt, electron donors *Filler:* 76% by weight (mean: 0.47 µm) Quartz(fine) and yttrium fluoride Stabilizers, Pigments
	SOLARE P Microhybrid composite **(SOLP)**	GC Corporation, Tokyo, Japan	*Resin:* UDMA *Fillers:* Silica(13%), fluoro-aluminosilicate glass (24%) and pre-polymerized resin fillers(28%) by volume
Glass ionomer	GC Fuji II LC Reinforced glass ionomer restorative **(LCGIC)**	GC Corporation, Tokyo, Japan	*Powder:* FAS glass *Liquid:* Distilled water, polyacrylic acid, 2-HEMA (30-35%), UDMA, camphorquinone
Gel etchant	Gel etchant Scotchbond,	3M ESPE, St. Paul, MN, USA	Phosphoric acid 35%

Abbreviations: Silorane represents a mixture that is made of both Siloxane and Oxirane structural, Bis-GMA: Bisphenol A-glycidyl Methacrylate, HEMA: 2-Hydroxyethyl Methacrylate, TEGDMA: Triethylene Glycol Dimethacrylate, UDMA: Urethane Dimethacrylate.

Table 2. *Scoring Criteria.*

0	No dye penetration
1	Dye penetration at the 1/3rd initial side of the cavity wall
2	Dye penetration at the 2/3rdmiddle side of the cavity wall
3	Dye penetration at the 1/3rd last side of the cavity wall
4	Dye penetration at the axial wall

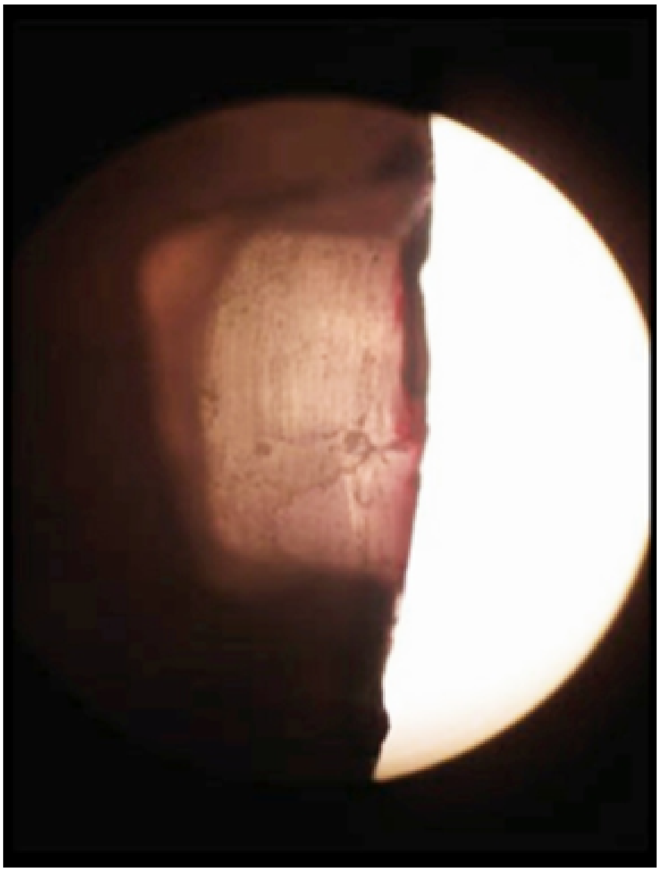


Figure 1. *Digital photograph of a specimen restored with SIL showing a "1" score (dye penetration seen up to less than 1/3rd the cavity wall).*

significant than to Solare P and LCGIC. This is in accordance with studies done by Bagis [21], Yamazaki [22], Palin [23] and Al-Boni et al. [24] who proved that microleakage of silorane is lower than that of methacrylate-based composite resin. Additionally, Thalacker et al. [25] reported that the silorane-based composite resin system showed a better marginal integrity on both enamel and dentin than the methacrylate-based composite resin system. Similarly, a clinical study revealed that silorane-based composite resin exhibited better performance in occlusal and proximal marginal adaptation than a methacrylate-based composite resin [26].

Various techniques have been used to evaluate microleakage such as dye penetration, bacterial leakage, electrochemical method, fluid filtration, radioisotope labelling, and scanning electron microscope analysis [27]. Among these techniques, dye penetration is the most widely used method to assess microleakage because of its sensitivity, ease of use, and convenience [27,28]. However, it is essential to select a suitable dye solution to be used with tooth structure and restorative materials tested and other factor such as particle size of the dye solution should also be taken into consideration to prevent less reliable final results [28]. Therefore, Rhodamine-B dye under vacuum was used in this study to assess microleakeage around class V restorations because of its small particle size, better penetration, water solubility, diffusability and hard tissue non-reactivity [29]. Vacuum helps to remove entrapped air which can prevent complete dye penetration [30].

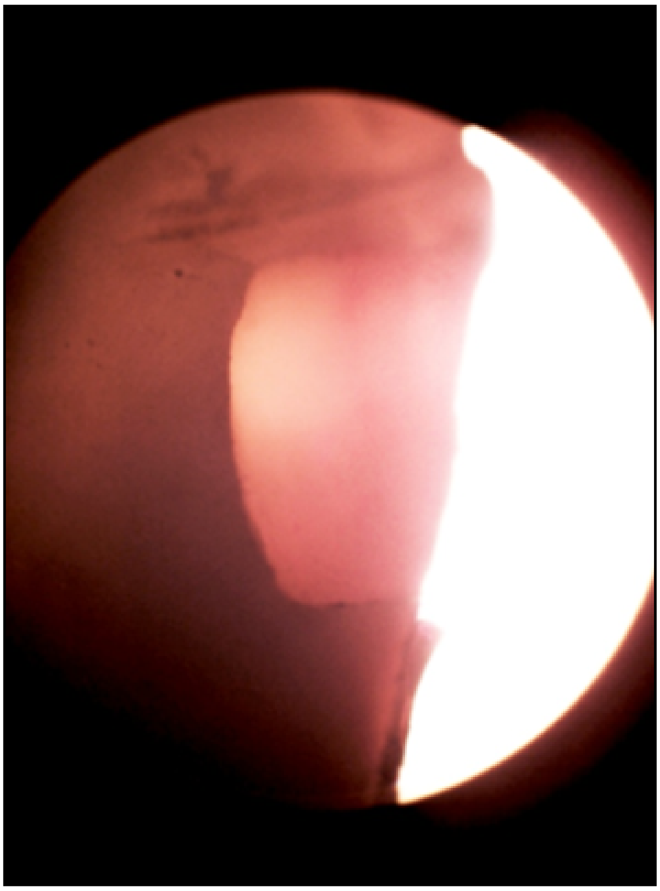


Figure 2. *Specimen restored with LCGIC. The depth of dye penetration at 2/3rd middle side of the cavity wall was given a "2" score.*

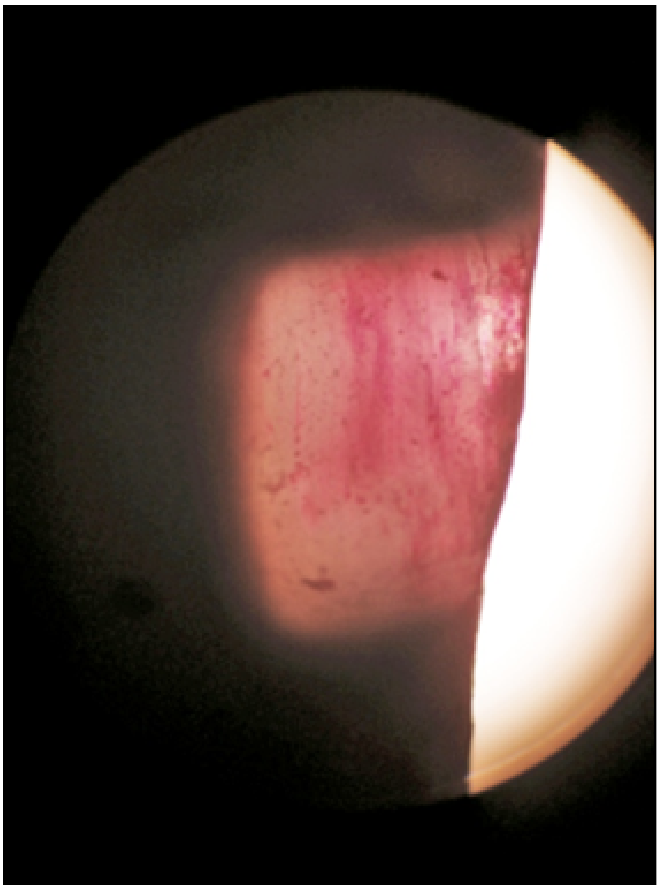


Figure 3. *Dye penetration seen at 1/3rd last side of the cavity wall restored with LCGIC (score 3).*

In the current study, lower microleakage scores obtained with SIL could be attributed to the ring opening chemistry of the silorane

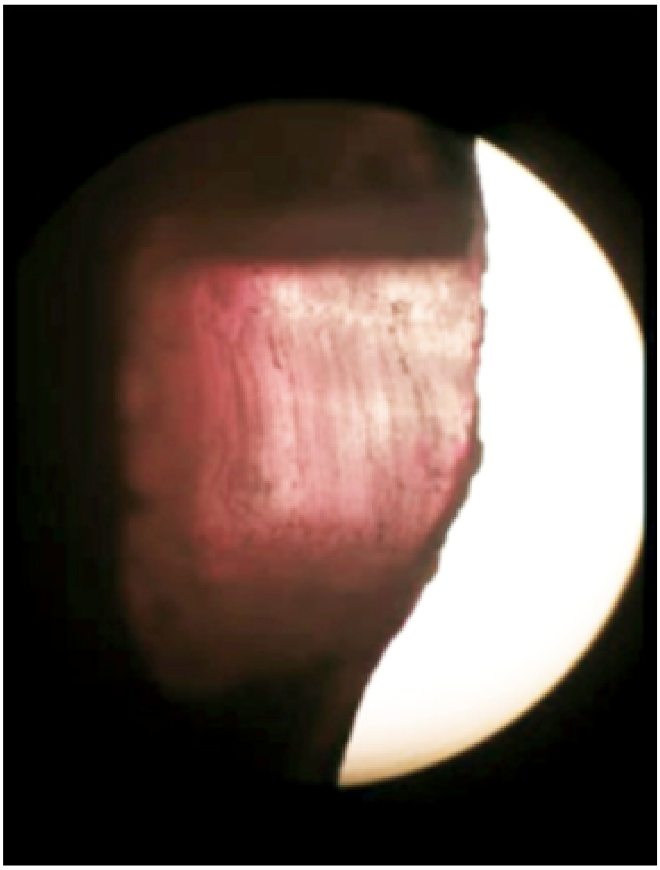


Figure 4. Digital photograph of a specimen restored with SOLP showing the highest degree of leakage, score "4" (dye penetration seen up to axial wall).

system and the use of different nature of the silorane system adhesive [22]. Silorane based composite resin possess two key advantages: polymerization shrinkage lower than 1% due to the presence of oxirane monomers and increased hydrophobicity due to the siloxane in its composition [9,10]. Defined factors in the prevention of microleakage are bonding resistance, wetting properties, solvent structure and application properties in dentin adhesive systems and molecular elasticity, contraction and thermal expansion coefficients in restorative materials [31].

Presence of water reduces modulus of elasticity and strength of the bond interface [32,33]. Water sorption is dependent on hydrophilicity of its constituent monomers [34]. Urethane Dimethacrylate (UDMA) and 2-Hydroxyethyl Methacrylate (HEMA) are highly hydrophilic monomers [35]. Although these monomers convert into hydrophobic polymer but when the polymer is subjected to the wet environment it swells up due to presence of molecule's hydrophilic pendant group and absorbs water. Therefore, there is an increase penetration of fluids into the material leading to more degradation and this could explain the lower performance of SOLP and LCGIC than SIL. The silorane-based composite exhibits decreased water sorption and solubility compared to conventional methacrylate-based composites, which suggests better hydrolytic stability in water immersion [36]. In resin-based silorane, functional groups of polymer network can contribute to greater free volume (due to the higher degree of freedom of the chain ends), which can enhance the penetration of the solvent, however, this penetration is reduced by the hydrophobic character of the molecule silorane [37]. Moreover, silorane-based composite resins are esthetic materials. Since they have good polishability, wear resistance and strength,these materials last long even against wear forces [37].

In the current study, a two-step total-etch adhesive was used with SOLP and the two-step self-etch Silorane system adhesive was used with SIL composite resin. The application of two-step total-etch adhesives has higher technical sensitivity than self-etch adhesives. Additionally, an adhesive agent when applied on the tooth surface shows its beneficial property by wetting all surfaces [38]. Previous studies [39,40] have reported that the poor wettability properties of high viscosity new composite materials necessitate a less viscous adhesive agent to penetrate the microcracks in the matrix of the composite and demineralized collagenous thus obtain micromechanical retention. Since silorane matrix is highly hydrophobic, it requires an individual adhesive system called Silorane System Adhesive (SSA) which is a two-step self-etch adhesive but bonding to dental structures is obtained in the first application step similar to one-step self-etch adhesives [41]. Previous study has also shown that the interaction of SSA with enamel/dentin and with silorane composite resin was free of voids in all sections offering benefits with regard to maintaining the interface sealed [42].

Studies have shown that the bonding of composite resin to enamel is better than dentin and less prone to hydrolytic breakdown [43]. Therefore, in the present study the cavity margins were kept in enamel. It has been shown that etch-and-rinse adhesive system shows less microleakage at the enamel interface than the self-etch adhesive system [44], contrary to our results, since, in the present study the group that applied SSA (SIL) showed better performance than SOLP group. Meharry et al. [45] found in their study that total–etch and self-etch adhesive systems were not significantly different

Table 3. *Showing F-test (ANOVA).*

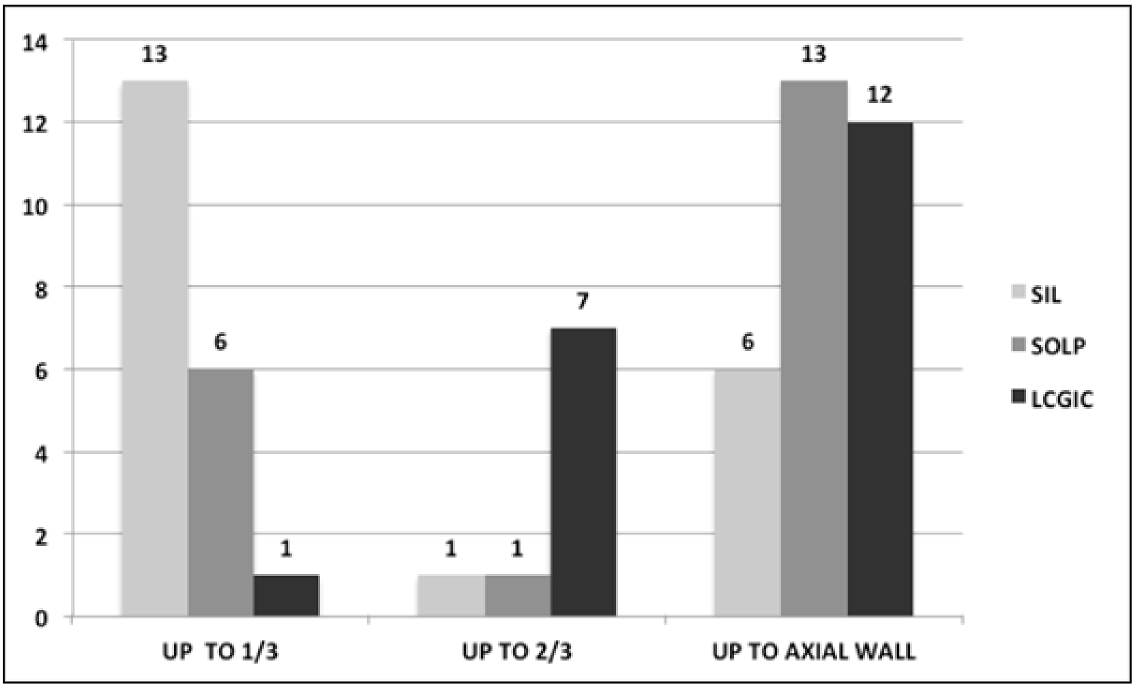
Leakage	Sum of Squares	df	Mean square	F	Sig.
Between Groups	10.078	2	5.039	2.580	0.000
Within Groups	13.956	57	.245		
Total	24.034	59			

In the present study P < 0.05 was considered statistical significant

Table 4. *Multiple comparison of dye penetration in between experimental groups using Post-HOC test.*

(I) TYPE (J) TYPE	Mean difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
SIL SOLP	-.5765*	.15648	**.002**	-.9625	-.1905
LCGIC	-1.0000*	.15648	**.000**	-1.3860	-.6140
SOLP SIL	.5765*	.15648	**.002**	.1905	.9625
LCGIC	-.4235*	.15648	**.027**	-.8095	.0375
LCGIC SIL	1.0000*	.15648	**.000**	.6140	1.3860
SOLP	.4235*	.15648	**.027**	.0375	.8095

In the present study P < 0.05 was considered statistical significant.



Graph 1. *Dye Penetration in different groups.*

from each other. Possibly the development of newer bonding systems has resulted in bonding agents with better performance.

The technique sensitivity of total-etch adhesive systems arises from the wet bonding stage required to keep the collagen network in an expanded state [46]. The presence of water and ethanol as solvents in adhesives composition facilitate resin penetration into the collagen, despite dentinal humidity [47]. Moreover, the simplified version of the two-step etch-and-rinse adhesive is very hydrophilic, allowing the passage of fluid through the polymerized adhesive to the subjacent hybrid layer [48,49], reducing the polymerization and consequently the bond strength causes poor sealing of bonded interface.

In methacrylate-based composite resin, a volumetric shrinkage occurs because of proximity of monomers that react to establish a covalent bond in the polymerization process [50]. Although this phenomenon also occurs with the silorane-based composite resin but the ring-opening chemistry promotes expansion of the molecule during the polymerization process. The kinetics of the initiation and polymerization begin with cleavage and opening of the ring systems via a cationic ring-opening reaction, allowing a gain of space that counteracts the reduction in free volume. Overall, the polymerization process yields reduced volumetric shrinkage (<1%) compared with methacrylate-based composites (2-5%) [10].

LCGIC was used as control in the present study. It has shown to create less stress on the residual cavity walls and improve marginal adaptation better than conventional glass ionomer cements [51]. Although, results of our study have shown that large amount of marginal microleakage in LCGIC group.

Resin modified glass ionomer cement contains the components similar to conventional glass ionomer, but in addition, it also contains polymerizable resin monomers in liquid (HEMA) along with initiators and activators. When the powder and liquid are mixed, both the acid–base reaction of conventional glass ionomer and the polymerization reaction of resin components take place resulting in the formation of two separate matrices, i.e. metal polyacrylate matrix and poly HEMA matrix [52]. Those results could indicate the effects of thermo-cycling and water sorption on RMGIC. Thermo-cycling is a combination of hydrolytic degradation and thermal stresses and is a method to simulate temperature-related breakdown by repeated sudden temperature changes. It causes deterioration of the interface and/or the materials. High water sorption potentiates the undesirable effects on restorative materials. Those materials which exhibit higher levels of water sorption presents higher expansion and are more easily stained by hydrophilic pigments, in that case water acts as a vehicle for dye penetration [53]. LCGIC has greater affinity for water and gets degraded by water; hence, it justifies its poor performance in this study.

Conclusion

Within the limitations of the present study, silorane-based composite exhibited least microleakage in restoring class V cavities when compared to methacrylate-based composite resin and light-cured glass ionomer cement. Hence, silorane-based composite resins can be recommended to restore cervical lesions.

References

1. Stavridakis MM, Krejci I, Magne P. Immediate dentin sealing of onlay preparations: Thickness of pre-Cured Dentin Bonding Agent and effect of surface cleaning. *Operative Dentistry*. 2005; **6**: 747–757.

2. Sadowsky SJ. An overview of treatment considerations for esthetic restorations: a review of the literature. *Journal of Prosthetic Dentistry*. 2006; **96**: 433-442.

3. Zanchi CH, Carvalho RV, Rodrigues Júnior AS, Demarco FF, Brunetti Júnior LH. Shrinkage stress of three composites under different polymerization methods. *Brazilian Oral Research*. 2006; **20**: 137-142.

4. González-López S, Vilchez Díaz MA, de Haro-Gasquet F, Ceballos L, de Haro-Muñoz C. Cuspal flexure of teeth with composite restorations subjected to occlusal loading. *Journal of Adhesive Dentistry*. 2007; **9**: 11–15.

5. Santini A, Plasschaert AJ, Mitchell S. Effect of composite resin placement techniques on the microleakage of two self-etching bonding agents. *American Journal of Dentistry*. 2001; **14**: 132-136.

6. Santini A, Plasschaert AJ, Mitchell S. Marginal leakage of filled dental adhesives used with wet and dry bonding techniques. *American Journal of Dentistry*. 2000; **13**: 93-97.

7. Malhotra N, Kundabala M, Shashirashmi A. Strategies to overcome polymerization shrinkage- materials and techniques: A review. *Dentistry Update*. 2010; **37**: 115-118.

8. Kubo S, Yokota H, Yokota H, Hayashi Y. The effect of light-curing modes on the microleakage of cervical resin composite restorations. *Journal of Dentistry*. 2004; **32**: 247–254.

9. Ilie N, Hickel R. Silorane-based dental composite: Behavior and abilities. *Dental Materials*. 2006; **25**: 445-454.

10. Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. *Dental Materials*. 2005; **21**: 68-74.

11. Guggenberger R, Weinmann W. Exploring beyond methacrylates. *American Journal of Dentistry*. 2000; **13**: 82-84.

12. Bouillaguet S, Gysi P, Wataha JC, Ciucchi B, Cattani M, Godin CH, Meyer JM. Bond strength of composite to dentin using conventional, one-step and self-etching adhesive systems. *Journal of Dentistry*. 2001; **29**: 55–61.

13. Zheng L, Pereira PN, Nakajima M, Sano H, Tagami J. Relationship between adhesive thickness and microtensile bond strength. *Operative Dentistry*. 2001; **26**: 97–104.

14. Van Meerbeek B, Vargas M, Inoue S, Yoshida Y, Peumans M, Lambrechts P, Vanherle G. Adhesives and cements to promote preservation dentistry. *Operative Dentistry*. 2001; **6**: 119–144.

15. Ceballos L, Camejo DG, Victoria Fuentes M, Osorio R, Toledano M, Carvalho RM, et al. Microtensile bond strength of total-etch and self-etching adhesives to caries-affected dentin. *Journal of Dentistry*. 2003; **31**: 469–477.

16. Wang Y, Spencer P. Hybridization efficiency of the adhesive/ dentin interface with wet bonding. *Journal of Dental Research*. 2003; **82**: 141–145.

17. Santini A, Ivanovic V, Ibbetson R, Milia E. Influence of marginal bevels on microleakage around Class V cavities bonded with seven self-etching agents. *American Journal of Dentistry*. 2004; **17**: 257–261.

18. Owens BM, Johnson WW. Effect of insertion technique and adhesive system on microleakage of Class V resin composite restorations. *Journal of Adhesive Dentistry*. 2005; **7**: 303–308.

19. Manuja N, Nagpal R, Pandit IK. Dental adhesions: mechanism, techniques and durability. *Journal of Clinical Pediatric Dentistry*. 2012; **36**: 223-234.

20. Alavi AA, Kianimanesh N. Microleakage of direct and indirect composite restorations with three dentin bonding agents. *Operative Dentistry*. 2002; **27**: 19–24.

21. Bagis YH, Baltacioglu IH. Comparing microleakage and layering methods of silorane based resin composite in wide Class 2 MOD cavities. *Operative Dentistry*. 2009; **34**: 578-585.

22. Yamazaki PC, Bedran-Russo AK, Pereira PN, Wsift EJ Jr. Microleakage evaluation of a new low shrinkage composite restorative material. *Operative Dentistry*. 2006; **3**: 670-676.

23. Palin WM, Fleming GJ, Nathwani H, Burke FJ, Randall RC. In-vitro cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. *Dental Materials*. 2005; **21**: 324-335.

24. Al-Boni R, M raja O. Microleakage evaluation of silorane based composite versus methacrylate based composite. *Journal of Conservative Dentistry*. 2010; **13**: 152–155.

25. Thalacker C, Heumann A, Weinmann W, et al. Marginal integrity of Class V silorane and methacrylate composite restorations. *Journal of Dental Research*. 2004; **83** (SI-A): 1364.

26. Schmidt M, Kirkevang LL, Horsted-Bindslev P, Poulsen S. Marginal adaptation of a low-shrinkage silorane-based composite: 1-year randomized clinical trial. *Clinical Oral Investigations*. 2011; **15**: 291–295.

27. Alani AH, Toh CG. Detection of microleakage around dental restorations: a review. *Operative Dentistry*. 1997; **22**: 173-185.

28. Taylor MJ, Lynch E. Microleakage. *Journal of Dentistry*. 1992; **20**: 3-10.

29. Azoubel E, Veeck EB. Analysis of apical sealing in teeth monoradicular underwent retrograde filling and laser irradiation with Nd: YAG. *Revista da Faculdade de Odontologia da Universidade Federal da Bahia*. 1998; **17**: 25-36.

30. Wimonchit S, Timpawat S, Vongsavan N. A comparison of techniques for assessment of coronal dye leakage. *Journal of Endodontics*. 2002; **28**: 1-4.

31. Manhart J, Chen HY, Mehl A, Weber K, Hickel R. Marginal quality and microleakage of adhesive class V restorations. *Journal of Dentistry*. 2001; **29**: 123-130.

32. Yiu CKY, King NM, Pashley DH, Suh BI, Carvalho RM, Carrilho MRO, et al. Effect of resin hydrophilicity and water storage on resin strength. *Biomaterials*. 2004; **25**: 5789-5796.

33. Ito S, Hashimoto M, Wadgaonkar B, Svizero N, Carvalho RM, Yiu C. Effects of resin hydrophilicity on water sorption and changes in modulus of elasticity. *Biomaterials*. 2005; **26**: 6449-6459.

34. Sideridou I, Tserki V, Papanastasiou G. Study of water sorption, solubility and modulus of elasticity of light-cured dimethacrylate-based dental resins. *Biomaterials*. 2003; **24**: 655-665.

35. Mine A, Munck J, Van Ende A, Cardoso M, Kuboki T, Yoshida Y, Van Meerbeek B. TEM characterization of a silorane composite bonded to enamel/dentin. *Dental Materials*. 2010; **26**: 524–532.

36. Porto ICCM, Aguiar FHB, Brandt WC, Liporoni PCS. Mechanical and physical properties of silorane and methacrylate-based composites*.* *Journal of Dentistry*. 2013; **41**: 732-739.

37. Boaro LC, Gonçalves F, Guimarães TC, Ferracana JL, Pfeifer CS, Braga RR. Sorption, solubility, shrinkage and mechanical properties of "low-shrinkage" commercial resin composites. *Dental Materials*. 2013; **29**: 398-404.

38. Hamano N, Ino S, Fukuyama T, Hickel R, Kunzelmann K-H. Repair of silorane-based composites: microtensile bond strength of silorane-based composites repaired with methacrylate-based composites. *Dental Materials Journal*. 2013; **32**: 695–701.

39. Puckett AD, Holder R, O'Hara JW. Strength of posterior composite repairs using different composite/bonding agent combinations. *Operative Dentistry*. 1991; 16: 136-140.

40. Swift EJ Jr, LeValley BD, Boyer DB. Evaluation of new methods for composite repair. *Dental Materials*. 1992; 8:362-365.

41. Mine A, De Munck J, Van Ende A, Cardoso MV, Kuboki T, Yoshida Y, Van Meerbeek. TEM characterization of a silorane composite bonded to enamel/dentin. *Dental Materials* 2010; **26**: 524-532.

42. Mine A, De Munk, J, Van Landuyt K, Poitevin A, Kuboki T, Yoshida Y. Bonding effectiveness and interfacial characterization of a HEMA/TEGDMA-free etch&rinse adhesive. *Journal of Dentistry*. 2008; **36**: 767-773.

43. Frankenberger R, Lohbauer U, Roggendorf MJ, Naumann M, Taschner M. Selective enamel etching reconsidered: Better than etch-and-rinse and self-etch? *Journal of Adhesive Dentistry*. 2008; **10**: 339-344.

44. Häfer M, Schneider H, Rupf S, Busch I, Fuch A, Merte I, Jentsch H, Haak R, Mert K. Experimental and Clinical Evaluation of a Self-etching and an Etch-and-Rinse Adhesive System. *Journal of Adhesive Dentistry*. 2013; **15**: 275-286.

45. Meharry MR, Moazzami SM Li Y. Comparison of Enamel and Dentin Shear Bond Strengths of Current Dental Bonding Adhesives from Three Bond Generations. *Operative Dentistry*. 2013; **38**: E237-E245.

46. Itthagarun A, Tay FR. Self-contamination of deep dentin by dentin fluid. *Journal of Dentistry.* 2000; **13**: 195–200.

47. Swift Jr E, Bayne SC. Shear bond strength of a new one bottle dentin adhesive. *American Journal of Dentistry*. 1997; **10**: 184–188.

48. Tay F, Gwinnett JA, Wei SH. The overwet phenomenon: A transmission electron microscopic study of surface moisture in the acid-conditioned, resin-dentin interface. *American Journal of Dentistry*. 1996; **9**: 161–166.

49. Tay FR, Frankenberger R, Krejci I, Bouillaguet S, Pashley

DH, Carvalho RM, Lai CN. Single-bottle adhesives behave as permeable membranes after polymerization. I. *In vivo* evidence. *Journal of Dentistry* 2004; **32**: 611–621.

50. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin-composites: A systematic review. *Dental Materials*. 2005; **21**: 962–970.

51. Friedl KH, Schmalz G, Hiller KA, Mortazavi F. Marginal adaptation of composite restorations versus Hybrid ionomer/composite sandwich restorations. *Operative Dentistry*. 1997; **22**: 21-29.

52. Sidhu SK, Watson TF. Resin modified glass ionomer materials. A status report for the American Journal of Dentistry. *American Journal of Dentistry*. 1995; **8**: 59-67.

53. Dietschi D, Campanile G, Holz J, Meyer JM. Comparison of the color stability of ten new-generation composites: an *in vitro* study. *Dental Materials*. 1994; **10**: 353-362.