

Effect of mechanical load cycling on class V glass- ionomer and composite restorations; a microleakage and scanning electron microscopic evaluation

E. Yassini ¹, H. Kermanshah ², M. Mirzaei ², B. Ranjbar Omid ³✉

¹ Professor, Department of Operative Dentistry, School of Dentistry, Tehran University of Medical Sciences. Tehran, Iran.

² Assistant Professor, Department of Operative Dentistry, School of Dentistry, Tehran University of Medical Sciences. Tehran, Iran.

³ Assistant Professor, Department of Operative Dentistry, School of Dentistry, Qazvin University of Medical Sciences. Qazvin, Iran

Abstract

Background and Aim: Microleakage is an important problem with direct restorations and familiarity with its contributing factors is of utmost importance. The aim of this study was scanning electron microscopic evaluation of marginal integrity in three types of class V tooth-colored restorations and the effect of load cycling on their microleakage.

Materials and Methods: In this in vitro study, class V cavity preparations were made on the buccal and lingual surfaces of 30 bovine incisors (60 cavities). The specimens were divided into three groups (n=10 each or 20 cavities) and restored as follows: group 1: with Filtek Z350 (nanocomposite), group 2: Fuji IX/G Coat Plus (CGIC), and group 3: Fuji II LC (RMGI).

All specimens were finished and polished immediately and were thermocycled ($\times 2000, 5-50^{\circ}\text{C}$). In each group, half of the teeth were load cycled. Epoxy resin replicas of 12 specimens were evaluated under FE-SEM and interfacial gaps were measured. Finally the teeth were immersed in 0.5% basic fuchsin dye for 24 hours at room temperature, sectioned and observed under stereomicroscope. Data were analyzed with Kruskal-Wallis and Mann-Whitney U tests and a comparison between incisal and cervical microleakage was made with Wilcoxon test.

Results: It was shown that the mechanical load cycling caused a statistically significant increase in cervical microleakage of Fuji IX and Fuji II LC and in incisal microleakage of Fuji II LC. Microleakage in Z350 with load-cycling and Fuji IX with and without load-cycling was significantly higher in cervical compared with incisal area. Both incisal and cervical microleakage were significantly different among these materials under load-cycling. (Fuji II LC > Fuji IX > Z350).

Conclusion: It was concluded that the marginal sealing ability of Fuji IX under load-cycling was better than that of Fuji II LC. Z350 showed better marginal integrity while being load-cycled than both Fuji II LC and Fuji IX.

Key Words: Microleakage - Glass ionomer cement - composite resin

✉ Corresponding author:

Dr. Ranjbar Omid B., Assistant Professor, Department of Operative Dentistry, School of Dentistry, Qazvin University of Medical Sciences. Qazvin, Iran
baharan_o@yahoo.com

Received: 9 June 2011
Accepted: 29 August 2011

Journal of Islamic Dental Association of IRAN (JIDAI) / Summer 2012 / 24 / (2)

Introduction

Cervical lesions occur due to incorrect brushing, caries or excessive occlusal forces [1]. Microleakage is considered as the most important problem of cervical restorations [2]. The main reason for restoration failure is microleakage through the tooth-restoration interface [2, 3]. This can cause bacterial penetration through tooth-restoration interface thereby leading to secondary caries and pulpal irritation. Factors within the oral cavity such as occlusal forces, thermal changes, difference in physical properties of teeth and restorative materials such as polymerization shrinkage, coefficient of thermal expansion and modulus of elasticity are associated with microleakage [4]. Several studies have been conducted to eliminate the tooth-restoration gap, this goal has not yet been achieved. There is still a considerable challenge in marginal seal of even advanced bonded restoration systems with margins located beneath the CEJ [5-11]. Numerous types of materials have been introduced to establish a bond to tooth structure including glass ionomers. Which have the ability to bond to enamel and dentin [12, 13], release fluoride, and prevent caries. They are compatible with pulpal and periodontal tissues, have a coefficient of thermal expansion similar to that of dentin and a polymerization shrinkage less than that of composite [13,14]. The effect of restoration material on microleakage of class V cavities is a matter of debate, with some studies reporting better [15], some worse [16], and some others a comparable seal of glass ionomer in comparison with that of composite [17]. However, evaluation of changes in microleakage of these two materials while being subjected to occlusal forces is of paramount importance. Controversial issues exist concerning the effects of mechanical cycling on microleakage [18-20]. Few investigations have been performed on the effect of mechanical cycling on marginal adaptability of glass ionomers [21]. On the other hand, a novel restorative glass ionomer, Equia, has been introduced which is a combination of Fuji IX glass ionomer

and a coating material (G Coat Plus). It has been claimed that better physical properties, fast contouring and decreased microleakage can be achieved following application of a nano-filled varnish. The objective of this study was to evaluate the effects of mechanical cycling on microleakage of three different tooth-colored restorative materials (i.e., Z350 composite, Fuji IX, and Fuji II LC) in class V cavities and evaluation of their marginal adaptability by scanning electron microscopy (SEM).

Materials and Methods

A total of 30 bovine central incisor teeth were used in this study. Teeth were inspected not to have any surface defects. Two class V cavities, one on buccal and the other on lingual surface of the teeth were prepared. Then, teeth were immersed in 0.5% chloramine T solution for disinfection and stored in normal saline at 4 degrees centigrade prior to the experiment. Standardized cavities had 3mm mesiodistal and 3mm occlusogingival dimensions. The intradentinal depth was 1mm and the gingival margin was 1mm beneath the CEJ. Cavities were prepared by round diamond burs (DIAMIR, Italy, FGS 001018) with a high-speed handpiece and water spray. Burs were discarded after 5 preparations. Tooth pulps were also mechanically removed. Samples were randomly divided according to the type of restoration material and use of mechanical cycling. Group 1: following desiccation, the enamel and dentin parts of the cavity were etched by 37% phosphoric acid (Kimia Co, Iran) for 30 and 15 seconds, respectively, rinsed for 15 seconds and dried with a cotton pellet. The procedure was done in a way that the cavity was not completely dried. Then, two layers of Single Bond adhesive (Adper Dental Products, ESPE, 3M, St. Paul, MN, USA) was applied and cured for 10 seconds, using a quartz-tungsten-halogen device (Optilux 501, Kerr, USA). Afterwards, each cavity was filled with three layers of Z350 composite (3M ESPE, Dental Products, USA) and cured in each stage with the same curing

device with an intensity of 520 mW/m² for 40 seconds.

Group 2: In this group cavities were conditioned with a dentin conditioner (GC, Japan), rinsed and dried using an air syringe preventing over-desiccation of dentin and finally filled with self-curing injectable Fuji IX cement (GC Fuji IX GP EXTRA). One layer of coating (G Coat plus, GC Corp, Japan) was applied after complete hardening of the cement (2.5 minutes).

Group 3. In this group the cavities were conditioned (Dentin Conditioner, GC, Japan) for 20 seconds, rinsed and dried with air spray and eventually filled with a glass ionomer cement (Fuji II, LC, Japan) and cured as stated previously. The glass ionomer cement was prepared in a way that 2 parts of powder were mixed with one drop of liquid on a glass slab to produce 3 minutes of working time. After curing, the surface was coated by Fuji Varnish (GC, Tokyo, Japan)

All teeth were polished using a super-fine grit diamond bur (FGSF 273012) under water spray. Coating were applied after polishing in groups 2 and 3. The teeth were thermocycled for 2000 cycles using 5-50 degrees centigrade. Subsequently, half of the samples underwent mechanical cycling (Germany, SD Mekanotronik). This procedure was performed as follows: initially a cylindrical tube was covered with a layer of wax, then the teeth were mounted up to a 1mm distance below the gingival margin of the restoration in a self-curing acrylic resin (Acropars 200, Malic Medical Industries Co, Tehran, Iran) at the middle and parallel to walls of the tube. Samples were then tested under 25000 axial and eccentric cycles using a force of 100 Newtons, a displacement of 1 millimeter and a frequency of 1 Hz. Afterwards, each tube was rotated in 180 degrees and another set of 25000 cycles was performed with the above mentioned specifications. Therefore, the total mechanical cycling time was about 14 hours for 50 cycle sets.

Preparation of Replicas for Field Emission Scanning Electron Microscopy

Before sectioning the teeth and in order to evaluate microleakage, an impression (Precise, Coltene, Switzerland) was made from two teeth in each group and positive epoxy resin (Epothin, Buehler Ltd., Lake Bluff, IL) replicas were prepared. Each replica was mounted on a metal stub and was gold sputtered. Samples were then visualized under a field-emission scanning electron microscope (FE-SEM) (Hitachi s4160, Japan) with 10,000x magnification to evaluate marginal adaptability. Before this evaluation, occluso-gingival and mesiodistal dimensions of each restoration was measured using FE-SEM software and the results were compared with those of cavity dimensions, to rule out the presence of any overextended margin influencing on marginal gaps. Restoration margins were evaluated and gaps, if present, were recorded. Total length of interfacial gaps were pointed to as a percentage of total length restoration margins. The margins of the cavity was divided into 8 sections (see fig.1) each comprising 12.5% of the total length of restoration margins. Each section was visualized separately and percentage of gap formation was recorded. The total length of the interfacial gaps was considered as the sum of the total percentage of recorded marginal gaps for each section. (See fig.2)

Microleakage evaluation

After preparation of SEM replicas, the surfaces of all teeth were covered with three layers of nail varnish.

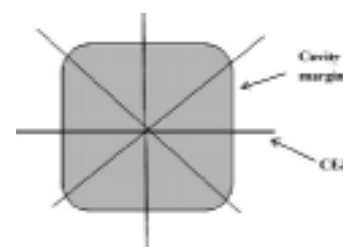


Figure 1: Cavity margins were divided into 8 sections and each section was visualized for evaluation of the percentage of gap formation

Samples were immersed into 0.5% basic fuchsin solution in 27 degrees centigrade for 24 hours.

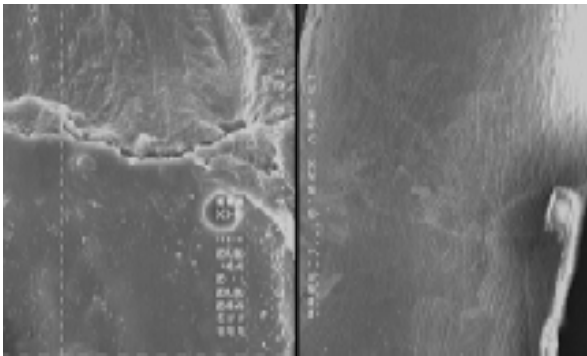


Figure 2: A replica is shown on the right (20x) and interfacial gap of the same sample is shown on the left (10,000x)

Samples were rinsed with a physiologic solution and air dried. The teeth were mounted in self-curing acrylic resin molds. Two longitudinal sections (Presi, Mecatome, T 201 A, France) were made through the restored area so that a one-millimeter-thick cut was placed at the middle portion of the restoration, preparing two halves for microleakage evaluation [4]. Microleakage was visualized as dye penetration under a stereomicroscope (Nikon, SMZ 800, Tokyo, Japan) with 10 and 40x magnification settings according to the following scores:

Score 0. No dye penetration

Score 1. Dye penetration less than half of the incisal or gingival wall

Score 2. Dye penetration more than half of the incisal or gingival wall but not reaching the axial wall

Score 3. Dye penetration involving the axial wall

Data were analyzed by Wilcoxon, Mann-Whitney U and Kruskal-Wallis statistical tests and $p < 0.05$ was considered a statistically significant difference.

Results

Results of incisal and cervical microleakage are shown in table 1. Microleakage was significantly

more in cervical than in incisal margins of composite restorations while being under cycling and Fuji IX restorations with and without mechanical cycling. (See table 2) However, there was no statistically significant difference in incisal and cervical microleakage of Fuji II LC restorations with or without mechanical cycling and Z350 composite restorations without mechanical cycling.

Mechanical cycling significantly increased cervical microleakage of glass ionomer- restored samples. Besides, incisal microleakage of Fuji II LC was significantly increased following mechanical cycling. (See table 3) On the other hand this process did not have any statistically significant effect on incisal and cervical microleakage of Z350 composite and incisal microleakage of Fuji IX. (See table 3)

Kruskal-Wallis test indicated that there was a significant difference in cervical microleakage of the restorative materials while being mechanically cycled. ($p = 0.002$) Also, there was a significant difference among all three restorative materials in incisal microleakage after mechanical cycling. ($p = 0.001$) It has to be mentioned that the difference between incisal and cervical microleakage of restorative materials within the three groups was not statistically significant when no mechanical cycling was applied. ($p > 0.05$)

Results of field-emission scanning electron microscopic evaluation

The results of field-emission scanning electron microscopic (FE- SEM) evaluation of the two random samples from each groups showed that in Z350 composite group after mechanical cycling 1.534% and 0.01% interfacial gap was observed, but in the same group without mechanical cycling both random samples showed 0% interfacial gap formation. Within the group restored with Fuji IX after mechanical cycling, the first sample showed 1.647% and the second 8.167% interfacial gap formation, but in those without mechanical cycling one sample showed 0% and the other 0.71% gap formation.

Table 1: Frequency of microleakage in each margin according to the use of restorative material and mechanical cycling

	Microleakage scores	Incisal microleakage				Cervical microleakage			
		0	1	2	3	0	1	2	3
Z350	Mechanical cycling	16	4	0	0	11	7	2	0
Z350	No Mechanical Cycling	15	2	2	1	14	2	3	1
Fuji IX	Mechanical Cycling	9	7	4	0	5	1	10	4
Fuji IX	No Mechanical Cycling	14	0	5	1	9	5	5	1
Fuji II LC	Mechanical Cycling	6	4	4	6	5	4	3	8
Fuji II LC	No Mechanical Cycling	11	5	4	0	9	7	4	0

Table 2: The results of Wilcoxon test in comparison of microleakage scores according to the use of the restorative material and mechanical cycling (a, b, and c are considered statistically significant)

Restorative material	Loading	margin	number	Z value	p
Z350	Mechanical Cycling	Incisal	20	-2/333	0/02 ^a
		Cervical	20		
	No Mechanical Cycling	Incisal	20	-0/557	0/557
		Cervical	20		
Fuji IX	Mechanical Cycling	Incisal	20	-2/924	0/003 ^b
		Cervical	20		
	No Mechanical Cycling	Incisal	20	-2/236	0/025 ^c
		Cervical	20		
Fuji II LC	Mechanical Cycling	Incisal	20	-0/95	0/342
		Cervical	20		
	No Mechanical Cycling	Incisal	20	-0/44	0/66
		Cervical	20		

Table 3: The results of Mann-Whitney U test about microleakage according to the application of mechanical cycling or lack thereof in any of the restorative materials in cervical or incisal margins (* shows significance of difference)

Margin	Restorative material	Loading	number	Z value	P
Incisal	Z350	Mechanical Cycling	20	-0/594	0/678
		No Mechanical Cycling	20		
	Fuji IX	Mechanical Cycling	20	-0/82	0/478
		No Mechanical Cycling	20		
	Fuji II LC	Mechanical Cycling	20	-2/252	*0/033
		No Mechanical Cycling	20		
cervical	Z350	Mechanical Cycling	20	-0/533	0/659
		No Mechanical Cycling	20		
	Fuji IX	Mechanical Cycling	20	-2/196	*0/038
		No Mechanical Cycling	20		
	Fuji II LC	Mechanical Cycling	20	-2/435	*0/018
		No Mechanical Cycling	20		

In groups restored with Fuji II LC, the samples which had undergone mechanical cycling showed 1.712% and 6.861% interfacial gap formation, but in those without mechanical cycling one sample had 0.55% and the other 0.02% interfacial gaps.

Discussion

In this study bovine teeth were used because they have shown great similarities in structure with human teeth in literature [22-23]. In addition Kubo et al stated that there was no difference in mechanical cycling between human and bovine teeth. They also used repeated bucco-lingual loading and proposed that such loading can produce higher tensile strain in interfacial area compared with the time when axial loading I applied. They attributed this fact to the flexural load applied to the tooth [18] It is noteworthy that in the current study, both axial and bucco-lingual loadings have been used but due to the flattening of incisal surfaces in all samples in order to equalize the condition, flexure caused by bucco-lingual loading was far less than the time when no reduction is performed. This could have simulated an edge-to-edge occlusal relationship. On the other hand, during axial loading, teeth were subjected to flexural loading as well because they were mounted on a rigid platform [24].

According to Heymann et al factors related to the flexure of the teeth can be significantly influential in class V composite retention failures [25]. Additionally, one of the etiologic factors in non-carious cervical lesions is occlusal or incisal forces that can cause loads on dentinoenamel junction in cervical areas [26]. Elastic or plastic deformations of restored teeth cause bond failures in restoration margins due to compressive stresses resulted from occlusal forces [27]

In the current study, the effect of mechanical cycling on incisal and cervical microleakage of Single Bond/Z350 composite was not considered significant. This finding is in accordance with the results of previous studies [24,28,29] but sta-

tistically significant results were reported in microleakage of samples after mechanical cycling using 5000 cycles and 125 and 250 newton forces by Davidson and Abdalla [21]. Rigsby also stated that composites showed increased microleakage in cervical areas only when teeth were subjected to a combination of mechanical and thermal cycling [30]. It has also been shown that, 71% of class V restorations in third molars with opposing teeth indicate more leakage than those without opposing teeth [27].

Such differences in laboratory studies can be attributed to the difference in materials examined, the amounts of and methods, by which forces are applied, mechanical preparation of the cavities and/or the evaluation procedure.

In this study, microleakage of Fuji IX occurred only in cervical area following mechanical cycling. According to Yap et al, when condensable silver-reinforced glass ionomer (Shofu Hi Dense) was placed in class III cavities with intradental cervical margins and subjected to 100 cycles using a maximal force of 170 ± 8 N, no significant difference was observed between experimental and control groups within enamel-restoration interface, but marginal microleakage at dentin-restoration interface was significantly higher in samples which had been subjected to cycling compared with those which had not (i.e., control). This can be attributed to the higher inorganic content of enamel which can provide a better seal with glass ionomer even when mechanical cycling is performed [31]. On the other hand, Ichim and co-workers who conducted a three-dimensional finite element analysis of cervical cavities filled with glass ionomer, in the cervical margin showed that more tensile stress was concentrated within the cervical margin- the area with increased susceptibility of restoration failure [22].

In Fuji II LC, both cervical and incisal microleakage was influenced by mechanical cycling. Nonetheless, in an investigation by Davidson and Abdalla, no significant effect of mechanical cycling on Fuji II LC was observed

when the samples underwent a 125-newton axial force for 5000 cycles, but following an increase in the force up to 250 newtons a significant effect on microleakage of this material was observed following mechanical cycling [21]. Of course, in the current study, the applied force was 100 N and the mechanical cycles were ten times that of Davidson et al's study. Since it is stated by Xie and colleagues that Fuji II LC undergoes plastic deformation following application of compressive forces [33], such increase in microleakage following cycling can be due to plastic deformation of Fuji II LC glass ionomer and disruption of micromechanical bonds.

It was shown in this study that increased microleakage of composite was seen after being subjected to mechanical cycling. This was in agreement with Rigsby et al [30].

It has been declared by several investigators that adhesive strength in inferior in cemental substrate with respect to enamel in composite restorations [34, 35]. increased microleakage in cemental margins is expectable [36, 37]. Although Z350 is a low-shrinkage composite and oblique incremental technique was used in this study to minimize the effects of stresses resulting from C-factor, low polymerization shrinkage was not able to overcome the adhesive strength and microleakage ensued especially following mechanical cycling.

In the current study, cervical area microleakage of Fuji IX following mechanical cycling was significantly more than that of incisal area. This was congruent with Ichim et al who stated that parafunctional forces applied on teeth with class V cavities restored with glass ionomer can initially cause strain softening of the material in cervical area thereby leading to marginal weakening and finally cervical fracture of the restoration [28]. Likewise, significance of cervical and incisal microleakage of Fuji IX without application of mechanical cycling can be attributable to the higher inorganic content of enamel in incisal margin with respect to dentin and cementum in cervical region.

It can be declared by this study that mechanical cycling increases microleakage of Fuji II LC in both cervical and incisal and that of Fuji IX only in cervical areas. SEM evaluation also corroborated these results by showing increased percentage of marginal gap formation.

Lack of a significant difference between incisal and cervical microleakage in Fuji II LC with and without mechanical cycling, might have been related to destruction of both margins thereby equally increasing the microleakage.

When mechanical cycling was performed, incisal as well as cervical microleakage was significantly different among restorative materials. The minimal and maximal amount of microleakage in both incisal and cervical margins was recorded for composite and Fuji II LC, respectively. No statistically significant difference was observed among any of the restorative materials when no mechanical cycling was performed.

These results are congruent with Castro and co-workers who stated that Fuji IX had less microleakage compared with older standard glass ionomer cements but had similar microleakage in comparison with resin-modified glass ionomer cement and composite [17].

In the present study, there was no significant difference in microleakage of Fuji IX and Fuji II LC without application of mechanical cycling. This was in accordance with the results of Rodrigues who stated that microleakage of Fuji II LC was similar to that of other self-curing glass ionomer cements [39]. There are numerous controversial issues in the literature concerning comparison of self- and light-curing glass ionomer cements in terms of their microleakage, with some reporting self- and some others light-curing materials to have more microleakage [40]. This diversity can be related to different methods of investigation, different materials used as well as improvements in manufacturing process of glass ionomer cements.

Although there has not been any investigation to compare microleakage of composite and glass ionomer under similar cycling conditions, the

reason for increased incisal and cervical microleakage of glass ionomer in comparison with composite under cycling condition is probably attributable to the strain softening of glass ionomer under bucco-lingual (such as parafunctional) forces that cause marginal weakening [28] In the present study Z350 nanohybrid composite was used. This composite contains nanoclusters. Infiltration of silane into nanoclusters can modify the response to the applied loadings and increase failure tolerance, thereby improving clinical performance and providing an inherent strengthening mechanism in this type of composite in comparison with microhybrid and microfilled composite resins [42] This can be a reason for superior results obtained in composite in our study compared with other similar works.

Conclusion

Based upon the obtained results, it appears that Fuji IX provides better marginal adaptability under mechanical cycling compared with Fuji II LC. Z350 showed the highest marginal adaptation under mechanical cycling. Enamel margins indicated a better seal in compared with dentinocemental counterparts in Fuji IX and Z350 composite after mechanical cycling. Also, mechanical cycling was found to increase cervical and incisal microleakage of Fuji II LC and cervical microleakage of Fuji IX.

Acknowledgements

This paper is a part of a postgraduate dissertation and an approved research project of Dental Research Center at Tehran University of Medical Sciences, School of Dentistry No. 132/633. Assistance of all officials in accordance with this project is hereby acknowledged.

References

- 1-Litonjua LA, Andreana S, Bush PJ, Tobias TS, Cohen RE. Noncarious cervical lesions and abfractions: A reevaluation. *J Am Dent Assoc.* 2003 Jul;134(7):845-850.
- 2- Bergenholtz G, Cox CF, Loesche WJ, Syed SA. Bacterial leakage around dental restorations: Its effect on the dental pulp. *J Oral Pathol.* 1982 Dec;11(6):439-450.
- 3-Jang KT, Churg DH, Shin D, Garcia-Godoy F. Effect of eccentric load cycling on microleakage of class v flowable and packable composite resin restorations. *Oper Dent.* 2001 Nov-Dec;26(6):603-608.
- 4-Manhart J, Chen HY, Mehl A, Weber K, Hickel R. Marginal quality and microleakage of adhesive CIV restorations. *J Dent.* 2001 Feb; 29 (2):123-130.
- 5-Bezno C. Microleakage at the cervical margin of class II cavities with different restorative techniques. *Oper Dent.* 2001 Jan-Feb;26(1):60-69.
- 6-Demarco FF, Ramos OL, Mota CS, Formola E, Justino LM. Influence of different restorative techniques on microleakage in class II cavities with gingival wall in cementum. *Oper Dent.* 2001 May-Jun;26(3):253-259.
- 7-Derhami K, Coli P, Brannstorm M. Microleakage in class II composite resin restorations. *Oper Dent.* 1995 May-Jun;20(3):100-105.
- 8-Ferrari M, Cagidiaco MC, Davidson CL. Resistance of cementum in class II and v cavities to penetration by an adhesive system. *Dent Mater.* 1997 May;13(3):157-162.
- 9-Ferrari M, Mason PN, Fabianelli A, Cagidiaco MC, Kugel G, Davidson CL. Influence of tissue characteristics at margins on leakage of class II indirect porcelain restorations. *Am J Dent.* 1999 Jun;12(3):134-142.
- 10-Hilton TJ, Schwartz RS, Ferracane JL. Microleakage of four class II resin composite insertion techniques at intra oral temperature. *Quint Int.* 1997 Feb;28(2):135-44.
- 11-Neme AL, Maxson BB, Pink FE, Aksu MN. Microleakage of class II packable composites lined with flowables: An invitro study. *Oper Dent.* 2002 Nov-Dec;27(6):600-605.
- 12-Tyas MJ, Burrow MF. Adhesive restorative materials: A review. *Aust Dent J.* 2004 Sep; 49 (3):112-21.

- 13-De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, et al. A critical review of the durability of adhesion to tooth tissue: Methods and results. *Dent Res.* 2005 Feb;84(2):118-32.
- 14-Hickel R, Dasch W, Janda R, Tyas M, Anusavice K. New direct restorative materials. FDI Commission Project. *Inter Dent J.* 1998 Feb; 48(1):3-16.
- 15-Atash R, Bottenberg P, Petein M, Vanden Abbeele A. Invitro evaluation of the marginal seal of four restoration materials on deciduous molars. *Bull Group Int Rech Sci Stomatol Odontol.* 2003 Jan- Apr;45(1):34-41.
- 16-Xie H, Zhang F, Wu Y, Chen C, Liu W. Dentine bond strength and microleakage of flowable composite, compomer and glassionomer cement. *Aust Dent J.* 2008 Dec;53(4):325-331.
- 17-Castro A, Feigal RE. Microleakage of a new improved glass ionomer restorative material in primary and permanent teeth. *Pediat Dent.* 2002 Jan-Feb;24(1):23-8.
- 18-Kubo S, Yokota H, Sata Y, Hayashi Y. The effect of flextural load cycling on the microleakage of cervical resin composites. *Oper Dent.* 2001 Sep-Oct;26(5):451-459.
- 19-Ozel E, Korkmaz Y, Ahar N. Influence of location of the gingival margin on the microleakage and interval voids of nanocomposites. *J Contemp Dent Pract.* 2008 Nov 1;9(7):65-72.
- 20-Ausiello P, Davidson CL, Cascone P, Dee Gee AJ, Rengo S. Debonding of adhesively restored deep class II MOD restirations after functional loading. *Am J Dent.* 1999 Apr;12(2):84-88.
- 21-Davidson CL, Abdalla AL. Effect of occlusal load cycling on the marginal integrity of adhesive CIV restorations. *Am J Dent.* 1994 Apr; 7 (2):111-4.
- 22-Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. *J Dent Res.* 1983 Oct;62(10):1076-81.
- 23-Reeves GW, Fitchie JG, Hembree JH, Puckett AD. Microleakage of new dentin bonding systems using human and bovine teeth. *Oper Dent.* 1995 Nov-Dec;20(6):230-5.
- 24-Shneider LFJ, Consani S, Mundstock GV, Tango RN, Milan FM, Sinhoreti MAC. Microleakage evaluation of composite restorations submitted to load cycling. *Cienc Odontol Bras.* 2004 Out./Dez.; 7(4):27-33.
- 25-Heymann HO, Sturdevant JR, Bayne S, Wilder AD, Sluder TB, Brunson WD. Examining tooth flexure effects on cervical restorations: A two-year clinical study. *J Am Dent Assoc.* 1991 May;122(5):41-7.
- 26-Lee WC, Eakle WS. Possible role of tensile stress in the etiology of cervical erosive lesions of teeth. *J Prost Dent.* 1984 Sep;52(3):374-80.
- 27-Qvist V. The effect of mastication on marginal adaptation of composite restorations in vivo. *J Dent Res.* 1983 Aug;62(8):904-6.
- 28-Arisu HD, Uctasli MB, Eliguzelolu E, Ozcan S, Omurlu H. The effect of occlusal loading on the microleakage of class V restorations. *Oper Dent.* 2008Mar-Apr;33-2:135-141.
- 29-Li H, Burrow MF, Tyas MJ. The effect of load cycling on the nanoleakage of dentin bonding systems. *Dent Mat.* 2002 Mar;18(2):111-19.
- 30-Rigsby DF, Retief DH, Bidez MW, Russell CM. Effect of axial load and temperature cycling on microleakage of resin restorations. *Am J Dent.* 1992 Jun;5(3):155-9.
- 31-Yap AUJ. Effects of storage, thermal and load cycling on a new reinforced glass-ionomer cement. *J Oral Rehab.* 1998 Jan;25(1):40-44.
- 32-Ichim I, Schmidlin PR, Kieser JA, Swain MV. Mechanical evaluation of cervical glass-ionomer restorations: 3D finite element study. *J Dent.* 2007 Jan;35(1):28-35.
- 33-Xie D, Brantley WA, Culbertson BM, Wang G. Mechanical properties and microstructures of glass-ionomer cements. *Dent Mater.* 2000 Mar; 16(2):129-138.
- 34-Fruits TJ, VanBrunt CL, Khajotia SS, Duncanson MG Jr. Effect of cyclical lateral forces on microleakage in cervical resin composite restorations. *Quintessence Int.* 2002 Mar; 33 (3):205-12.

- 35-Yap AU, Ho KS, Wong KM. Comparison of marginal sealing ability of new generation bonding systems. *J Oral Rehabil.* 1998 Sep;25(9):666-71.
- 36-Davidson CL, de Gee AJ, Feilzer A. The competition between the composite-dentin bond strength and the polymerization contraction stress. *J Dent Res.* 1984 Dec;63(12):1396-9.
- 37-Sidhu SK, Henderson LJ. Dentin adhesives and microleakage in cervical resin composites. *Am J Dent.* 1982 Oct;5(5):240-4.
- 38-Ichim I, Loughran J, Li Q, Swain MV, Kieser J. Restoration of non-carious cervical lesions. Part I. Modelling of restorative fracture. *Dent Mater.* 2007 Dec; 23:1553-1561.
- 39-Rodrigues JA, DeMagalhaes CS, Serra MC, Rodrigues AL. In vitro microleakage of glass-ionomer composite resin hybrid materials. *Oper Dent.* 1999 Mar-Apr;24(2):89-95.
- 40-Crim GA. Marginal leakage of visible light-cured glass ionomer restorative materials. *J Prosthet Dent.* 1993 Jun; 69(6):561-3.
- 41-Puckett AD, Fitchie JG, Bennett B, Hembree JH. Microleakage and thermal properties of hybrid ionomer restoratives. *Quint Int.* 1995 Aug; 26(8):577-81.
- 42-Curtis AR, Palin WM, Fleming GJP, Shortall ACC, Marquis PM. The mechanical properties of nanofilled resin-based composites: The impact of dry and wet cyclic pre-loading on biaxial flexure strength. *Dent Mater.* 2009 Feb; 25:188-197.