Frontiers in Dentistry

Effect of Mechanical Load Cycling on Microleakage of Restorative Glass Ionomers Compared to Flowable Composite Resin in Class V Cavities

Zahra Hasani[1], Effat Khodadadi[2*], Fariba Ezoji[2], Soraya Khafri[3]

1. Department of Pediatric Dentistry, School of Dentistry, Semnan University of Medical Sciences, Semnan, Iran
2. Dental Materials Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran
3. Department of Biostatistics and Epidemiology, Faculty of Medicine, Babol University of Medical Sciences, Babol, Iran

Article Info

Article type:
Original Article

Article History:
Received: 11 June 2018
Accepted: 3 September 2018
Published: 30 April 2019

**** Corresponding author:***
Faculty of Dentistry, Babol University of Medical Sciences, Babol, Iran

E-mail:
dr.efatkhodadadi@gmail.com

ABSTRACT

Objectives: Microleakage is the most important factor responsible for the destruction of restoration margins. The aim of this study was to assess the effect of mechanical load cycling on microleakage of four types of glass ionomer cement (GIC) in comparison with a flowable composite resin.

Materials and Methods: In this in-vitro experimental study, 100 Class V cavities were prepared on the buccal and lingual surfaces of 50 intact premolars. The prepared cavities were divided into five groups of (A) Z350, (B) Equia Forte, (C) encapsulated Fuji II LC, (D) hand-mixed Fuji II LC, and (E) Ketac Molar. All the samples were thermocycled (×2,000, 5-55°C), and half of the samples in each group were load cycled. All the teeth were then immersed in 0.5% basic fuchsine for 24 hours, sectioned, and observed under a stereomicroscope. Data were analyzed with Kruskal-Wallis and Mann-Whitney-U tests. Comparison between the incisal and gingival microleakage was made with Wilcoxon test. $P<0.05$ was considered statistically significant.

Results: Load cycling and type of restorative material had a significant effect on microleakage. Gingival microleakage was significantly higher than occlusal microleakage with Equia Forte, encapsulated Fuji II LC, hand-mixed Fuji II LC, and Ketac Molar in the absence of loading, and with Z350 after loading.

Conclusion: The sealing ability of Z350 under load cycling was better than that of Equia Forte, hand-mixed Fuji II LC, and Ketac Molar. The marginal integrity of encapsulated Fuji II LC was not significantly different than that of Z350.

Keywords: Dental Leakage; Flowable Composite; Glass Ionomer Cements

- **Cite this article as:** Cite this article as: Hasani Z, Khodadadi E, Ezoji F, Khafri S. Effect of Mechanical Load Cycling on Microleakage of Restorative Glass Ionomers Compared to Flowable Composite Resin in Class V Cavities. *Front Dent*. 2019;16(2):136-143. doi: 10.18502/fid.v16i2.1365

INTRODUCTION

Microleakage is the most important factor responsible for the destruction of restoration margins, which causes postoperative tooth hypersensitivity, secondary caries, pulpal irritation, pulp necrosis, and marginal discoloration of restorations [1,2]. Oral conditions such as occlusal forces, variations in temperature, and the difference between the physical properties of teeth and restorative materials can contribute to microleakage [3]. Accordingly, finding a material with proper bonding properties that decrease marginal microleakage has always been a topic of interest [4]. Glass ionomer cements (GICs), introduced in 1972 [5], have the ability to chemically bond to enamel and dentin [6]. They have many other advantages as a restorative material such as biocompatibility, suitable thermal expansion, lower sensitivity to moisture, and the ability to store and release fluoride [7]. However, conventional GICs have some clinical limitations such as long setting time, dehydration potential during the initial steps of polymerization, and rough surface texture. In order to overcome such disadvantages, light-cure resin-modified GICs (RMGICs) were introduced with longer working time, faster setting time, improved esthetic properties, and higher initial strength in comparison with conventional GICs [8]. RMGICs are available in two forms of hand-mixed and premeasured unit dose capsules that enable easier application and fewer errors on mixing [9]. Today, high viscosity GICs, such as Ketac Molar, and hybrid ionomers, such as Equia Forte, are also available.

Their manufacturers claim that they have lower polymerization shrinkage, optimal marginal sealing, and long-term resistance to microleakage [10]. However, clinical and experimental studies are lacking in this respect. Also, the effect of occlusal loading and buccolingual forces on the degree of microleakage should be studied.

There are some controversies about the effect of mechanical load cycling on microleakage. Some studies have suggested that mechanical loading does not increase microleakage [11], while some others have reported a significant increase in microleakage after mechanical load cycling [12-16]. The purpose of this study was to assess the effect of mechanical load cycling on microleakage of Equia Forte (GC Corp., Tokyo, Japan), Ketac Molar (3M ESPE Dental Products, St. Paul, MN, USA), encapsulated Fuji II LC (GC Corp., Tokyo, Japan), and hand-mixed Fuji II LC (GC Corp., Tokyo, Japan) GICs in comparison with Filtek Z350 flowable composite (3M ESPE Dental Products, St. Paul, MN, USA) as the control group.

MATERIALS AND METHODS

This in-vitro experimental study was conducted at the Dental Material Research Center of Babol University of Medical Sciences in 2017. In accordance with similar studies [12,13], fifty intact premolars, freshly extracted for orthodontic reasons, were used for this study. The teeth were immersed in 0.5% chloramine-T solution for one week after mechanical debridement and were then were kept in saline at 4°C until the experiment. Class V cavities were prepared in the buccal and lingual surfaces of the teeth using a high-speed handpiece under water spray with a straight carbide fissure bur (ISO #012; Jota, Ruthi, Switzerland) according to the following standards:

The length, width, and depth of the cavities were 3 mm mesiodistally, 3mm occlusogingivally, and 1 mm in dentin, respectively. The gingival margins of the cavities were prepared 1 mm below the cementoenamel junction (CEJ).

All cavities were prepared by one clinician, and burs were replaced after five preparations. Finally, 100 dental cavities were prepared.

The teeth were then randomly divided into five groups according to the restorative material used (n=20). All the samples were subjected to thermocycling, and half of them randomly underwent mechanical load cycling. The materials' compositions and manufacturers are listed in Table 1.

Group A: After the application of 37% phosphoric acid gel (Scotchbond Etchant, 3M ESPE Dental Products, St. Paul, MN, USA) on enamel surfaces for 30 seconds and on dentin surfaces for 15 seconds, the cavities were rinsed with water spray and dried with airflow.

Table 1: Characteristics of the materials used in this study

Material	Manufacturer	Composition
Filtek Z350 XT (nanohybrid flowable composite)	3M ESPE, St. Paul, MN, USA	Bis-GMA, UDMA, Bis-EMA 6, TEGDMA Zirconia/silica cluster, silica nanoparticle
Equia Forte (hybrid GI)	GC Corp., Tokyo, Japan	Fluoro-alumino-silicate glass, polyacrylic acid powder, surface-treated glass, polybasic carboxylic acid, water
Encapsulated Fuji II LC (resin-modified GI)	GC Corp., Tokyo, Japan	Fluoro-alumino-silicate glass, polyacrylic acid, HEMA, urethane dimethacrylate, camphorquinone, water
Hand-mixed Fuji II LC (resin-modified GI)	GC Corp., Tokyo, Japan	Fluoro-alumino-silicate glass, polyacrylic acid, HEMA, urethane dimethacrylate, camphorquinone, water
Ketac molar (high viscosity GI)	3M ESPE, St. Paul, MN, USA	Al-Ca-La fluorosilicate glass, 5% copolymer acid (acrylic and maleic acid), polyalkenoic acid, tartaric acid, water

GI: Glass Ionomer

Two layers of Adper Single Bond (3M ESPE Dental Products, St. Paul, MN, USA) were applied to etched surfaces and light-cured with a light-curing device (VALO Ultradent Products Inc., South Jordan, UT, USA) with a light intensity of 2300 mW/cm^2 for 20 seconds.

The cavities were then restored with Filtek Z350 flowable composite, light-cured for 20 seconds, and finally polished with a super fine diamond bur. The light intensity of the device was calibrated before and during the procedure using a radiometer.

Group B: After the application of a cavity conditioner (GC Corp., Tokyo, Japan) for 20 seconds, the cavities were rinsed with water spray, dried with airflow, and restored with Equia Forte hybrid GIC. Two minutes and 30 seconds after starting the mixing process, final polishing was performed using a super fine diamond bur under water spray. Finally, a coating layer (Equia Forte Coat, GC Corp., Tokyo, Japan) was applied to the restoration and light-cured for 20 seconds.

Group C: After the application of the cavity conditioner (GC Corp., Tokyo, Japan) for 20 seconds, the cavities were rinsed with water spray, dried with airflow, and restored with encapsulated Fuji II LC RMGIC, which was then cured for 20 seconds. After polishing of the restoration, one layer of varnish (Fuji Varnish, GC Corp., Tokyo, Japan) was applied and cured for 20 seconds.

Group D: After the application of the cavity conditioner (GC Corp., Tokyo, Japan) for 20 seconds, the cavities were rinsed with water spray, dried with airflow, and restored with hand-mixed Fuji II LC RMGIC, which was cured for 20 seconds. After polishing of the restoration, one layer of varnish (Fuji Varnish, GC Corp., Tokyo, Japan) was applied and cured for 20 seconds.

Group E: After the application of Ketac conditioner (3M ESPE Dental Products, St. Paul, MN, USA) for 10 seconds, the cavities were rinsed with water spray, dried with airflow, and restored with Ketac Molar high-viscosity GIC. When the final setting was completed (4 minutes and 30 seconds after the initiation of mixing), the restorations were polished.

All the specimens were thermocycled for 2,000 cycles between 5-55°C with a dwell time of 30 seconds and a transfer time of 15 seconds (Nemo thermocycling machine, Mashhad, Iran). Half of the teeth in each group were randomly selected and subjected to 50,000 mechanical load cycles in a chewing simulator (SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). The chewing stroke properties were as follows: stroke length of 0.8 mm, frequency of 2 Hz, and 100 N magnitude of stroke. The total load cycling time was approximately 7 hours with a rate of 2 Hz (50,000 cycles). First, 25,000 cycles were applied in the lingual-buccal direction through the buccal cusp of the tooth. Then, the tooth was rotated by 180°, and 25,000 chewing cycles were applied again through the lingual cusp in the buccolingual direction. The teeth were kept wet during the procedure.

Microleakage assessment:

All the surfaces of the teeth were coated with three layers of nail varnish up to 1 mm around the restoration margins. The apical foramina were sealed with modeling wax. The samples were immersed in 0.5 % basic fuchsine solution for 24 hours. Before sectioning, the teeth were washed with water and dried. Finally, the samples were sectioned in the buccolingual direction by a cutting machine and assessed under a stereo-microscope (S-4160; Hitachi, Japan) at ×40 magnification. Based on the color penetration depth, the microleakage scores were classified as follows [1,14]:

0: No evidence of dye penetration
1: Dye penetration along the interface up to one-third of the occlusal and gingival cavity
2: Dye penetration by more than one-third of the occlusal and gingival cavity but not involving the pulpal wall
3: Dye penetration along the pulpal wall.

SPSS version 23 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

The data were analyzed using Kruskal-Wallis and Mann-Whitney-U tests. Wilcoxon matched pairs test was used to compare the occlusal and gingival margin microleakage in each tooth. The statistical significance was set at $P<0.05$.

RESULTS

Effect of restoration margins:

Gingival microleakage was significantly higher than occlusal microleakage with Equia Forte, encapsulated Fuji II LC, hand-mixed Fuji II LC, and Ketac Molar in the absence of loading, and with Z350 after loading (Table 2).

Table 2: Wilcoxon test results for comparison of micro-leakage at the occlusal and cervical margins (n=10)

Filling material	Loading status	Margin	Median	P
Z350	No cycle	Occ	0	0.15
		Ging	1	
	Cycle	Occ	0	0.006
		Ging	1.5	
Equia Forte	No cycle	Occ	0	0.024
		Ging	2.5	
	Cycle	Occ	0	0.317
		Ging	3	
Encapsulated Fuji II LC	No cycle	Occ	0	0.039
		Ging	0.5	
	Cycle	Occ	2	0.157
		Ging	2	
Hand-mixed Fuji II LC	No cycle	Occ	0	0.016
		Ging	3	
	Cycle	Occ	3	1.000
		Ging	3	
Ketac Molar	No cycle	Occ	0	0.016
		Ging	3	
	Cycle	Occ	3	1.000
		Ging	3	

Occ: Occlusal; Ging: Gingival

Effect of mechanical load cycling:

The application of mechanical loading led to an increase in microleakage in the occlusal and gingival margins of the restorations. The difference was statistically significant in the occlusal margin of Equia Forte, encapsulated Fuji II LC, hand-mixed Fuji II LC, and Ketac Molar and in the gingival margin of Equia Forte (Table 3).

Effect of restorative materials:

The results of Kruskal-Wallis test showed that there was a significant difference in occlusal microleakage between the restorative materials under load cycling (Table 4). Pairwise comparison of the groups with Dunn's multiple comparison test showed that the occlusal microleakage of Z350 was significantly less than that of Equia Forte (P<0.001), hand-mixed Fuji II LC (P<0.001), and Ketac Molar (P<0.001). However, the difference in the microleakage of Equia Forte, hand-mixed Fuji II LC, and Ketac Molar was not statistically significant (P>0.05), and no significant difference was found between Z350 and encapsulated Fuji II LC (P>0.05).

Table 3: Effect of loading status on microleakage of occlusal and gingival margins (Mann-Whitney test; n=10)

Margin	Filling material	LS	MR	P
Occ	**Z350**	No cycle	10.00	**0.317**
		cycle	11.00	
	Equia Forte	No cycle	5.60	**<0.001**
		cycle	15.40	
	Encapsulated Fuji II LC	No cycle	6.00	**<0.001**
		cycle	15.00	
	Hand-mixed Fuji II LC	No cycle	6.70	**0.001**
		cycle	14.30	
	Ketac Molar	No cycle	6.00	**<0.001**
		cycle	15.00	
Ging	**Z350**	No cycle	8.75	**0.150**
		cycle	12.25	
	Equia Forte	No cycle	8.00	**0.013**
		cycle	13.00	
	Encapsulated Fuji II LC	No cycle	9.60	**0.474**
		cycle	11.40	
	Hand-mixed Fuji II LC	No cycle	9.80	**0.486**
		cycle	11.20	
	Ketac Molar	No cycle	9.00	**0.018**
		cycle	12.00	

Occ: Occlusal; Ging: Gingival; LS: Loading Status; MR: Mean rank

Gingival microleakage was significantly different between the groups under load cycling. Z350 showed a significantly lower microleakage compared to Equia Forte (P<0.001), hand-mixed Fuji II LC (P=0.002), and Ketac Molar (P<0.001), while its microleakage was not significantly different than that of encapsulated Fuji II LC (P>0.05). Encapsulated Fuji II LC had a significantly lower microleakage than Equia Forte (P<0.001), hand-mixed Fuji II LC (P=0.005), and Ketac Molar (P<0.001), while the gingival microleakage scores of Equia Forte, hand-mixed Fuji II LC, and Ketac Molar were not significantly different (P>0.05). In the absence of mechanical loading, there was no significant difference in the occlusal and gingival microleakage of the studied groups (P>0.05).

Table 4: Effect of filling material on microleakage of occlusal and gingival margins (Kruskal-Wallis test; n=10)

Margin	Loading status	Filling material	MR	P
Occ	No cycle	Z350	21	0.078
		Equia Forte	26.1	
		Encapsulated Fuji II LC	21	
		Hand-mixed Fuji II LC	31.1	
		Ketac Molar	28.3	
	Cycle	Z350	6.5	<0.001
		Equia Forte	33.05	
		Encapsulated Fuji II LC	20.35	
		Hand-mixed Fuji II LC	32.6	
		Ketac Molar	35	
Ging	No cycle	Z350	16.95	0.041
		Equia Forte	27	
		Encapsulated Fuji II LC	19.9	
		Hand-mixed Fuji II LC	32.7	
		Ketac Molar	30.95	
	Cycle	Z350	10.25	<0.001
		Equia Forte	36.5	
		Encapsulated Fuji II LC	11.95	
		Hand-mixed Fuji II LC	32.3	
		Ketac Molar	36.5	

Occ: Occlusal; Ging: Gingival; MR: Mean rank

DISCUSSION

In the current in-vitro study, we used eccentric mechanical loading in addition to axial loading because they induce more tensile stress at the tooth-restoration interface in comparison with axial forces alone. Evidence shows an association between eccentric loading and marginal failure of Class V restorations due to the generation of flexural forces in the tooth structure [11,17,18].

In this study, flowable composite (Filtek Z350 XT) was used as the control group. Fruits et al [19] reported that microfilled and flowable composite resins, with a lower modulus of elasticity and higher flexibility during flexural movements of the tooth, exhibit less microleakage and better marginal adaptation in Class V restorations. In addition, Filtek Z350 is a nanocomposite containing both nanoparticle and nanocluster fillers (zirconia/silica fillers) in its composition. Nanoclusters further reinforce the composite structure in comparison with microfilled and microhybrid systems [20].

Effect of restoration margins:

Under load cycling, the gingival microleakage of Z350 was significantly higher than its occlusal microleakage, while in the absence of load cycling, no significant difference was observed in the microleakage at the gingival and occlusal margins. These results are in agreement with those of previous studies [12,13,19]. Considering the fact that Z350 is a composite with low polymerization shrinkage [21], the slight contraction due to polymerization before load cycling was unable to overcome the adhesive bond strength; thus, the gap and microleakage were also minimal, and only when the mechanical load was applied to the restoration, the microleakage of weaker gingival margins significantly increased.

In the absence of mechanical loading, the gingival microleakage scores of Equia Forte, encapsulated Fuji II LC, hand-mixed Fuji II LC, and Ketac Molar were significantly higher than their occlusal microleakage scores. The mechanism of adhesion of GICs to dental structures involves chelation of carboxylic groups of poly-acids with calcium in the apatite of enamel and dentin [22]. Better marginal adaptation of GICs to enamel in comparison with dentin has been confirmed in previous studies [12,13], which is related to the presence of higher amounts of hydroxyapatite ions in the enamel, which create a stronger ionic bond.

Effect of mechanical load cycling:

In the present study, after applying mechanical load cycling, the occlusal and gingival microleakage of Z350 increased (not significantly). These findings were in agreement with those of previous studies [12,13, 16,23-25]; however, a number of studies have reported that microleakage of composite restorations increases under mechanical load cycling [15,16,26]. These differences in the results of experimental studies could be related to variations in the tested restorative materials, the magnitude of the applied force, method of force application and cavity preparation and evaluation technique.

The application of mechanical loading increased the microleakage at the margin of GI restorations; this increase was statistically significant in the occlusal margins of Equia Forte, encapsulated Fuji II LC, hand-mixed Fuji II LC, and Ketac Molar and in the gingival margin of Equia Forte. Davidson and Abdalla [16] showed that following the exertion of a 125-N force, microleakage of Ketac Fil GI significantly increased, while Fuji II LC showed good marginal integrity. Increasing the load up to 250 N resulted in degradation of Fuji II LC marginal adaptation [16]. In the present study, this result was obtained by the application of a 100-N force; this difference could be due to the difference in the direction and the frequency of mechanical loading. In the study by Davidson and Abdalla [16], only axial forces were applied, and the frequency of mechanical cycles was 10 times lower than that in the present study.

Effect of restorative materials:

After load cycling, the occlusal and gingival microleakage scores of Z350 were significantly lower than that of Equia Forte, hand-mixed Fuji II LC, and Ketac Molar. These findings are consistent with those of previous studies [12,13]. This difference in microleakage of GI and composite resin can be due to the weaker adhesive bond strength of GI compared to resin-based materials [27]. Moreover, Ichim et al [28] showed that lateral loading causes greater strain softening in GI restorations compared to composite resin restorations, which results in weakening of the margins and greater microleakage.

In the absence of mechanical load cycling (thermocycling only), there was no significant difference in occlusal microleakage between the studied groups. This finding was in agreement with the results of previous studies [12,13,28].

Under load cycling, the gingival microleakage of encapsulated Fuji II LC was significantly lower than the microleakage of Equia Forte and Ketac Molar. Singla et al [22] found the same results for the microleakage of high-viscosity GIs in comparison with Fuji II LC. These findings can be due to the higher modulus of elasticity and a more rigid structure of these materials, allowing less elastic changes during the application of mechanical forces. In addition, the micro-leakage might have been due to the high viscosity of restorative materials, interfering with proper wetting of the tooth surface and preventing a good seal at the tooth-restoration interface.

The marginal integrity of encapsulated Fuji II LC in the gingival margin under load cycling was better than that of hand-mixed Fuji II LC. The difference between the microleakage of encapsulated and hand-mixed GIs has not yet been reported in the literature. However, Dowling and Fleming [29] demonstrated that encapsulated GI has better mechanical properties in comparison with hand-mixed GI; this difference could be associated with the more complete mixing of the encapsulated type and the higher stickiness of the hand-mixed type on the instrument during the application, which can lead to inappropriate adaptation of restorative material with cavity walls and increased marginal microleakage.

CONCLUSION

As indicated by the results, the application of mechanical load cycling significantly increases the microleakage at the restoration margins. The sealing ability of Z350 under load cycling was better than that of Equia Forte, hand-mixed Fuji II LC, and Ketac Molar in Class V cavities. The marginal integrity of encapsulated Fuji II LC was not significantly different than that of Z350.

ACKNOWLEDGMENTS

The present study was part of a postgraduate thesis by the corresponding author with grant number 4866. The authors would like to thank the Dental Material Research Center of Babol University of Medical Sciences for the time and material supplements for the laboratory procedures.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. 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):439-50.

2. Parveen N, Ahmed B, Butt AM, Bari A. The effects of mechanical stresses on the comparative microleakage of two different restorative materials. J Univ Med Dent Coll. 2012 Jan-Jun;3(1):48-53.
3. Manhart J, Chen HY, Mehl A, Weber K, Hickel R. Marginal quality and microleakage of adhesive class V restorations. J Dent. 2001 Feb;29(2):123-30.
4. Castro A, Feigal RE. Microleakage of a new improved glass ionomer restorative material in primary and permanent teeth. Pediatr Dent. 2002 Jan-Feb;24(1):23-8.
5. Smith DC. Development of glass-ionomer cement systems. Biomaterials. 1998 Mar;19(6):467-78.
6. Powell LV, Gordon GE, Johnson GH. Clinical evaluation of direct esthetic restorations in cervical abrasion/erosion lesions: one-year results. Quintessence Int. 1991 Sep;22(9):687-92.
7. Cho SY, Cheng AC. A review of glass ionomer restorations in the primary dentition. J Can Dent Assoc. 1999 Oct;65(9):491-5.
8. Abd El Halim S, Zaki D. Comparative evaluation of microleakage among three different glass ionomer types. Oper Dent. 2011 Jan-Feb;36(1):36-42.
9. Dowling AH, Fleming GJ. Is encapsulation of posterior glass-ionomer restoratives the solution to clinically induced variability introduced on mixing? Dent Mater. 2008 Jul;24(7):957-66.
10. EQUIA® Forte bulk fill glass hybrid restorative system. EQUIA® Forte Fil / EQUIA® Forte Coat. Available at: https://cdn.gceurope.com/v1/PID/equiaforte/ifu/IFU_EQUIA_Forte_W.pdf /Accessed April 12, 2018.
11. Kubo S, Yokota H, Sata Y, Hayashi Y. The effect of flexural load cycling on the microleakage of cervical resin composites. Oper Dent. 2001 Sep-Oct;26(5):451-9.
12. Mirzaie M, Yasini E, Kermanshah H, Omidi BR. The effect of mechanical load cycling and polishing time on microleakage of class V glass-ionomer and composite restorations: A scanning electron microscopy evaluation. Dent Res J (Isfahan). 2014 Jan;11(1):100-8.
13. Ranjbar Omidi B, Madani L, Mirnejad Joybari A, Rashvand E, Oveisi S. Effect of mechanical load cycling on the microleakage of three different glass ionomer restorations in class V cavities. J Dent Med. 2015 Jul;28(2):95-102.
14. Mandras RS, Retief DH, Russell CM. The effects of thermal and occlusal stresses on the microleakage of the Scotchbond 2 dentinal bonding system. Dent Mater. 1991 Jan;7(1):63-7.
15. 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.
16. Davidson CL, Abdalla AI. Effect of occlusal load cycling on the marginal integrity of adhesive Class V restorations. Am J Dent. 1994 Apr;7(2):111-4.
17. Litonjua LA, Andreana S, Bush PJ, Tobias TS, Cohen RE. Noncarious cervical lesions and abfractions: a re-evaluation. J Am Dent Assoc. 2003 Jul;134(7):845-50.
18. 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.
19. 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.
20. Curtis AR, Palin WM, Fleming GJ, Shortall AC, Marquis PM. The mechanical properties of nanofilled resin-based composites: the impact of dry and wet cyclic pre-loading on bi-axial flexure strength. Dent Mater. 2009 Feb;25(2):188-97.
21. Kwon Y, Ferracane J, Lee IB. Effect of layering methods, composite type, and flowable liner on the polymerization shrinkage stress of light cured composites. Dent Mater. 2012 Jul;28(7):801-9.
22. Singla T, Pandit IK, Srivastava N, Gugnani N, Gupta M. An evaluation of microleakage of various glass ionomer based restorative materials in deciduous and permanent teeth: An in vitro study. Saudi Dent J. 2012 Jan;24(1):35-42.
23. Shneider LFJ, Tango RN, Milan FM, Mundstock GV, Consani S, Sinhoreti MAC. Microleakage evaluation of composite restorations submitted to load cycling. Braz Dent Sci. 2004;7(4):27-33.
24. Arisu HD, Uçtasli MB, Eligüzeloglu E,

Ozcan S, Omürlü H. The effect of occlusal loading on the microleakage of class V restorations. Oper Dent. 2008 Mar-Apr;33(2):135-41.
25. Li H, Burrow MF, Tyas MJ. The effect of load cycling on the nanoleakage of dentin bonding systems. Dent Mater. 2002 Mar;18(2):111-9.
26. Qvist V. The effect of mastication on marginal adaptation of composite restorations in vivo. J Dent Res. 1983 Aug;62(8):904-6.
27. Papacchini F, Goracci C, Sadek FT, Monticelli F, Garcia-Godoy F, Ferrari M. Microtensile bond strength to ground enamel by glass-ionomers, resin-modified glass-ionomers, and resin composites used as pit and fissure sealants. J Dent. 2005 Jul;33(6):459-67.
28. Ichim I, Li Q, Loughran J, Swain MV, Kieser J. Restoration of non-carious cervical lesions. Part I. Modelling of restorative fracture. Dent Mater. 2007 Dec;23(12):1553-61.
29. Dowling AH, Fleming GJ. Are encapsulated anterior glass-ionomer restoratives better than their hand-mixed equivalents? J Dent. 2009 Feb;37(2):133-40.