EFFECT OF LIGHT CURING MODES ON POLYMERIZATION SHRINKAGE AND MARGINAL INTEGRITY OF DIFFERENT FLOWABLE BULK-FILL COMPOSITES (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Bulk-Fill flowable composites are low viscosity materials with reduced percentage of inorganic fillers, leading to more shrinkage but with minimal stress contraction, maintaining the marginal seal of the restoration.

OBJECTIVES: To evaluate the polymerization shrinkage and marginal integrity of two flowable bulk-fill composites cured by different light curing modes at different curing distances.

MATERIALS AND METHODS: Two types of flowable bulk-fill composites (Tetric EvoFlow, CLEARFIL AP-X Flow) were tested. For shrinkage test, 30 cylindrical specimens (5 mm diameter x 2 mm thickness) were prepared from each type of composite. For marginal integrity evaluation, 30 class II occluso-mesial cavities (3 mm width x 2.5 mm depth at the occlusal box and 3 mm width x 1.5 mm depth x 1 mm occluso-cervical height of the proximal box) were prepared and restored from each type of composite. The composites were cured using three LED light curing modes for 10 seconds (high mode at 1200 mW/cm2, low mode at 650 mW/cm2 and soft-start mode at 650 up to 1200 mW/cm2 for 5 seconds then at 1200 mW/cm2 for 5 seconds) at two curing distances (0 mm, 3 mm). Strain gauge was used to measure the shrinkage. Stereomicroscope was used to evaluate the microleakage and scanning electron microscope was used to measure the gap width. Data was analyzed using Mann-Whitney U, Kruskal-Wallis and Pearson's Chi square tests.

RESULTS: Tetric EvoFlow showed less marginal gap values than CLEARFIL AP-X Flow. Soft-start and high modes showed less microleakage and gap than low mode. 0 mm distance showed less shrinkage and microleakage in soft-start and high modes than low mode. 3 mm distance showed less gap proximally in soft-start and low modes than high mode.

CONCLUSIONS: Different LED light curing modes and distances showed comparable results of shrinkage, microleakage and gap values for both composites tested.

KEYWORDS: Flowable bulk-fill composite, Polymerization shrinkage, Marginal integrity, Soft-start, High power, Low power.

RUNNING TITLE: Effect of curing modes on flowable bulk-fill composites.

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INTRODUCTION

Bulk-fill composites are a class of resin based composites, which allow a restoration to be built in thick layers up to 4 mm. Due to modifications in the filler content and organic matrix, bulk-fill composites have low modulus of elasticity and low levels of polymerization stresses without compromising on the depth of cure. This would eliminate the need for the incremental placement technique and its subsequent drawbacks, where it is time consuming for the patient and the operator with the possibility of air bubble inclusion and moisture contamination occurance between individual increments of resin composite restorations (1).

Polymerization of dimethacrylate resin composites and formation of a cross-linked polymer bring a volumetric shrinkage of about 1.5-6 vol%. Stresses from shrinkage create forces that compete with the adhesive bond which may disrupt the bond to cavity walls. These shrinkage stresses are still one of the main causes of marginal failure frequently resulting in microleakage (2).

Different types of photo-initiators are used in composite resins, possibly affecting the polymerization shrinkage.

Camphorquinone is used as a visible light photo-initiator, which has to be used together with a co-initiator. After light absorption between 400 and 500 nm, camphorquinone is promoted to an excited triplet state that interacts with an electron donor molecule, usually tertiary amine to generate free radicals (3).

Ivocerin is a new visible light photo-initiator based on germanium compounds, which allows fast and deep curing without increasing translucency or reducing working time of resin based composite materials. It does not only cure fast, it also cures beyond the 2 mm limit of traditional initiators achieving an efficient depth of cure at 4 mm (4).

Different curing modes of LED light are used for polymerization of dental composites such as high mode, normal mode, low mode, soft-start mode, pulse-soft start mode, pulse mode and turbo mode which may have different effects on the mechanical and physical properties of the composite resin material (5).

In the continuous high power curing mode, the composite is cured at a continuous high intensity of light (1000-1200 mW/cm^2) providing higher degree of monomer conversion, but unfortunately the degree of conversion of these materials is always associated with high rate of shrinkage. In the continuous low power curing mode, the composite is cured at a continuous low intensity of light (100-650 mW/cm^2) allowing a more extended period of viscous flow in the pre-gel phase in order to reduce the contraction stresses (6). In the soft-start curing mode, the composite is first cured at low intensity then stepped up to a high intensity light to reduce polymerization stresses by inducing the composite to flow in the gel state during the first application, facilitating a certain degree of shrinkage stress relaxation. It is believed that soft-start polymerization partially relieves shrinkage stresses and achieves improved marginal integrity of the restoration (7).

The distance between the light source and resin composite might have different effects on shrinkage stresses and marginal quality of composite resin restorations. Light intensity diminishes when the distance of the tip to the resin composite increases as insufficient total energy of light reaches the resin surface (8).

The aim of the study was to compare the effect of three LED light curing modes (high, low, soft-start) on polymerization shrinkage and marginal integrity of Tetric EvoFlow and CLEARFIL AP-X Flow flowable bulk-fill composites at different curing distances of 0 mm and 3 mm. The null hypothesis tested is that neither the LED light curing modes nor the curing distances will have an effect on the polymerization shrinkage and the marginal integrity of the two types of flowable bulk-fill composites containing different photo-initiators.

MATERIALS AND METHODS

In the present study, two types of flowable bulk-fill composites with their bonding agents were used. CLEARFIL AP-X Flow, a flowable nano-filled bulk-fill composite with self etch CLEARFIL^{TM} S^3 bond (KURARAY CO., LTD, AMERICA, INC.) and Tetric EvoFlow, a flowable nano-hybrid bulk-fill composite with self etch Tetric® N-Bond Universal (Ivoclar Vivadent Inc., Amherst, N.Y., USA.) (Table 1).

For polymerization shrinkage test, sixty cylindrical composite specimens (5 mm diameter and 2 mm thickness) were prepared and divided into two groups of thirty specimens each according to the type of composite used (group 1: CLEARFIL AP-X Flow, group 2: Tetric EvoFlow). The thirty specimens were further subdivided into three subgroups of ten specimens each according to the LED light curing mode used (subgroup 1: high power curing mode at 1200 mW/cm^2 for 10 seconds**,** subgroup 2: low power curing mode at 650 mW/cm^2 for 10 seconds**,** subgroup 3: soft-start curing mode at 650 up to 1200 mW/cm^2 for 5 seconds then at 1200 mW/cm^2 for 5 seconds). Half of the specimens of each subgroup (n=5) were cured at 0 mm distance (surface contact) and the other half were cured at 3 mm distance from the light curing tip.

A Teflon split mold was used to prepare the cylindrical shaped specimens. To measure the polymerization shrinkage, a strain gauge (1 mm length, 119.6 ± 0.4 Ω gauge resistance, 2.13 ± 1.0% gauge factor) was centralized on top of each specimen and connected to a strain monitoring device connected to the computer software program. Strain measurements were recorded immediately after application of the light source up to 3 minutes following light irradiation in 10 seconds interval (10).

Table 1: Composition and manufacturers of the materials and bonding agents used.

Material	Composition	Manufacturer
Tetric Evo Flow flowable bulk-fill composite	- The resin matrix consists of bisphenol A glycidylmethacrylate (Bis-GMA), Bis-EMA and urethane dimethacrylates (UDMA). - The fillers are 68 wt% and 46 vol% barium glass, ytterbium trifluoride, mixed oxide and prepolymer. - Additional contents are catalyst, stabilizer and ivocerin photoinitiator.	Ivoclar Vivadent Inc., Amherst, N.Y., USA.
CLEARFIL AP-X Flow flowable bulk-fill composite	- The resin matrix consists of hydrophobic aromatic dimethacrylate and triethylene-glycol dimethacrylate (TEGDMA). - Fillers are 86 wt% and 70 vol% silanated barium glass, silanated silica and silanated colloidal silica. - Additional contents are accelerators, pigments and camphorquinone photo-initiator.	KURARAY CO., LTD, AMERICA, INC.
Tetric® N-Bond Universal	Methacrylates, ethanol, water, highly dispersed silicon dioxide, initiators and stabilizers.	Ivoclar Vivadent Inc., Amherst, N.Y., USA.
CLEARFIL^{TM} S^3 Bond	10-methacryloyloxydecyl dihydrogen phosphate (MDP), bis phenol-A diglycidyl-methacrylate, 2-hydroxyehyl metacrylate, hydrophobic dimethacrylate, dl-camphorquinone, ethyl alchol, water and silanated colloidal silica.	KURARAY CO., LTD, AMERICA, INC.

For marginal integrity evaluation, sixty molar teeth free of caries, attrition, abrasion, erosion, cracking or previous restoration were used. Molars were collected from out-patients visiting the Oral Surgery Department at the Faculty of Dentistry, University of Alexandria. Teeth extracted due to periodontal reasons were used. The study was conducted after receiving the approval of the ethical committee at Faculty of Dentistry, Alexandria University, Egypt. Teeth were thoroughly cleaned and stored in 0.5% chloramines T aqueous solution to prevent bacterial growth until used (11).

A total of 60 standardized class II occluso-mesial cavities (3 mm width x 2.5 mm depth at the occlusal box and 3 mm width x 1.5 mm depth x 1 mm occluso-cervical height of the proximal box) were prepared in the sixty molar teeth with a high-speed handpiece using water spray and a cylindrical rounded end bur (JOTA AG Rotary Instruments, 9464 Rüthi, Switzerland).

The molars were divided into two groups of thirty molars each according to the type of composite used (group 1: restored with CLEARFIL AP-X Flow, group 2: restored with Tetric EvoFlow). According to the LED light curing mode used, the thirty molars of each type of composite were subdivided into three subgroups of ten molars each (subgroup 1: high power curing mode at 1200 mW/cm^2 for 10 seconds**,** subgroup 2: low power curing mode at 650 mW/cm^2 for 10 seconds**,** subgroup 3: soft-start curing mode at 650 up to 1200 mW/cm^2 for 5 seconds then at 1200 mW/cm^2 for 5 seconds). Then the molars of each subgroup were divided according to the distance from the light curing tip, where half of the molars were cured at 0 mm distance (surface contact) and the other half at 3 mm distance.

The prepared teeth were mounted in a model and the preparations were cleaned and palodent matrix bands and wedges (DENTSPLY Caulk, DENTSPLY International Inc. Milford, DE 19963-0359, USA) were installed. Composite resin was first injected and polymerized into the proximal box then occlusally. Finishing was done with a diamond fine shaped composite finishing bur TR-13EF (MANI, INC. UTSUNOMIYA, TOCH IGI, JAPAN.) and polishing was conducted with fine-grit Sof-Lex flexible disks (KerrHawe SA, 6394 Bioggio/Switzerland.).

The restored teeth were stored in distilled water at 37°C for 24 hours. They were then subjected to artificial thermal ageing for 500 cycles between water baths held at temperature of 5°C and 55°C with a dwell time of 30 seconds for each bath in a thermocycling device (11).

The root apices of the molar teeth were sealed with sticky wax then the molars were coated with two layers of nail varnish leaving a 2 mm window around the restoration margins. All molar teeth were immersed in 0.5% basic fuchsin dye at 37°C for 24 hours then washed by water to remove excess dye. The teeth were sectioned longitudinally in a mesio-distal direction through the center of the restoration using water cooled diamond coated discs (NSK, Eschborn, Germany). The-sections-were-evaluated-with-a-stereomicroscope-(OLYMPUS Stereomicroscope SZX7, Japan) at -20X-to-50X magnification to determine the extent of dye penetration at the occlusal and proximal walls (Figure 1,2) (12).

The degree of leakage was determined at the occlusal and proximal margins based on an ordinal ranking system as follows (11):

0: No dye penetration.

1: Dye penetration is only along enamel not passing the dentin-enamel junction.

2: Dye penetration is beyond the dentin-enamel junction but not reaching the axial wall.

3: Dye penetration is beyond the axial wall but not to the pulpal wall.

4: Dye penetration is extended to the pulpal wall.

For measuring the marginal gap, the sections were evaluated under scanning electron microscope, where scanning electron microscope photographs of the tested molar teeth were taken at 1000 X magnification (Figure 3). The marginal gap width (the distance between the dental wall and the restoration) was measured in micrometers at the occlusal and proximal margins of each molar using Orion 6 camera connected to the scanning electron microscope device (JEOL – Model JSM- 5300- Scanning electron microscope, Japan) (13).

Statistical analysis

Data were collected and entered to the computer using SPSS version 25 (Statistical Package for Social Science) program for statistical analysis. Kolmogorov-Smirnov test of normality revealed non parametric distribution of the results, so the non-parametric statistics was adopted. Descriptive statistics for polymerization shrinkage and marginal gap were displayed as mean and standard deviation. Categorical variables for microleakage were described using percentage.

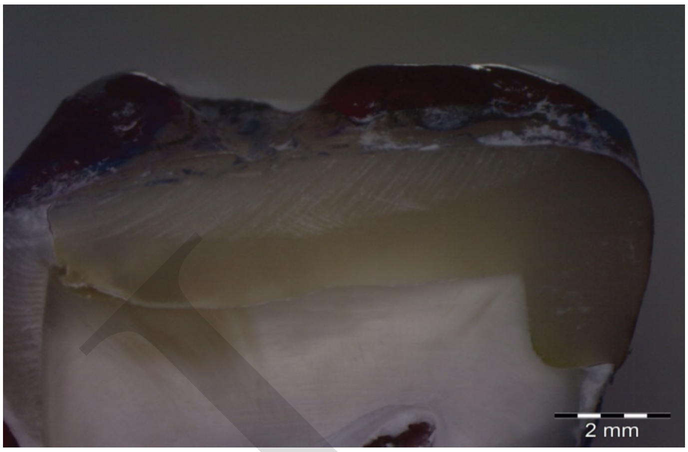

Figure 1: Schematic illustration of dye penetration in Tetric EvoFlow cured with high mode at 0 mm distance under stereomicroscope showing score 1 leakage.

Figure 2: Schematic illustration of dye penetration in CLEARFIL AP-X Flow cured with low mode at 3 mm distance under stereomicroscope showing score 2 leakage.

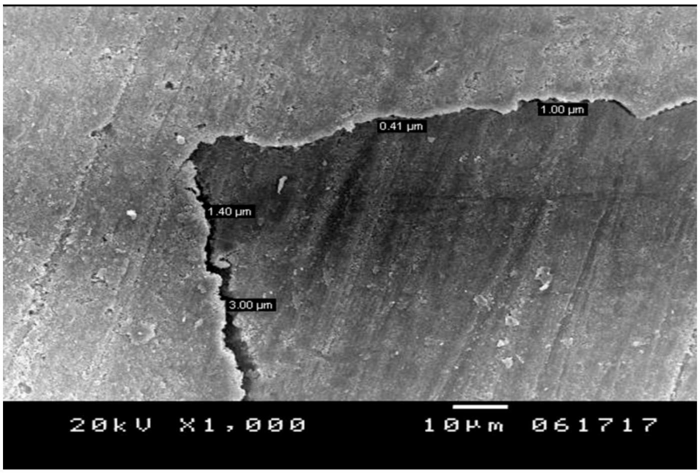

Figure 3: Schematic illustration of marginal gap in CLEARFIL AP-X Flow cured with low

mode at 3 mm distance under scanning electron microscope showing gap formation occlusally and proximally.

Comparisons were carried out between two studied independent not-normally distributed subgroups using Mann-Whitney U test and between more than two studied independent not-normally distributed subgroups using Kruskal-Wallis test. Chi-square test was used to test association between qualitative variables. Monte Carlo correction was carried out when indicated. Statistical comparison between microleakage scores and marginal gap width of the molar teeth was done.
Box and Whiskers plot was used accordingly. An alpha level was set to 5% with a significance level of 95% and a beta error accepted up to 20% with a power of study of 80%.

RESULTS

Regarding polymerization shrinkage, there was no significant difference between both materials (p>0.05), between the three curing modes (p>0.05) and between both curing distances in CLEARFIL AP-X Flow and Tetric EvoFlow (Figure 4) except for the soft-start mode in Tetric EvoFlow, where 0 mm distance showed less shrinkage than 3mm distance (p=0.047).
The results of microleakage showed no significant difference between both materials (p>0.05) (Table 2), between the three curing modes in both materials (p>0.05) except proximally for Tetric EvoFlow, where soft-start mode (37.74%) showed the least leakage followed by high mode (110.19%) then low mode (152.08%). There was no significant difference between both curing distances occlusally and proximally for all the three curing modes in both materials except proximally for CLEARFIL AP-X Flow, there was a significant difference between both curing distances in high mode, where 0 mm distance (146.15%) showed less leakage than 3 mm distance (153.85%).

Table 2: Occlusal and proximal microleakage of CLEARFIL AP-X Flow and Tetric EvoFlow flowable bulk-fill composites.

Scores	**Microleakage (occlusal)**		**Total**	**Microleakage (proximal)**		**Total**
	Material			**Material**		
	CLEARFIL AP-X Flow	**Tetric EvoFlow**		**CLEARFIL AP-X Flow**	**Tetric EvoFlow**	
0.00 - n -% of microleakage	37 46.84%	42 53.16%	79 100.00%	46 46.46%	53 53.54%	99 100%
1.00 - n -% of microleakage	15 46.88%	17 53.13%	32 100.00%	8 61.54%	5 38.46%	13 100.00%
2.00 - n -% of microleakage	8 88.89%	1 11.11%	9 100.00%	6 75.00%	2 25.00%	8 100.00%
Total - n -% of microleakage	60 50.00%	60 50.00%	120 100.00%	60 50.00%	60 50.00%	120 100.00%
Test of Significance	$\chi^2_{(df=2)} = 5.886$ $P_{(MC)}$=0.067 NS			$\chi^2_{(df=2)} = 3.187$ $P_{(MC)}$=0.196 NS		

As for marginal gap, Tetric EvoFlow showed less marginal gap formation than CLEARFIL AP-X Flow (Figure 5). High mode showed occlusally less gap formation for CLEARFIL AP-X Flow and Tetric EvoFlow than the other two modes while proximally for Tetric EvoFlow, soft-start mode showed less gap formation than the other two modes. There was no statistically significant difference in gap formation proximally between the three curing modes in CLEARFIL AP-X Flow.

There was no significant difference in marginal gap formation between both curing distances in the three curing modes occlusally for Tetric EvoFlow and proximally for CLEARFIL AP-X Flow. In CLEARFIL AP-X Flow occlusally, there was no significant difference between both curing distances in high and soft-start modes while for low mode, 3 mm distance showed less gap formation than 0 mm distance (p=0.003). In Tetric EvoFlow Proximally, there was no significant difference between both curing distances in high mode while for low mode, 0 mm distance showed less gap formation than 3 mm distance (p=0.000) and for soft-start mode, 3 mm distance showed less gap formation than 0 mm distance (p=0.003) (Table 3).

Table 3: Occlusal and proximal marginal gap of Tetric EvoFlow at different modes of LED light at 0 mm and 3 mm curing distances.

	Marginal gap (occlusal)						**Marginal gap (proximal)**					
	High Mode		**Low mode**		**Soft-start mode**		**High mode**		**Low mode**		**Soft-start mode**	
n Min-Max Median IQR	80 0.00-2.80 0.00 0.00-0.91		80 0.00-9.20 0.02 0.00-2.14		80 0.00-9.20 1.04 0.00-3.37		80 0.00-2.65 0.01 0.00-0.61		80 0.00-6.20 0.31 0.00-0.71		80 0.00-2.20 0.00 0.00-0.00	
Test of significance	$\chi^2_{(KW)(df=2)}$=13.246 p=0.001*						$\chi^2_{(KW)(df=2)}$=14.187 p=0.001*					
	0mm	**3mm**	**0mm**	**3mm**	**0mm**	**3mm**	**0mm**	**3mm**	**0mm**	**3mm**	**0mm**	**3mm**
n (Min-Max) Median (IQR)	40 (0.00-2.80) 0.00 (0.00-1.00)	40 (0.00-2.65) 0.00 (0.00-0.82)	40 (0.00-3.67) 0.40 (0.00-1.53)	40 (0.00-9.20) 0.00 (0.00-6.60)	40 (0.00-9.20) 1.04 (0.00-5.60)	40 (0.00-5.51) 1.12 (0.00-2.14)	40 (0.00-1.20) 0.00 (0.00-0.60)	40 (0.00-2.65) 0.00 (0.00-0.82)	40 (0.00-0.82) 0.00 (0.00-0.00)	40 (0.00-6.20) 0.30 (0.00-1.80)	40 (0.00-2.20) 0.01 (0.00-0.00)	40 (0.00-0.00) 0.00 (0.00-0.00)
Test of significance	$Z_{(MW)}$=0.471 p=0.638 NS		$Z_{(MW)}$=0.664 p=0.507 NS		$Z_{(MW)}$=1.174 p=0.240 NS		$Z_{(MW)}$=0.480 p=0.631 NS		$Z_{(MW)}$=3.571 p=0.000*		$Z_{(MW)}$=2.958 p=0.003*	

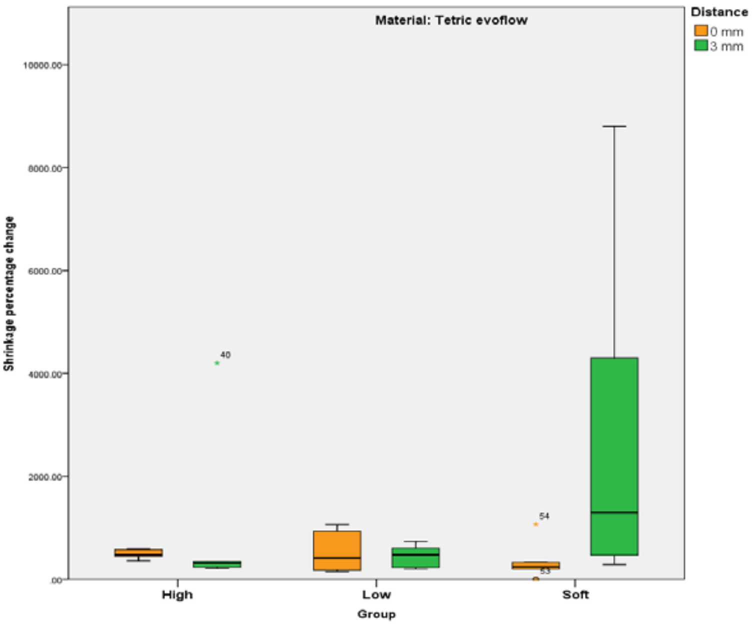

Figure 4: Polymerization shrinkage of Tetric EvoFlow at different modes of LED light at 0 mm and 3 mm curing distances.

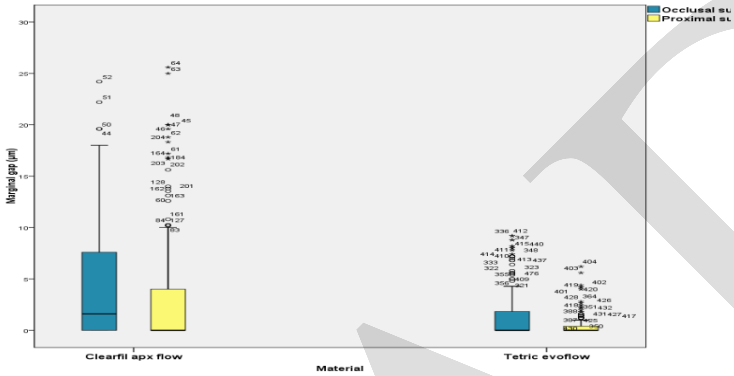

Figure 5: Occlusal and proximal marginal gap of CLEARFIL AP-X Flow and Tetric EvoFlow flowable bulk-fill composites.

DISCUSSION

A resin composite undergoing polymerization exhibits volumetric shrinkage as its individual monomer units form covalent bonds with neighboring monomers to form polymers. These bonds reduce the distance between them producing shrinkage during polymerization which results in undesirable stresses leading to marginal gaps, staining, postoperative sensitivity, secondary caries and crack development (14).

Regarding polymerization shrinkage, the results of the current study showed no significant difference between both materials. This non significance suggests that ivocerin photo-initiator might have similar effect as camphorquinone photo-initiator on shrinkage of composite resin restorations. This result was in disagreement with Gan et al (15)-who compared the curing depth of bulk-fill composites and found that SDR containing camphorquinone photo-initiator showed better shrinkage ratios and marginal quality than Tetric N-Ceram containing ivocerin photo-initiator. This could be related to the ability of camphorquinone photo-initiator to absorb blue light at a longer wavelength than ivocerin photo-initiator, where the light absorption spectra of camphorquinone photo-initiator is coincident with the emission spectra of most popular light curing units. Due to this match, the CQ/amine system is able to efficiently initiate the polymerization, facilitating the conversion of low viscosity monomer units into a polymer matrix and fulfilling most of the requirements for an adequate initiation system for a resin-based restorative material (15).

The results of the current study showed no significant difference in shrinkage between the three curing modes. This was in agreement with a previous study by Han et al (16) who studied the influence of light curing modes (high intensity, low intensity, soft-start) on shrinkage and hardness of composite resins and concluded that there was no difference in polymerization shrinkage of composites cured by the three light curing modes.

On the other hand, this result was in disagreement with Oliveira et al (17) and Chye et al (18), where they both found that soft-start curing mode showed the lowest level of shrinkage of flowable composite resins compared to other LED light curing modes. This could be due to providing an initial rate of polymerization, which reduces stresses by giving more time for stress relaxation before reaching the gel phase (6).

The results of the current study also showed no significant difference in shrinkage between the two curing distances. This result was in agreement with the results that have been found by Ilie et al (19) who evaluated the influence of curing distance on the polymerization kinetics of bulk-fill resin based composites and found that the distance has no effect on polymerization properties of composite resins.

The only condition in the present study where 0 mm distance showed less shrinkage than 3 mm distance was when soft-start curing mode of light was used to cure Tetric EvoFlow, which may have been caused by diminishing of the light intensity as the tip of the light source moves away from the composite surface. This was in agreement with Dunne et al (9) who found that the depth of cure and quality of polymerization decreased as the separation distance increased. This is explained by changes in the light intensity that reaches the material surface due to changes in the distance between the light curing tip and the resin composite surface, which interferes with the polymerization depth. The total energy that reaches the surface of the composite resin restoration during polymerization may affect the mechanical and chemical properties of the resin composites (8).

Regarding microleakage, the results of the current study showed no significant difference between both materials, which suggests comparable effects of camphorquinone and ivocerin photo-initiators on microleakage of composite resins. This result was in disagreement with Orłowski et al (20) who compared the leakage of bulk-fill composite restorations and concluded that composites containing camphorquinone photo-initiator showed less microleakage than composites containing ivocerin photo-initiator.

The results of the current study showed no significant difference in microleakage between the three curing modes. This was in agreement with a previous study by Abdolrahim Davari et al (21) who concluded that the degree of microleakage of composites cured with soft-start curing mode was not significantly different from that cured with conventional low and pulse curing modes. On the other hand, Santos et al (22) found that the soft-start mode resulted in statistically significant less microleakage of composite restorations than the conventional low curing mode.

The only condition in the present study where soft-start mode showed less microleakage than high and low modes was in Tetric EvoFlow proximally. This was likely due to curing the composite first at low intensity then increasing the curing intensity gradually to a high intensity light which causes slowest and maximal possible conversion allowing for better flow by molecular rearrangement of the polymer chains, which in turn decreases contraction stress in the filling material by delaying the initiation of gelation of the resin and the onset of shrinkage strain, maintaining the marginal seal of resin restorations (7).

In the current study, there was no significant difference in microleakage between the two curing distances (0 mm, 3 mm). This was in disagreement with Zhu et al (23) who concluded that curing efficiency decreased significantly and leakage increased as the curing tip distance increased. The only condition in the present study where 0 mm distance showed less microleakage than 3 mm distance was when high mode of light was used to cure CLEARFIL AP-X Flow proximally. This may be related to the increase in the light dispersion of the light curing unit as the distance increases leading to difficulty in obtaining effective polymerization (8). This was in agreement with Rueggeberg et al (24) who found that a tip distance greater than 4 mm from the composite surface demonstrated a significant decrease in resin polymerization. It is recommended to minimize the curing distance and if not possible either to extend the curing time or use a higher irradiance level light curing unit to compensate for the expected reduction in irradiance exposure (9).

Regarding marginal gap, the results of the current study showed that Tetric EvoFlow resulted in less marginal gap than CLEARFIL AP-X Flow. Ivocerin photo-initiator may have showed better effect due to significant improvement in polymerization properties acting as a polymerization booster as it has high quantum efficiency, high absorption capacity and very good bleaching properties (4). These results were in agreement with Norbert Moszner et-al (25) who found that composites based on ivocerin photo-initiator showed an improved curing depth, stability and marginal quality comparable to that of composites based on camphorquinone photo-initiator.

The results of the current study showed no significant difference in marginal gap between the three different curing modes. This was in agreement with Friedl et al (26) who found that soft-start mode did not improve the marginal adaptation of composite resin restorations compared to conventional low mode. On the contrary, Junior et al (27) found that soft-start curing mode promotes better marginal adaptation of composite resin restorations than continuous high and continuous low curing modes. Feilzer et al (28) reported that initial low intensity only retarded the polymerization rate at early periods but brought about the same final shrinkage as did a higher light intensity. Therefore, differences in contraction stress cannot be accounted for by differences in the extent of cure or volumetric contraction. This adds support to the hypothesis that a slower curing reaction accompanied by either a prolonged gel stage or a slow development of elastic modulus are responsible for reduced stress with better sealing ability and marginal adaptation of composite resin restorations.

The only condition in the present study where soft-start curing mode showed less marginal gap formation than high and low curing modes was proximally in Tetric EvoFlow. Slower polymerization during the first exposure with the soft-start method may favor the formation of extended polymer chains and less cross-linking and consequently slow development of the elastic modulus, resisting deformation and maintaining marginal integrity of composite restorations (22). This was in agreement with Ernst et al (29) who concluded that soft-start mode is able to reduce the marginal gap formation of a composite restoration than other curing modes.

The only conditions in the present study where high curing mode showed less marginal gap formation than soft-start and low curing modes were occlusally in CLEARFIL AP-X Flow and Tetric EvoFlow. This could be related to the increase in the light cure unit output intensity, providing increased rate of the degree of conversion, increasing the depth of cure and polymerization quality at different depths of the resin based composite which preserves composite–cavity interfacial seal (30).

The results of marginal gap in the current study showed no significant difference between the two curing distances (0 mm, 3 mm). This was in disagreement with Prati et al (31) who concluded that light curing intensity diminishes with increasing curing distance, resulting in poor marginal adaptation of composite restorations. The only condition where 0 mm distance showed less marginal gap formation than 3 mm distance was when low curing mode of light was used to cure Tetric EvoFlow proximally. This result was in agreement with Subbiya et al (32) who found that reducing the curing tip distance from the resin surface reduces shrinkage stresses and improves marginal integrity of resin restorations.

The only conditions in the present study where 3 mm distance showed less marginal gap formation than 0 mm distance were when low curing mode of light was used to cure CLEARFIL AP-X Flow occlusally and when soft-start curing mode of light was used to cure Tetric EvoFlow proximally. In some circumstances the cavity design does not allow the polymerization within a surface contact distance (8). On the contrary, Rode et al (33) concluded that greater tip distances produced a decrease in microhardness,-degree of conversion and polymerization shrinkage. A short distance between the tip of the light curing unit and the surface of the restoration more evenly distributes light throughout the restoration. This is because light disperses in open spaces. A longer curing distance causes light to disperse rather than focus on a certain area thus decreasing the degree polymerization resulting in poor marginal integrity of resin restorations (24).

In the present study, statistical comparison between microleakage scores and marginal gap values of each molar tooth was done. There was no statistically significant difference in the marginal gap among different microleakage scores. This was studied at material level [occlusally ($p=0.413$) and proximally ($p=0.277$)], at group level within each material and at distance level within each group in each material ($p > 0.05$; in all comparisons). This means that the extent of dye penetration does not depend on the size of the marginal gap, where a large marginal gap does not indicate a high score of dye penetration and vice versa.

Thus, the null hypothesis was rejected for polymerization shrinkage; which demonstrated significant difference in curing distance, where 0 mm distance showed less shrinkage than 3 mm distance. It was also rejected for marginal integrity; where soft-start curing mode demonstrated significantly less microleakage and marginal gap formation than high and low modes and 0 mm distance showed less microleakage than 3 mm distance.

CONCLUSION

Within the limitations of our study, the following conclusions can be drawn:

1. Ivocerin photo-initiator showed less marginal gap formation than camphorquinone photo-initiator, while no significant difference was noted in polymerization shrinkage and microleakage between composites containing different photo-initiators.
2. Different light curing modes did not affect the degree of composite shrinkage.
3. Soft-start and high modes are highly recommended than low mode to reduce marginal gap formation and microleakage.
4. The closer the tip of the LED light curing unit to the composite surface, the less the polymerization shrinkage and microleakage.
5. The extent of dye penetration does not depend on the size of the marginal gap and vice versa.

CONFLICT OF INTREST

The authors declare that they have no conflicts of interest.

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