Effect of different curing units/modes and load cycling on the tooth/restoration interfacial seal

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Abstract: Objectives: The aim of this study was to evaluate the effect of using two different curing units and two different curing modes on the longevity of the tooth/restoration seal after being subjected to load cycling. **Methods:** Kerr adhesive (Opti Bond Solo Plus) and resin composite (HERCULITE) were used in this study. Wedge-shaped cavities were prepared at CEJ of buccal surfaces on 80 sound extracted human premolars. Cavities were randomly divided into four groups according to the curing units and modes (n=20), 1) cured with Elipar S10 unit (3M/ESPE) for 20seconds continuous curing (continuous mode), 2) cured with Bluephase G2 unit (Ivoclar Vivadent) for 20seconds continuous curing, 3) cured with Elipar S10 unit (3M/ESPE) for 5seconds then 10seconds rest followed by 20 seconds curing (pulse-delay mode)and 4) cured with Bluephase unit (Ivoclar Vivadent) for 5seconds then 10seconds rest followed by 20 seconds curing. Each group was further divided into 2 subgroups (n=10): subgroup A; No load cycling was applied, and subgroup B; was subjected to occlusal load cycling (90 N) for 10000 cycles. Specimens were tested for gap formation along both occlusal and gingival interfaces using Quanta Environmental SEM. Data were statistically analyzed using three-way Analysis of Variance (ANOVA) and Bonferroni's post-hoc test ($P<.05$). **Results:** Elipar S10 curing unit showed statistically significantly higher mean gap values than Bluephase G2 curing unit. Whereas, continuous mode showed statistically significantly higher mean gap values (10.1 ± 2.4) than pulse-delay mode (5.0 ± 1.9). However, these values significantly increased following load cycling. **Conclusions:** Under the conditions of this study, Bluephase G2provided better interfacial sealing. The pulse-delay mode of curing improved the adhesive sealing ability. Meanwhile, the load cycling deteriorated the interfacial sealing of the tested material.

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1. Introduction:

Throughout the recent decades, the increasing demands for aesthetic dentistry resulted in a continuous and rapid improvement in the adhesives and resin composites. However, the quality and the durability of the bonding interface constitute an urgent problem in resin composite restorations[1, 2]. In an attempt to simplify the clinical application procedures and reduce the technique sensitivity of adhesive systems, the one bottle or 2-step etch and rinse adhesives appeared on the market as an alternative to the 3-step etch and rinse adhesives[3-4]. However, although the two-step total-etch technique can achieve high bond strength, the problems of high technical sensitivity and uncontrollable interface moisture remain and challenge the restorations' sealing ability and durability[5].

Since the introduction of the light cured resin composites, the quality and depth of their polymerization represented one of the major concerns[6]. It is well known that, adequate polymerization depends mainly on the intensity of the light source, the wavelength emitted and the exposure time[7, 8]. Therefore, there was a rapid turnover in the light curing units to enable production of the appropriate amount of light required to provide efficient polymerization of resin composites, with consequent enhancement of their physical-mechanical properties[9].

The use of light-emitting diode (LED)curing units to polymerize resin composites was offered by Mills in 1995 to replace the Halogen light curing units[6]. LEDs claimed to possess the following advantages over the frequently used halogen light curing units, do not need a filter to produce blue light, generate high light intensity, produce little heat, consume little energy and shorten treatment time[5, 6]. Moreover, they produce light with a wavelength close to the absorption peak of camphorquinone[10]. Nevertheless, despite of the improvement in the resin monomer conversion with the use of high light intensity, the shrinkage stresses of the resin matrix are increased because of the shortening of the time required to reach the gel point of the composite resin[11], with consequent reduction in the adhesion properties.

Therefore, different radiant exposure times and protocols were proposed in an attempt to minimize the effects of polymerization shrinkage[12, 13]. They include soft-start light curing mode in which the resin composite is exposed to initial low light intensity, followed by a high light intensity to complete conversion of the resin monomer[14]. Also, pulse-delay curing mode, in which there is a short period between the initial exposure and the final high-energy cure[15]. This can make the resin flow sufficiently to compensate for the volume shrinkage generated by the polymerization reaction[16]. Accordingly, light intensity and light curing modes affect the polymerization reaction and the degree of curing[4]. However, to date, no technique has been completely effective in counteracting the effects of polymerization shrinkage which subsequently influencing the bonding performance leading to replacement of resin composite restorations[13].

In clinical situations, teeth are unavoidably subjected to mechanical stresses during mastication and parafunctional habits[17]. These stresses may negatively affect the resin dentin bond as they have been reported to induce micro cracks which subsequently endanger the long-term survival rate of the bonding resulting in dislodgement of the restorations[13, 18-20]. Moreover, several studies have shown that, the degradation of dentin bonding interface could be accelerated by the masticatory loadings[21-23]. Therefore, the integrity of the adaptation and sealing efficiency of resin composite restorations is adversely affected by cyclic loading, in terms of gap formation and leakage[24].

The present study was undertaken to evaluate the effect of the light curing units, the curing modes and load cycling on the sealing ability of resin composite restorations, in terms of gap formation. The null hypotheses of this research are that, (1) the sealing efficiency is not affected by the curing units, (2) the sealing efficiency is not affected by the use of different curing modes, and (3) load cycling adversely affect the sealing efficiency.

2. Materials and Methods:

I. Preparation of the specimens:

Total of eighty sound human premolars of almost same size were collected after the patients' informed consent was obtained under a protocol reviewed and approved by the Ethical Research Committee, School of Dentistry, King Abdulaziz University, Saudi Arabia. Extracted teeth were thoroughly cleaned using brushes and curettes under running water and were stored in 1% chloramine solution at room temperature for one month until use[25]. A standardized wedge–shaped class V cavity was prepared at the cement-enamel junction (CEJ) on the buccal surfaces of each tooth with the occlusal margin in enamel and the gingival margin in dentin/cementum.

The prepared cavities were 5mm occlusogingivally, 3mm mesiodistally and 2.5mm in depth with diverging walls and butt joint margins[26]. The outline of the cavities was standardized using a stainless steel matrix band into which a window representing the selected length and width was cut into its middle. The preparation and restoration of Class V lesions is minimal and relatively easy, thereby reducing practitioner variability[27]. The cavities were cut with a carbide tapered fissure bur (No.170L) at high speed with water coolant. The bur was replaced every five preparations[28].

II. Application of the restorative material:

Kerr adhesive (OptiBond Solo Plus) and resin composite (HERCULITE) were used in this study (Table 1). The bonding system was applied according to manufacturer's instructions and the cavities were restored with the corresponding resin composite. The treated cavities were filled using the oblique incremental technique. Each increment of resin composite was cured using the assigned curing mode and light curing unit. The intensity of the light curing unit was measured after each 10 specimens by a radiometer (Optilux, Demetron/Kerr, Orange, CA, USA) to ensure a constant value of 600 mW/cm2. Afterwards, the specimens were finished and polished with abrasive disks (Sof-Lex Pop-on, 3M-ESPE).

III. Grouping of the specimens:

The eighty teeth were randomly divided into 4 groups according to the curing units and modes (n=20),

1) Cured with Elipar S10 unit (3M/ESPE) for 20seconds continuous curing,

2) Cured with Bluephase G2 unit (Ivoclar Vivadent) for 20seconds continuous curing,

3) Cured with Elipar S10 unit (3M/ESPE) for 5seconds then 10seconds rest followed by 20 seconds continuous curing, and

4) Cured with Bluephase G2 unit (Ivoclar Vivadent) for 5seconds then 10seconds rest followed by 20 seconds continuous curing.

Each group was further divided into 2 subgroups (n=10):

Subgroup A; No load cycling was applied, and

Subgroup B; was subjected to occlusal load cycling (90 N) for 10000 cycles.

IV: Mounting of teeth in acrylic molds:

A specially fabricated split cylindrical Teflon mould of 20 mm height and 15 mm internal diameter was used for the formation of the acrylic resin molds. The root and the restoration of each tooth were covered using an aluminum foil in order to remove the teeth easily from the molds to be examined for gap formation. Each tooth was then mounted into the mold, with its long axis perpendicular to the acrylic resin base.

V: Load cycling:

Load cycling was done using Lloyd LRX Plus II universal testing machine (Ametek, Inc., Berwyn, PA, USA). Each specimen was firmly held to the lower jig of the machine by two side screws to avoid any possible slippage and was subjected to occlusal load cycling of 90N for 10000 cycles, in the form of a sine wave at a rate of 1 Hz. The used rate was equal to the average cycles of mastication of 0.8–1.0 seconds. A specially designed stainless-steel loading tip (5 mm in diameter) was used to apply the force on the middle of the occlusal surface parallel to the long axis of each tooth for standardization.

IV. Gap measurements:

Each tooth was sectioned longitudinally in a buccolingual direction through the center of the restoration using a low speed diamond saw(Buehler-Isomat, Lake Bulff, IL, USA) under water coolant. The sectioned teeth were polished using three descending orders of the sof-lex discs and then cleaned ultrasonically. Gap formation along both occlusal and gingival interfaces was examined using Quanta Environmental Scanning Electron Microscope (200, FEI, Netherland). Each gap present along the occlusal and gingival walls (Figs. 1, 2) was divided into several points, the width of each point (the distance between the tooth wall and the restoration) was measured in µm, and then the mean of the widths of the measured gap was calculated by Quanta image processing software.

Table (1): Compositions and manufacturer of the testedmaterials.

Material	Principal components	Manufacturer
OptiBond Solo Plus (Single Component Total-Etch Adhesive)	**Gel etchant:** 37.5% Phosphoric Acid Ge **The resin matrix:** Ethanol, 2-hydroxyethyl methacrylate, 2-hydroxy-1, 3-propanediyl bismethacrylate. **The filler:** 0.4 µm barium glass, alkali fluorosilicate (Na).	Kerr Corporation, Orange, CA, USA
Herculite Ultra (nanohybrid Composite restorative)	**The resin matrix:** 7,7,9-trimethyl-4, 13-dioxo-3, 14-dioxo-5, 12-diazahexadecane-1, 16-diyl bismethacrylate, 2,2-bis(acryloyloxymethyl) butyl acrylate, 3-trimethoxysilylpropyl methacrylate **The filler:** Prepolymerized filler, barium glass of 0.4 µm and 20-50 µm nanoparticles of silica nanofiller.	Kerr Corporation, Orange, CA, USA

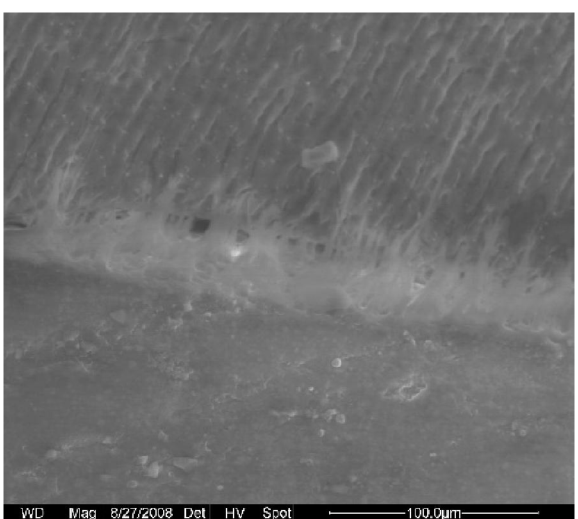

Fig (1): Scanning electron micrograph for one point atthe tooth/restoration interface representing subgroup (A) (without load cycling).

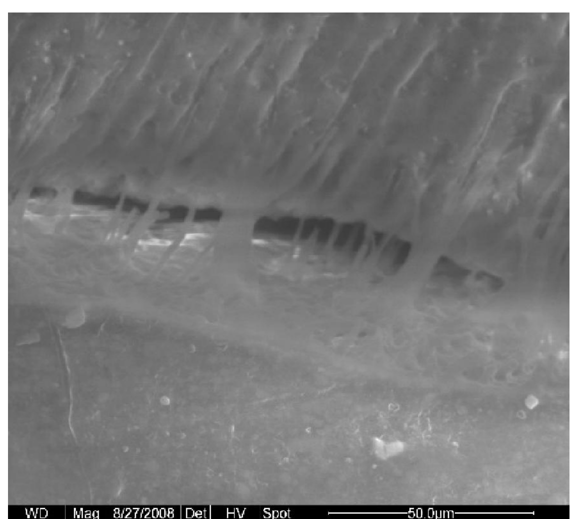

Fig (2): Scanning electron micrograph for one point atthe tooth/restoration interface representing subgroup (B) (with load cycling).

V. Statistical analysis

Data were presented as mean and standard deviation (SD) values. Data were explored for normality by checking data distribution, histograms, calculating mean and median values and finally using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Gap measurements data showed parametric distribution; so three-way Analysis of Variance (ANOVA) was used in testing significance for the effect of curing unit, curing mode, load cycling and their interactions on mean gap measurements. Bonferroni's post-hoc test was used for pair-wise comparison between the groups when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM (Corporation, NY, USA) SPSS (Inc., an IBM Company) Statistics Version 20 for Windows.

3. Results:

Three-way ANOVA results:

Three-way ANOVA resultsfor the effect of different variables on the mean gap width values presented in table (2) and showed that curing unit, curing mode and load cycling had a statistically significant effect on mean gap values ($P \leq 0.05$). Since the interaction between the three variables had no statistically significant effect on mean gap width values, so the variables (curing unit, curing mode and load cycling) are independent i.e. the effect of each variable is independent from the other variables. So we compared the main effects only.

Table (2): Three-way ANOVA results for the effect of different variables on mean gap values

Source of variation	Type III Sum of Squares	df	Mean Square	*F*-value	*P-value*
Curing unit	19.8	1	19.8	37.6	<0.001*
Curing mode	261.5	1	261.5	498.2	<0.001*
Load cycling	139.8	1	139.8	266.4	<0.001*
Curing unit x Curing mode x Load cycling interaction	0.6	1	0.6	1.2	0.281

*df: degrees of freedom = (n-1), *: Significant at P ≤ 0.05*

Effect of curing unit

The descriptive statistics and results of comparison between gap width values of the used curing units regardless of curing mode or load cycling were presented in table (3). The results showed that, Elipar S10 curing unit had statistically significantly higher mean gap width values than BluephaseG2 curing unit.

Table (3): Descriptive statistics and results of comparison between mean gap width values of the two curing units regardless of other variables

Elipar S10	Bluephase G2	*P*-value
Mean ± SD	Mean ± SD	
8.2 ± 3.3	6.8 ± 3.3	<0.001*

**: Significant at P ≤ 0.05*

Effect of curing mode

Table (4): Descriptive statistics and results of comparison between mean gap width values of the two curing modes regardless of other variables

Continuous mode	Pulse-delay mode	*P*-value
Mean ± SD	Mean ± SD	
10.1 ± 2.4	5.0 ± 1.9	<0.001*

**: Significant at P ≤ 0.05*

Table (4) showed that, regardless of curing unit or load cycling; the specimens that were cured using continuous mode showed statistically significantly higher mean gap width values than the specimens that were cured using the pulse-delay mode.

Effect of load cycling

Table (5) showed that, regardless of curing unit or mode; the specimens that were subjected to load cycling showed statistically significantly higher mean gap width values than the specimens that were not subjected load cycling.

Table (5): Descriptive statistics and results of comparison between mean gap width values with and without load cycling regardless of other variables

Load	Without load	*P*-value
Mean ± SD	Mean ± SD	
9.4 ± 3.0	5.7 ± 2.6	<0.001*

**: Significant at P ≤ 0.05*

The mean and the standard deviation values (error bars) of gap width values in the different groups of this study are presented by Bar chart in figure (3).

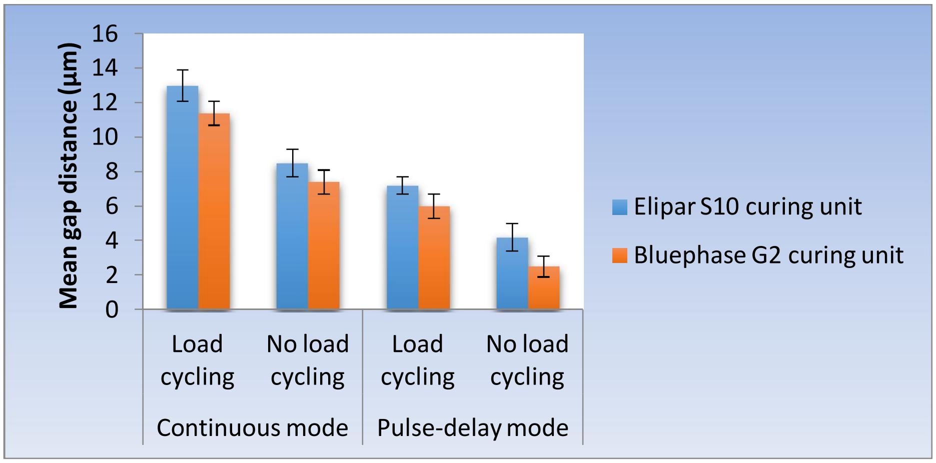

Figure (3): Bar chart representing mean and standard deviation values (error bars) of gap width values in the different groups

4. Discussion:

Bonding of the resin composite to the tooth substrates creates shrinkage stress on the bonding interfaces. If this stress exceeds the bond strength between the dental substrate and the adhesive, a contraction gap will be formed[29]. The breakdown of interfacial sealing presents a challenge to the longevity of restoration[30]. For this, bond efficiency has dominated most present researches in both resin-enamel and resin-dentin bonding. The bonds formed at enamel/adhesive interface are considered reliable and durable[31], meanwhile, bonding to dentin and cementum does not match the sealing ability and the durability of their neighboring hard tissue mainly because of heterogeneity of the structure and composition of dentin and cementum[31-34].

Therefore, in the present study, in order to evaluate the interfacial sealing of the restoration as a whole, we examined the presence of gaps along the whole tooth/restoration interface through enamel, dentin and cementum substrates. Moreover, in our research we prepared wedge-shaped Class V cavities which resembles Class V of non-carious cervical lesions to evaluate the clinical effectiveness of the tested adhesive[35], since, this approach provides direct evidence for the ability of the adhesive to effectively bond, because these restorations fail by loss of retention[30].

The results of this study made it necessary to reject the first null hypothesis, since, Elipar S10 curing unit had statistically significantly higher mean gap width values than Bluephase G2 curing unit regardless of curing mode or load cycling. This could be explained by the fact that, Bluephase utilizes polywave technology which features a second spectral peak at approximately 410 nm in addition to the peak at approximately 470 nm. The polywave Bluephase Style covers a wavelength spectrum of between 385 and 515 nm[36]. Thus, producing higher polymerization than Elipar S10 which utilizes single peak. Moreover, monowave LED units are well known to suffer from light dispersion[37].

The results of this study were in agreement with Price *et al.,* who compared the ability of four LED curing units to polymerize five resin composites and concluded that, the Bluephase G2 light delivered the broadest spectral range of wavelengths, greatest irradiance and energy density as it produced harder, better-cured resins compared to the other three lights[36].

On the other hand, the results of this study were in contradiction with Bortolotto *et al.,* who concluded that, monowave LED provided the highest percentages of continuous margin in Class V restorations, meanwhile, light-curing the adhesive system and restorative composite with a multiwave LED adversely affected marginal adaptation in enamel[38]. Furthermore, Aguiar *et al.,* found that there was no statistically significant difference in the degree of conversion of the tested resin composite among the LED groups, considering all irradiance values[12].

Efficient polymerization is an essential factor for obtaining optimum interfacial sealing with subsequent successful clinical performance of any resin composite restoration[39, 40]. Incomplete polymerization leads to several negative consequences including decreased bond strength, micro-phase separation and nanoleakage, which were considered the key factors affecting the longevity of restorations[41-43]. It is well known that, light intensity is directly related to the monomer-polymer conversion rate[44]. Therefore, several polymerization modes are suggested for curing of resin composites, including different radiant exposure times and protocols[12]. In the present study, two different curing modes had been used, pulse-delay mode and the continuous mode. The resin composite either cured for 20 seconds continuously (continuous mode) or cured for 5seconds then 10 seconds rest followed by 20 seconds curing (pulse-delay mode).

In the present work, the second null hypothesis was rejected since, continuous curing mode showed significantly higher mean gap width values than the pulse-delay curing mode. This could be attributed to that, the initial short light-curingperiod (5 seconds) could provide time for the resin to relief from the stresses created upon initial polymerization. Meanwhile, continuous curing results in a very short gelatinization state, producing a very rapid transformation of the resin matrix from a viscous-plastic into a rigid-elastic phase with consequent higher polymerization stresses[45, 46]. Another explanation of our finding was that, the total light-curing period in the pulse-delay mode was 25 seconds whereas in the continuous mode it was only 20 seconds, which means that pulse-delay provide more full potential polymerization[15].

This result was in agreement with da Silva *et al.,* they reported that, polymerization modes with high initial irradiance values might improving the degree of conversion. They attributed that, to the increase in the exothermic heat which consequently provide an increase in the mobility of the polymer chains[47]. However, this result was in contradiction with Fahmy *et al.,* they reported that, the pulse mode and fast mode have similar performance[48].

One of the good points of this study was evaluating the effect of simulated clinical conditions on the sealing efficiency of resin composite restorations. Intraoral restorations are constantly subjected to about 1 million (1000 K) mechanical strokes per year of the opposite tooth which might negatively affect the interfacial bonds at the tooth/restoration interface, resulting in their failure[49]. Therefore, this study was designed to compare the widths of the formed gaps along the tooth/restoration interface of class V restorations immediately after placement and after load cycling in order to clarify the possible failure mechanism preceding loss of the restorations. It was stated that, the chewing and swallowing force is between 70 and 150 N[50, 51]. In our study, the specimens were subjected to 90 N occlusal load cycling for 10000 cycles.

An interesting outcome of the present study was that, there was a significant difference in the gap measurements between the loaded and the non-loaded specimens, independently of the utilized curing unit and curing mode. Thus, the third null hypothesis was accepted. This could be attributed to the microstrain of restorations[26]. This microstrain might be due to the presence of tensile stresses on that side[52]. Thus, these stresses generated by load cycling along the tooth/restoration interface could increase the width of existent gaps or develop other new gaps[53-55].

This result was in agreement with Aggarwal *et al.,* who concluded that, cyclic loading affected the marginal adaptation of direct composite restorations[13]. On the other hand, this result was in contradiction with Li *et al.,* Mitsui *et al.,* and Bedran-de-Castro *et al.,* they found that, load cycling did not affect the microleakage or the nanoleakage pattern[52,56, 57]. Moreover, Arisu *et al.,* found that, 100 N occlusal loading did not change dye penetration[58]. This could be attributed to that, they used different load values and different number of cycles. Also, the effect of the occlusal loading in adhesive restorations may be transient, as it took place only at the moment of load application then the cusps would recover their initial configuration, resulting in marginal sealing that do not differ from those of the unloaded teeth[56].

Conclusions:

Under the conditions of this study:

Regardless of the used curing unit and load cycling, Blue phase G2provided better interfacial sealing. Moreover, the delayed-pulse mode of curing improved the adhesive sealing ability. Meanwhile, the load cycling deteriorated the interfacial sealing of the tested material.

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