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Influence of Irradiance on the Push-out Bond Strength of Composite Restorations Photoactivated by LED

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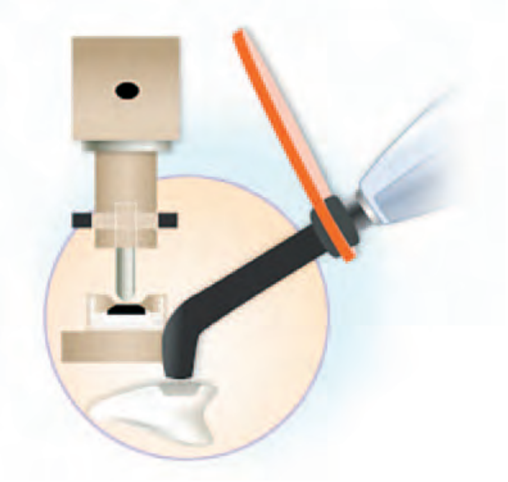

Abstract

Aim: The aim of this study was to compare the bond strength of resin composites to dental structure photoactivated with a light emitting diode (LED) curing unit.

Methods and Materials: One hundred bovine incisors were selected and a conical cavity was prepared in the facial surface of each tooth. Clearfil SE Bond (Kuraray CO., LTD. Osaka, Japan) adhesive system was applied, and the cavities were filled with a single increment of Filtek™ Z250 (3M ESPE, St. Paul, MN, USA) or Esthet-X (Dentsply-Caulk – Mildford, DE, USA). The specimens were assigned to ten groups (n=10) according to the irradiance used: 100, 200, 300, 400, or 500 mW/cm². Photoactivation was accomplished using an Ultrablue IS LED (DMC Equipamentos LTDA, São Carlos, SP, Brazil). The radiant exposure time was kept constant. A push-out test was conducted in a universal testing machine. Bond strength values were submitted to a two-way analysis of variance (ANOVA) and a Tukey's test at the 5% significance level.

Results: The bond strength of the Z250 was higher than the Eshet-X ($p<0.05$). However, the modulation of irradiance adjusted to the same radiant exposure had no influence on Z250. The bond strength using an irradiance of 100mW/cm² was higher than the other levels for Esthet-X. When composites were compared, no significant differences were detected between them for activation with irradiances of 100 and 200 mW/cm².

Conclusion: The modulation of the luminous energy emitted by LED was almost unable to provide significant differences among the groups for both composites, except for a lower irradiance of Esthet-X.

Keywords: Bond strength, photoactivation, resin composite, irradiance, push-out

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Introduction

At present, composite resin is one of the most used esthetic restorative materials in dentistry for the fabrication of direct restorations.[1,2] The activation mode used for the curing of these materials is an indispensable factor in order to maintain the effectiveness of the functionality of these direct restorations. The light-initiated dental composite resins are activated using light curing units (LCUs) that emit a narrow wavelength between 400 and 500 nm.[3] The emitted blue light excites the photoinitiator present in the organic formulation of the composites, unleashing the polymerization composite resin. The visible light photosensitizer camphorquinone (CQ) is widely used in dental resin formulations.[4]

Among the available LCUs, the light emitting diode (LED) is in common use. LEDs are made of semiconductor materials that determine the type of emitted light. Each semiconductor material presents a range of energy that determines the spectrum of light emission, characterizing the emitted color. LEDs are designed to emit blue light for the photoactivation of dental composites.[5]

LEDs for light-curing were introduced as a viable alternative to the traditional quartz tungsten halogen (QTH) LCUs. The main advantages of LEDs include greater durability, relatively lower heat generation, elimination of the need for filters, and the large concentration of luminous energy in a narrower wavelength interval.[6] This last advantage increases the efficiency of the photoactivation of composites containing photoinitiator systems within an absorbance range in the spectrum of emitted light of the light source.[7]

However, regardless of the activation mode, resin composites still contract during polymerization.[8]

The contraction of the composites is reported to be approximately 1% to 5% in volume.[9] The insertion of these contracting materials into bonded preparations induces the development of mechanical stress inside the material. The stress is then transmitted via bonded interfaces to the tooth structure.[10] In light cured composites, a rapid conversion induces a corresponding rapid increase in composite stiffness causing high shrinkage stresses at the restoration-tooth interface. Such stresses may disrupt the bonding between the composite and the cavity walls or may even cause cohesive failure of the restorative material or the adjacent tooth tissue.[11]

The rate of monomer conversion is dependent on the irradiance. As the irradiance increases, the monomer conversion accelerates but results in higher stress generation.[12] Polymerization using a lower irradiance can reduce the stress, but the light exposure time must be extended in order to maintain the radiant exposure similar to that used in conventional methods.[13]

Shrinkage strains the bond between tooth structure and the restoration, leading to stress generation at the bonding interface which can cause marginal gap formation, post-operative sensitivity, and pulp irritation.[14,15] Stress generation is often associated with the:

- Geometry and size of the cavity/C-factor[16]
- Composition of the materials[17]
- Restorative technique[18]

In order to attenuate stress generation during the polymerization process, different light-activation approaches have been proposed with the primary goal of increasing the time for the composite to flow during the early stages of polymerization and to enable a degree of polymer chain relaxation before reaching the rubbery stage.[9,19] Recently, the use of different photoactivation methods such as the modulation of the irradiance has also demonstrated to be efficient in this aspect.[20,21]

Many studies have evaluated the reduction of stress generation during polymerization contraction using photoactivation methods like soft-start or pulse delay.[14,20] However, the effect of continuous exposure with LEDs using different irradiance levels still needs to be investigated. Therefore, the purpose of this study was to evaluate the influence of irradiance on the bond strength of composite restorations photoactivated by LED. The tested hypothesis was that different irradiances, adjusted to a same energy dose, does not interfere with the push-out bond strength of composite restorations photoactivated with an LED curing unit.

Methods and Materials

One hundred bovine incisors were selected, and the crowns were cut off at the cementoenamel junction (CEJ) with a double-faced diamond disk (KG Sorensen, São Paulo, SP, Brazil) (Figure 1A). The buccal surfaces of the crowns were wet-ground in an automatic polisher using 600-grit SiC sandpaper.

A conical cavity (top diameter of 4.5 mm, bottom diameter of 4.0 mm, height of 2.5 mm) were prepared in the buccal surface of each tooth using a #3131 diamond tip (KG Sorensen, São Paulo, SP, Brazil), in a high-speed handpiece with a copious air-water spray and using a standard cavity preparation device (Figure 1B). The diamond tip was replaced after every five preparations. The C-factor of the cavity was approximately 3.0.

The Clearfil SE Bond™ (Table 1) was applied according to the manufacturer's instructions. Thereafter, Filtek™ Z250 or Esthet-X™ resin composite (Table 1) was inserted into the cavity in a single increment, and the teeth were randomly assigned into ten groups (n=10), according to the photoactivation irradiance used as described in Table 2 (Figure 1C). The photoactivation was accomplished with an Ultrablue IS LED (DMC Equipamentos LTDA, São Carlos, SP, Brazil) LCU, and the different irradiance levels were obtained using acrylic spacers with different heights. The irradiance was often checked with a handheld radiometer (Demetron Research Corp., Danbury, CT, USA).

After light curing, the specimens were stored in distilled water at 37°C for 24 hours and then finished with Sof-Lex (3M/ESPE Dental Products, St. Paul, MN, USA). Then a 3017HL diamond tip (Fava Metalúrgica, São Paulo, SP, Brazil) was used to ground the lingual face of the crown in order to expose the bottom surface of the restoration. The mesial and distal areas of the crown in the lingual surface were preserved as a mode of reinforcing the specimen for the push-out test (Figure 1D).

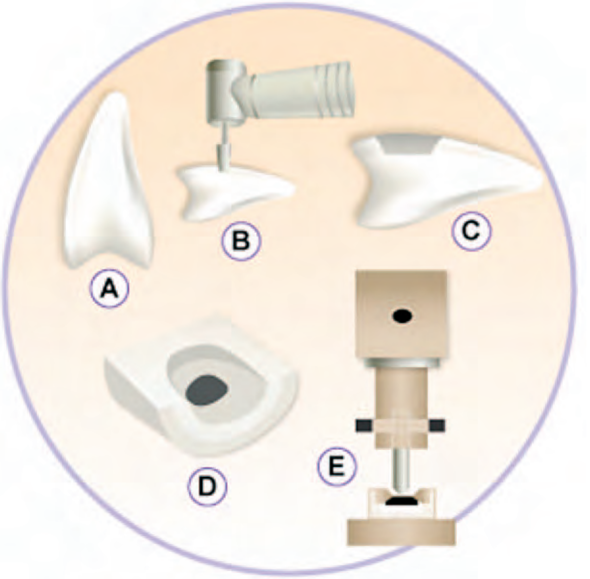
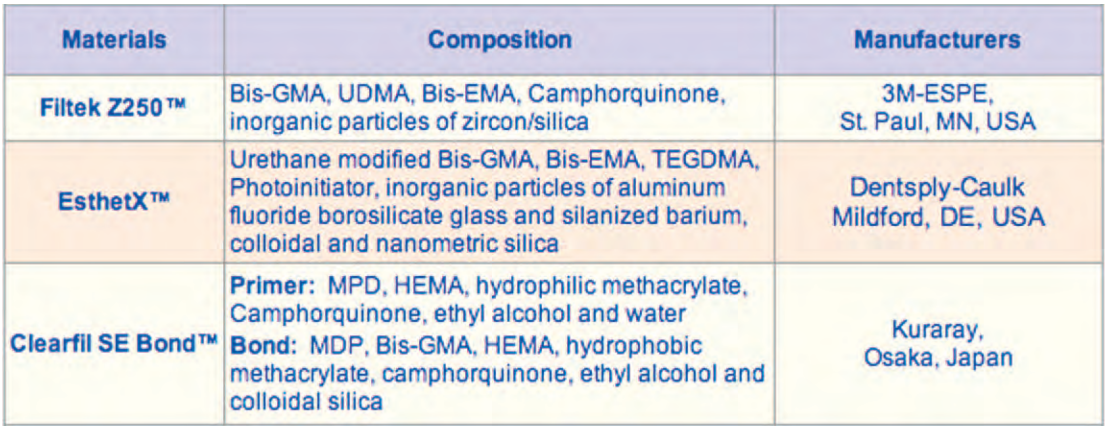


Figure 1. Schematic representation of the "push-out" test: **A.** Incisor crown fragment; **B.** Cavity preparation using standard cavity preparation appliance; C. Lateral view of the restored sample (2.5 mm in height, top diameter of 4.5 mm, and bottom diameter 4.0 mm); **D.** Selective wear of the lingual surface and exposure of the bottom area of the restoration; **E.** Lateral view of the testing set up.

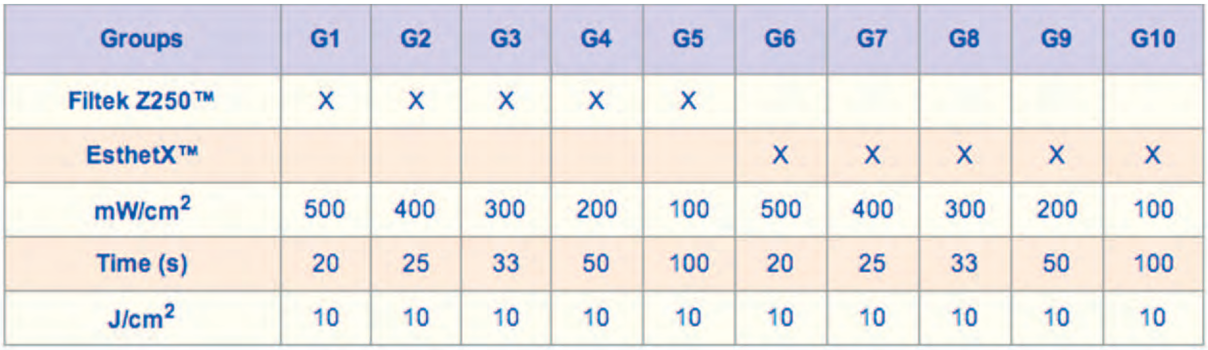
Table 1. Materials, composition, and manufacturers.*



Materials	Composition	Manufacturers
Filtek Z250™	Bis-GMA, UDMA, Bis-EMA, Camphorquinone, inorganic particles of zircon/silica	3M-ESPE, St. Paul, MN, USA
EsthetX™	Urethane modified Bis-GMA, Bis-EMA, TEGDMA, Photoinitiator, inorganic particles of aluminum fluoride borosilicate glass and silanized barium, colloidal and nanometric silica	Dentsply-Caulk Mildford, DE, USA
Clearfil SE Bond™	**Primer:** MPD, HEMA, hydrophilic methacrylate, Camphorquinone, ethyl alcohol and water **Bond:** MDP, Bis-GMA, HEMA, hydrophobic methacrylate, camphorquinone, ethyl alcohol and colloidal silica	Kuraray, Osaka, Japan

Note: * Manufacturer's information

Table 2. Group Distribution.



Groups	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Filtek Z250™	X	X	X	X	X					
EsthetX™						X	X	X	X	X
mW/cm^2	500	400	300	200	100	500	400	300	200	100
Time (s)	20	25	33	50	100	20	25	33	50	100
J/cm^2	10	10	10	10	10	10	10	10	10	10

The push-out test was performed to evaluate the bond strength. An acrylic device with a central hole was adapted on the base of a universal testing machine (Instron, Model 4411, Canton, MA, USA) (Figure 1E). The central hole was used for positioning the specimen with its cavity bottom side up (smaller diameter of the restoration cavity). In the superior area of the machine, a round tip was adapted (Figure 1E). This tip applied a compressive force on the bottom surface of the restoration in order to provoke the rupture of the tooth-composite bonding along the lateral walls. The speed used in the test was 0.5 mm/min. The values recorded (kgf) were divided by the area and converted into MPa. Data were submitted to a two-way analysis of variance (ANOVA) and a Tukey's test at a 5% significance level.

After the test, the fractured specimens were examined under magnification (40x), and the modes of failure were classified as follows: adhesive failure, cohesive failure within the composite, or mixed failure involving adhesive, dentin, and composite.

Results

Bond strength results are shown in Table 3. The values of bond strength obtained by the different photoactivation methods showed the Z250 resin composite obtained higher bond strength than the Esthet-X ($p<0.05$). However, when 100mW/cm² and 200mW/cm² were used, there was no statistical difference between the two composites.

The evaluation of each composite separately showed no significant difference for Z250 among all methods of photoactivation. On the other hand, for Esthet-X, the group that was light activated at 100mW/cm² presented a bond strength significantly higher compared with the other groups, which showed similar results among them. Failure mode classification for the two composites in the different photoactivation methods is shown in Table 4. Z250 demonstrated a larger prevalence of mixed failures when compared to the failure types obtained for the Esthet-X composite.

Table 3. Mean bond strengths (MPa).

Photoactivation Methods	Filtek Z250™	EsthetX™
500mW/cm^2 x 20s	7.03 (1.63) A, a	4.70 (1.34) B, b
400mW/cm^2 x 25s	7.35 (1.55) A, a	5.84 (1.51) B, b
300mW/cm^2 x 33s	8.15 (1.53) A, a	5.80 (1.49) B, b
200mW/cm^2 x 50s	6.84 (1.31) A, a	5.74 (1.50) A, b
100mW/cm^2 x 100s	7.97 (1.04) A, a	7.51 (1.15) A, a

Means followed by different capital letters on the line and small letters in the column are significantly different ($p<0.05$).

Table 4. Percentage (%) of failure mode.

Photoactivation Methods	Filtek Z250™			EsthetX™		
	Cohesive	Adhesive	Mixed	Cohesive	Adhesive	Mixed
500mW/cm^2 x 20s	0	70	30	0	90	10
400mW/cm^2 x 25s	0	60	40	0	70	30
300mW/cm^2 x 33s	0	60	40	0	80	20
200mW/cm^2 x 50s	0	60	40	0	80	20
100mW/cm^2 x 100s	0	50	50	0	60	40

Discussion

LCUs for the polymerization of oral biomaterials in dentistry using halogen bulbs are likely to be replaced in the near future by LCUs using LEDs. While studies[2,4] have shown powerful LED LCUs have the potential to replace conventional halogen LCUs, few studies have analyzed the effect of the irradiance level of LEDs on the bond strength.

The irradiance generated by the LCU is of critical importance in the process of curing composite resin as it imposes alterations in the kinetics of the polymerization reaction.[22,23] More specifically, the speed of the reaction is a direct function of irradiance. Irradiance also influences the intrinsic configuration of the polymer chain during formation and that determines the degree of tension generated in the bond interface between composite and tooth structure during and after photoactivation. Therefore, bond strength can be affected by the photoactivation method employed even though the radiant exposure is maintained constant.

Usually, the push-out test is used to evaluate the bond strength of endodontic cements to the radicular conduit.[24,19] However, in the present study, the push-out test was adapted to evaluate bond strength of restorative composites in a simulated Class V cavity.

Other bond strength tests such as shear, tensile, microshear, and microtensile evaluations are usually carried out to evaluate the bond strength of resin composites. However, these tests are generally performed on flat surfaces. In such a situation the C-factor is very low and the development of the shrinkage stress is not directed toward the bonding interface. The advantage of using the push-out test was the ability to evaluate bond strength in a high C-factor cavity (3.0) with high stress generation directed toward the bonding area. All of the bonding area was submitted to the compressive force at the same time allowing the shear bond strength to be evaluated in a cavity. In addition, the confidence of the push-out test could be confirmed by the

low variability of the data once the results showed low standard deviations.

The restorations made with the Filtek™ Z250 resin composite showed larger mean values of bond strength than those achieved with the composite Esthet-X™. This result is in agreement with Ernst et al.[25] which, in a photoelastic investigation, found polymerization stress smaller for Filtek™ Z250 (3.7 MPa) than for Esthet-X™ (4.6 MPa). In addition, the analysis of the mode of failure for the different photoactivation methods used showed Filtek™ Z250 restorations having a greater prevalence of the mixed failure type when compared with Esthet-X™ restorations.

These results can probably be explained by the existence of differences in the composition of the materials studied. The organic matrix of Filtek™ Z250 is composed mainly of BisGMA, UDMA, and BisEMA; the inorganic particles are zircon/silica (60% in volume). In contrast, the organic matrix of Esthet-X™ is composed mainly of urethane modified BisGMA, BisEMA, TEGDMA, and a combination of inorganic particles of aluminum fluoride borosilicate glass and silanized barium, colloidal, and nanometric silica (60% in volume). The higher bond strength means obtained for Filtek™ Z250 may be explained by differences in the organic matrix composition between both materials.

However, irradiance modulation along with the maintenance of a fixed radiant exposure was not capable of establishing statistically significant differences of bond strength for Filtek™ Z250 restorations. These results are in agreement with a previous, unpublished study (personal data) which did not find differences when this composite was photoactivated at a low irradiance level (150 mW/cm²). The lower bottom hardness for the group photoactivated with a low irradiance could explain the lower bond strength observed for this method because the degree of conversion is directly related to the bond strength between composite and adhesive.[26]

In the case of the Esthet-X™ the lowest irradiance (100 mW/cm²) was the one that presented the highest average of bond strength. The reduction of irradiance during the photoactivation of the composite may have propitiated a reduction of polymerization speed with a consequent slower generation of stress. Neves et al.[27] stated a lower irradiance was able to reduce the maximum polymerization rate and delay the formation of a rigid network, and the conversion before the formation of the rigid network was also enhanced by using a lower irradiance. This result was also confirmed by the analysis of the failure mode of the specimens. The group with the lowest irradiance presented fewer adhesive failures than the other groups. The reduction on the frequency of adhesive failure when compared with other groups could be associated with partial preservation of the adhesive interface and occurrence of cohesive fracture of the composite.

Based on the results of this study, the tested hypothesis was partially validated. The modulation of the irradiance in the photoactivation process using the Filtek™ Z250 resin composite did not interfere with the bond strength. However, low light intensity was associated with higher bond strength values when Esthet-X™ resin composite was used.

Conclusion

The combination of exposure time and irradiance or maintaining the radiant exposure can be considered as alternatives for the photoactivation of composite restorations. With some materials like Esthet-X™, higher bond strength results were found when low light intensity was used.

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