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**Laboratory Research**

# Influence of Different Cordless Light-emitting-diode Units and Battery Levels on Chemical, Mechanical, and Physical Properties of Composite Resin

IO Cardoso • AC Machado • DNR Teixeira • FC Basílio • A Marletta • PV Soares

### Clinical Relevance

Irradiance may decrease as the light-emitting diode (LED) is discharged. Therefore, the LED must be charged carefully to prevent the possibility of influencing the chemical, mechanical, and physical properties of composite resin.


## SUMMARY

**The aim of this study was to evaluate the influence of different light-emitting diode (LED) curing units and battery levels on the chemical, mechanical, and physical properties of composite resins. The irradiance for each cycle from full to completely discharged battery level was evaluated, for five different new cordless LED units: Optilight Color (Gnatus), Bluephase (Ivoclar), Valo (Ultradent), Radii Plus (SDI), and Radii Xpert (SDI). After the irradiance evaluation, composite resin specimens were prepared and light cured, while varying the battery level for each LED unit: high level (HL, 100%), medium level (ML, 50%), and low level (LL, 10%). The degree of conversion, diametral tensile strength, sorption, and solubility were also evaluated. Data were checked for homoscedasticity and submitted to two-way and three-way analysis of variance, depending on the test performed, followed by the Tukey test with a significance level of 95%. A negative correlation was found between irradiance and cycles of light curing, which was checked by the Pearson correlation test. Valo and Radii Xpert were not influenced by the battery level in any test performed. How-**



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**ever, different battery levels for some LED units can influence the degree of conversion, diametral tensile strength, sorption, and solubility of composite resins.**

## INTRODUCTION

Composite resins are widely used in clinical dentistry and have several indications for use, including direct restorations, sealants, inlays, onlays, crowns, luting agents, and orthodontic devices.[1] Composite resin restorations are esthetic, have good mechanical properties, and achieve success rates of up to 81.5% at 10 years.[1–3] The evolution of composite resins has been extensive over the past decades with regards to inorganic fillers, the organic matrix, and the form of activation.[4] The development of light-curing units (LCUs) was an additional milestone for adhesive dentistry, facilitating clinical practice, reducing working time, and improving the prognosis of restorations.[5]

Different LCUs can be used for light curing, which include quartz-tungsten halogen, plasma arc, argon laser, and light-emitting diode (LED), with LED being the most popular. LED curing units are currently the standard devices in most modern dental practices.[4] The light emitted by LCUs stimulates the initiator present in the composites and starts the polymerization reaction.[6,7] The polymerization reaction involves chemical reactions of organic oligomers to form a new polymeric material with an increase in molecular weight, resulting in the conversion of monomers into a polymer.[8] Thus, the light spectrum emitted by the LCU must stimulate the photoinitiator present in the restorative material.[6]

The most commonly used term to indicate the intensity of the light emitted by an LCU is *irradiance* (mW/cm$^2$), which is the value of the power divided by the area of the LCU tip.[9] Irradiance represents the light that reaches the target, not necessarily the light coming out of the LCU, and is maximized when the tip is pointing directly at the place to be polymerized.[10]

Composite resins need adequate light curing for maximum mechanical and aesthetic properties of the restorations, achieving a predictable clinical long-term outcome.[11,12] One of the most important factors related to the clinical performance of composites is the degree of conversion (DC), which is associated with excellent physical, mechanical, and biological properties of these composites. The DC may also be associated with irradiance, appropriate light spectrum, and the photoinitiator used.[13]

Even after light curing, composite resins remain unstable and can interact with the environment, indicating that these materials can absorb and release water and chemicals in the oral cavity.[14] This phenomenon is called *sorption and solubility*, and it can be a precursor of several physical and chemical processes that lead to deleterious effects on the mechanical properties of composite resins, which can cause functional damage and compromise the longevity of the restoration.[14,15]

For convenience, cordless LEDs are more commonly used than devices that need to be plugged in. Although a lithium battery is found in most cordless LCUs in dentistry, there are few studies regarding its influence on the performance of the resin materials. Previous studies have concluded that the battery level can influence the quality of restorations, showing that as some LED curing units are discharged, the irradiance also decreases, compromising the properties of the materials being cured.[16,17] However, it is still unclear what properties and how much the battery charge may be relevant to the final mechanical properties of the composite resin, considering that each device may behave differently.[18]

Thus, the aim of this study was to evaluate how different battery levels of different cordless LED curing units affect irradiance and its influence on the DC, diametral tensile strength, sorption, and solubility of a nanohybrid composite resin. The tested null hypothesis was that different battery levels and different cordless LED curing units do not influence the performance of the equipment and the properties of the composite resin.

## METHODS AND MATERIALS

### Irradiance Measurement

To determine the power percentage corresponding to each battery level, five new cordless LED curing units were selected: Optilight Color (GNATUS, Ribeirão Preto, Brazil), Bluephase N/G2 (Ivoclar Vivadent, Schaan, Liechtenstein), Valo (Ultradent, Salt Lake City, UT, USA), Radii Plus (SDI, Bayswater, Australia) and Radi Xpert (SDI). The curing units were fully charged as recommended by the manufacturer and used until completely unloaded. The maximum number of completed cycles of 20 seconds with a full battery (100%) was determined. Based on that data, the number of cycles corresponding to 50% and 10% battery levels was set.[16,19]

The higher power (mW) of the cordless LED units during the cycle was individually checked for all light cycles using a power meter (Nova, Ophir Spiricon, Logan, UT, USA), and was then divided by the tip area ($cm^2$), calculated from the optical diameter, as measured with a digital caliper (CD6 CS, Mitutoyo, Kanagawa, Japan), to obtain the irradiance ($mW/cm^2$).[7]

Irradiance as a function of battery discharge was measured in real time, and the radiant power output from each LCU was characterized over one full battery discharge cycle. Lights were used until either the battery ran out or the LCU ceased to function. The lights were allowed to rest for 30 seconds after each exposure to allow the units to cool down, and the operator had a 15-minute break after the 50th light exposure, and then after every hundred exposures, as needed.[16]

## Specimen Preparation

Nanohybrid composite resin specimens (Aura, shade DC1, SDI) were prepared in a stainless-steel matrix (5 mm in diameter and 2 mm in depth) for all tests. Discs were light cured through a Mylar strip for 20 seconds using the cordless LED curing unit, with the center of the tip positioned in the center of the sample at a distance of 1 mm with different battery levels according to the experimental groups: high battery level (HL, 100%), medium battery level (ML, 50%), and low battery level (LL, 10%).

## Degree of Conversion

The DC of the composite resin specimens (n=10) was evaluated using a Fourier transform infrared spectroscopy unit (FTIR) (Tensor 27, Bruker, Ettlingen, Germany) and measured on the bottom of the specimens. The number of remaining carbon double bonds was determined, which was calculated by comparing the percentage of aliphatic C=C (vinyl) (1638 $cm^{-1}$) and aromatic C=C absorption (1608 $cm^{-1}$) between cured and uncured specimens. The spectra of the cured and uncured specimens were obtained using 32 scans at a resolution of 4 $cm^{-1}$, within the range from 1000 to 6000 $cm^{-1}$. The spectra were subtracted from the background spectra using the software provided with the FTIR unit (OMNIC 6.1, Nicolet Instrument Corp, Madison, WI, USA). The acquired spectra were expanded and analyzed in the region of interest from 1560 to 1670 $cm^{-1}$. The DC was calculated using the standard baseline technique and a comparison between the peak area at 1639 $cm^{-1}$ (aliphatic C=C) and the internal standard peak at 1609 $cm^{-1}$ (aromatic C=C). Then, the DC was calculated using the following equation: DC (%) = [1 – (Cured aliphatic / Aromatic ratio) / (Uncured aliphatic / Aromatic ratio)] × 100.

## Sorption and Solubility

The sorption and solubility of the composite resin were verified for each experimental group using new specimens (n=10). After preparation, the specimens were stored in a desiccator with silica gel and maintained in an oven at 37°C for 24 hours. Then, the specimens were weighed on an analytical balance with 0.01 mg accuracy (AG200, Gehaka, São Paulo, Brazil) at 24-hour intervals until a constant weight was obtained, which was considered *m1*. After the weighing procedures, the specimens were immersed in an artificial saliva medium and kept in an oven at 37°C. After 7 days,[20] the specimens were removed from storage, the excess liquid was removed using absorbent papers, and the specimens were weighed to obtain *m2*. Afterward, the specimens were taken to the desiccator with silica gel at 37°C to eliminate the absorbed saliva and were weighed daily until reaching a constant mass, which was considered *m3*. The major and minor diameters and thickness of the specimens were measured at four points using a digital caliper (CD6 CS, Mitutoyo) after the final drying for $m1$. These measures were used to obtain the volume (V) of each specimen ($mm^3$) and to calculate the sorption (Sor) and solubility (Sol) rates, based on the following formulae: $Sor = (m2 - m3)/V$ and $Sol = (m1 - m3)/V$; where *m1* is the mass of the specimen (μg) before the immersion in liquid medium, *m2* is the mass of the specimen (μg) after immersion in liquid medium over 7 days, *m3* is the mass of the specimen (μg) after desiccation until reaching constant mass, and V is the volume of the specimen ($mm^3$).[21]

## Diametral Tensile Strength

A diametral tensile strength test was performed on the specimens before obtaining DC (n=10) and sorption and solubility (n=10) using a mechanical testing machine (DL 2000, EMIC, São José dos Pinhais, Brazil). Specimens subjected to sorption and solubility testing were compared with samples that were not subjected to any treatment. Specimens were positioned vertically on a testing machine between a stainless steel flat tip and a base. Then, a compressive load was applied vertically on the lateral portion of the cylinder at a crosshead speed of 0.5 mm/min, producing tensile stresses perpendicular to the vertical plane and passing through the

Table 1: *Tip Diameter, Power (mW), and Irradiance (mW/cm$^2$) for Different Battery Levels*

| | Bluephase | Optilight Color | Raddi Plus | Valo | Radii Xpert |
|---|---|---|---|---|---|
| Tip diameter (cm) | 0.93 | 0.70 | 0.60 | 0.95 | 0.78 |
| Tip area (cm$^2$) | 0.67 | 0.38 | 0.28 | 0.7 | 0.48 |
| Battery level power (mW) | | | | | |
| HL (100%) | 1237 | 1054 | 490 | 1103 | 769 |
| ML (50%) | 1182 | 644 | 487 | 1054 | 755 |
| LL (10%) | 1159 | 528 | 485 | 1054 | 744 |
| Irradiance (mW/cm$^2$) | | | | | |
| HL (100%) | 1846 | 2773 | 1750 | 1575 | 1611 |
| ML (50%) | 1749 | 1694 | 1739 | 1505 | 1581 |
| LL (10%) | 1731 | 1381 | 1732 | 1505 | 1557 |

*Abbreviations: HL, high level; LL, low level; ML, medium level.*

center of the specimen, until failure. After each compressive test, the fracture load (F) was recorded in newtons (N), and the diametral tensile strength ($\sigma t$) was calculated (MPa) as follows: $\sigma t = 2F / \pi dh$, where, d is the diameter (5 mm) of specimens, h is the height (2 mm) of specimens, and the constant $\pi$ is 3.1416.

### Statistical Analyses

The data were checked for homoscedasticity and submitted to analysis of variance (ANOVA) testing; The influence of battery level and LCU on water sorption, solubility, DC, and interaction between them were analyzed using two-way ANOVA; the influence of battery level, LCU, subjecting the specimens to water sorption and solubility challenge, and interaction between them were analyzed using three-way ANOVA. Both forms of ANOVA testing were submitted to the Tukey test. Correlations between irradiance and cycles were checked using the Pearson correlation test. SigmaPlot software (SigmaPlot 12.0, Systat Software, San, Jose, CA, USA) was used to conduct the tests, with a significance level set at 95%.

## RESULTS

The power and irradiance of each LED curing unit are shown in Table 1. The results for DC, sorption, solubility, and diametral tensile strength are presented in Tables 2 through 5, respectively. There was a negative correlation between irradiance and cycles of light curing (Figure 1). The LEDs lasted 190 (Valo), 191 (Bluephase), 447 (Radii Xpert), 528 (Optilight Color), and 642 (Radii Plus) cycles of 20 seconds until they were completely discharged.

For DC testing, both the LCU ($p \leq 0.001$) and battery level ($p = 0.010$) showed statistical differences. Optilight Color and Radii Plus were significantly influenced by the battery level, with the LL group presenting significantly inferior results (53.21% and 49.28%) compared with the HL (57.93% and 53.23%) and ML (54.93% and 52.17%) groups, which presented similar results. Optilight Color presented the highest statistical performance in the HL group. In the LL group, Valo presented similar results to Optilight Color and Radii Plus (Table 2).

In the sorption test, there was a significant difference in the battery level only for Optilight Color ($p = 0.003$). Optilight Color at HL presented significantly better performance compared with ML and LL. In the comparison between devices, Bluephase presented significantly superior sorption results at all battery levels (Table 3).

For the solubility results, Valo and Radii Xpert showed no influence based on the battery level. There were no differences among the five LED

Table 2: *Mean ± Standard Deviation for the Degree of Conversion (%) of Composite Resins With Different Light-emitting Diodes at Different Battery Levels (n=10)[a]*

| | Optilight Color | Bluephase | Valo | Radii Plus | Radii Xpert |
|---|---|---|---|---|---|
| HL (100%) | 57.93 ± 2.98 Aa | 51.39 ± 3.75 Ab | 52.92 ± 3.17 Ab | 53.23 ± 2.80 Ab | 52.89 ± 3.81 Ab |
| ML (50%) | 54.93 ± 2.92 ABa | 52.29 ± 2.75 Aa | 51.73 ± 5.15 Aa | 52.17 ± 3.22 ABa | 52.17 ± 3.20 Aa |
| LL (10%) | 53.21 ± 2.65 Ba | 48.95 ± 2.5 Ab | 52.85 ± 2.47 Aab | 49.28 ± 2.21 Bab | 50.56 ± 6.23 Aab |

*Abbreviations: HL, high level; LL, low level; ML, medium level.*
[a] *Different letters represent significant differences (p<0.05). Capital letters compare battery level (column), and lowercase letters compare devices (row).*

Table 3: *Mean ± Standard Deviation for Sorption (μg) of Composite Resins With Different Light-emitting Diodes at Different Battery Levels (n=10)*[a]

| | Optilight Color | Bluephase | Valo | Radii Plus | Radii Xpert |
|---|---|---|---|---|---|
| HL (100%) | 4.68 ± 6.71 Bc | 29.72 ± 8.36 Aa | 14.26 ± 7.84 Ab | 15.02 ± 3.47 Ab | 11.68 ± 4.92 Abc |
| ML (50%) | 12.75 ± 4.23 Ab | 33.57 ± 7.65 Aa | 19.55 ± 8.81 Ab | 12.75 ± 7.10 Ab | 13.23 ± 6.54 Ab |
| LL (10%) | 17.01 ± 6.83 Ab | 33.16 ± 7.40 Aa | 17.55 ± 8.31 Ab | 12.21 ± 4.13 Ab | 18.12 ± 6.00 Ab |

*Abbreviations: HL, high level; LL, low level; ML, medium level.*
[a] *Different letters represent significant differences (p<0.05). Uppercase letters compare battery level (column), and lowercase letters compare devices (row).*



curing units in the HL and ML groups. In LL, Radii Plus was significantly superior to Valo, which was similar to Bluephase and significantly superior to Optilight Color (Table 4).

The sorption and solubility challenge did not influence the result of the diametral tensile strength analysis ($p = 0.871$). Only Optilight Color was influenced by the battery level, while also presenting higher results than the other groups for HL (46.66 and 46.09 MPa). In ML, Valo presented higher values (41.41 and 42.26 MPa) than the other groups, which were similar to each other. In LL, Optilight Color and Valo were significantly superior to the other groups, which were similar to each other (Table 5).

## DISCUSSION

The battery level and the different LED curing units influenced the irradiance, DC, diametral tensile strength, sorption, and solubility of the composite resin. Thus, the null hypothesis was rejected.

The light curing of dental materials has facilitated clinical practice and is used worldwide; it is uncommon for an office to not have an LCU.[22] Several studies have related the light emitted by LCUs with the properties of the composite resin[13,23–25]; however, few studies have related the influence of the battery charge of cordless LCUs with the properties of composite resins.[16,19] Based on the prevalence of cordless LCUs, verifying their operation at full power has become even more important. The use of an LCU with a partially or an almost completely discharged battery may result in incomplete and unsatisfactory polymerization of restorative materials.[26] Although most devices use a lithium battery, the LCUs may behave differently as their batteries are discharged.[27]

The properties of composite resin are dependent on several factors, including composition, insertion technique, thickness, and method of light curing.[28,29] During polymerization of the composite, it is ideal for a greater quantity of monomers to be converted into polymeric chains.[30] Polymerization involves a free-radical reaction in which the state of a material is transformed from viscous to rigid. During this process for composite resins, the terminal aliphatic C=C bonds are broken and converted to primary C-C covalent bonds between methacrylate monomers. As polymerization progresses, however, the diffusion rate of the propagating free radicals reduces. Thus, monomer conversion is not complete at the end of the reaction; therefore, part of the monomers remain as pendant double bonds or trapped unreacted monomers.[31]

The DC is directly related to the physical and mechanical properties of a composite resin.[32] Lower DC is related to impaired mechanical properties, greater discoloration, and degradation, resulting in reduced strength and longevity.[33,34] The conversion readings of this study were performed on the bottom surface of the samples in order to evaluate the DC in the region that received less irradiance, which has a lower conversion of monomers into polymers.[35]

Table 4: *Mean ± Standard Deviation for Solubility (μg) of Composite Resins With Different Light-emitting Diodes at Different Battery Levels (n=10)*[a]

| | Optilight Color | Bluephase | Valo | Radii Plus | Radii Xpert |
|---|---|---|---|---|---|
| HL (100%) | 8.51 ± 5.77 Ba | 4.93 ± 8.3 Ba | 4.94 ± 8.85 Aa | 12.65 ± 1.27 Aa | 9.38 ± 6.63 Aa |
| ML (50%) | 10.1 ± 6.98 Ba | 9.44 ± 8.12 ABa | 10.55 ± 9.63 Aa | 13.03 ± 1.30 Aa | 12.78 ± 8.24 Aa |
| LL (10%) | 21.32 ± 5.81 Aa | 13.7 ± 5.52 Aab | 9.99 ± 7.72 Ab | −9.56 ± 7.08 Bc | 15.54 ± 4.99 Aab |

*Abbreviations: HL, high level; LL, low level; ML, medium level.*
[a] *Different letters represent significant differences (p<0.05). Uppercase letters compare battery level (column), and lowercase letters compare devices (row).*

Table 5: *Mean ± Standard Deviation for the Diametral Tensile Strength (MPa) of Composite Resins With Different Light-emitting Diodes at Different Battery Levels (n=10)*[a]

| | Optilight Color | | Bluephase | | Valo | |
|---|---|---|---|---|---|---|
| | N/SS | SS | N/SS | SS | N/SS | SS |
| HL (100%) | 46.66 ± 5.34 Aa | 46.09 ± 4.89 Aa | 33.03 ± 5.13 Ac | 33.77 ± 3.98 Ac | 40.02 ± .65 Ab | 42.13 ± 3.10 Ab |
| ML (50%) | 38.84 ± 3.03 Bb | 37.58 ± 4.95 Bb | 31.74 ± 2.56 Ac | 30.88 ± 2.62 Ac | 41.41 ± 4.53 Aa | 42.26 ± 3.08 Aa |
| LL (10%) | 40.34 ± 2.81 Ba | 37.69 ± 3.27 Ba | 32.20 ± 3.78 Ab | 32.98 ± 3.69 Ab | 39.49 ± 40.07 Aa | 39.17 ± 2.62 Aa |

*Abbreviations: HL, high level; LL, low level; ML, medium level; N/SS, group that did not pass the sorption and solubility challenge; SS, group that passed the sorption and solubility challenge,*

[a] *Different letters represent significant differences (p<0.05). Uppercase letters compare battery level (column), lowercase letters compare the devices (row). There was no significant difference between the SS and N/SS groups.*

The distance from the tip and the thickness of the resin, especially when greater than 2 mm, considerably reduces the irradiance[6] and may influence the properties of the resin, according to the DC, strength, sorption, and solubility results of this study. Therefore, the irradiance was found to influence the DC of composite resins.[37]

The ISO 10650:2015 standard for measuring the output from dental LCUs recommends using a laboratory-grade power meter to measure the total radiant power output.[38] This power value is then divided by the tip area to produce an irradiance value for the light. Therefore, it is possible to increase the irradiance in two ways: by increasing the power or reducing the area of the tip. The irradiance value can only represent an average output value across the light tip.[27] The light output from many LCUs is not uniform, and some areas of the tip may contain points of very high irradiance, while others have practically no light, but the only value considered and disclosed is the average. Ideally, the beam profile should be homogeneous; however, the central part of the tip of most LCUs has a higher irradiance and the peripheral areas have a reduced irradiance.[9,39,40] In an LED curing unit with an irradiance of 868 mW/cm$^2$, the tip will likely present about 40% of the area emitting less than 500 mW/cm$^2$, while the central region presents more than 2500 mW/cm$^2$.[7]

This study used a new device from each manufacturer. Although all LCUs in the present study featured a lithium battery, with the exception of Valo, which uses an iron phosphate lithium battery, the present results cannot be extrapolated to all LCUs, even though most cordless LCUs use a lithium battery, as the performance of each product may be different.[19]

In the oral environment, composite resins can absorb water and other substances from saliva, food, and drinks; which may have some influence on their degradation.[14] Sorption is influenced by the polarity of the molecular structure, the presence of hydroxyl groups capable of forming hydrogen bonds with water, and the degree of cross linking in the continuous matrix.[41] Water sorption is associated with solubility, which is the release of residual products as unreacted monomers. These products alter the matrix microstructure, creating voids suitable for the formation of microfractures.[42,43] Sorption and solubility in composite resins have a significant effect on the clinical success of restorative materials, influencing the esthetic appearance, integrity, and surface properties.[41] During and after the polymerization process, free monomers remain present in the restorative material and can detach from the composite resin and be incorporated in the oral fluids.[44,45] The level of battery and different LEDs can influence the sorption and solubility, as shown in the results of this study. The negative value of the Radii Plus in the LL group of the solubility test can be explained by the fact that the fluid absorbed during the sorption process is confined and included as part of the polymeric structure of the material.[19,46]

Valo and Radii Xpert were not influenced by battery level in any test and presented satisfactory results compared with the other devices. The Optilight Color presented excellent results in the tests, but it was most influenced by the battery level; even with the irradiance and test results decreasing as the battery was discharged, it showed good results even at the 10% battery level. Bluephase and Valo emitted greater light power, therefore, the number of cycles until the battery was totally discharged was smaller compared with other groups that used less power. While Valo and Bluephase were discharged at about 190 cycles, Radii Plus required 642 20-second cycles.

Table 5: *Mean ± Standard Deviation for the Diametral Tensile Strength (MPa) of Composite Resins With Different Light-emitting Diodes at Different Battery Levels (n=10)[a] (ext.)*

| | Radii Plus | | Radii Xpert | |
|---|---|---|---|---|
| | N/SS | SS | N/SS | SS |
| HL (100%) | 36.52 ± 3.26 Ac | 35.87 ± 3.47 Ac | 34.15 ± 4.01 Ac | 33.00 ± 2.85 Ac |
| ML (50%) | 34.50 ± 3.67 Abc | 36.63 ± 3.36 Abc | 33.03 ± 4.02 Ac | 32.10 ± 2.11 Ac |
| LL (10%) | 33.61 ± 4.40 Ab | 34.98 ± 3.17 Ab | 32.57 ± 2.44 Ab | 32.65 ± 2.66 Ab |

A previous study evaluated the influence of the battery level of the LED curing unit Coltolux (Coltene, Feldwiesenstrasse, Switzerland) on the DC, sorption, solubility, and diametral tensile strength. The lowest battery level (10%) negatively affected all analyzed mechanical properties.[19] Another study found a decrease in radiant exposure of Bluephase (~4%), which was similar to the present study (~6%).[16] On the other hand, no influence of the battery level on the irradiance emitted by Bluephase was found in another study.[18] The difference between these two results may be explained by the way irradiance was measured (Radiometer, Kerr, Orange, CA, USA), which was not performed according to the specifications of ISO 10650: 2015.[38]

Another factor that may influence the DC and the other mechanical properties is the light spectrum emitted by the LED and the light spectrum that stimulates the initiators present in the composite resin.[47] Valo and Bluephase are polywave LCUs, delivering a light output with two or more wavelength peaks, which has the possibility of stimulating initiators with a different activating wavelength from camphorquinone (468 nm).[48] The manufacturer of the composite resin tested in this study did not provide information about which initiator is present.

This study was laboratory-based and has certain limitations. The LED curing units tested are from internationally renowned companies in dentistry, therefore, lower-quality LCUs may be detrimental to restorations.[7] In clinical practice, the deleterious effects should actually be worse because the distance from the tip of the LCU to the resin was minimal in the present study, separated only by a Mylar strip. Results tend to get worse when increasing the distance to the tip, reaching up to less than 25% of the irradiance emitted by the LED at only 9 mm of distance.[10]

In the present study, the analyzed samples had a 5-mm diameter and all LED tips were larger in diameter even LEDs with smaller tips like Radii Plus, Radii Xpert and Optilight Color. For devices that do not have a homogeneous beam profile, the center provides more irradiance compared with the periphery of the tip, which may have influenced the results of the study and the performance of the devices.[9] The DC was tested only at the center of the samples; therefore, LEDs that do not have a homogeneous distribution were favored in this experiment. On the other hand, the resistance test was less influenced because it is relevant that the polymerization occurs in the whole sample for better resistance.

Another limitation was found regarding the oral environment. During the process of restoration, restorative materials may be in close contact with adjacent gingival tissue, saliva, and gingival fluid before polymerization is complete, which may last about 24 hours.[49,50] The samples tested in the present study were immersed in artificial saliva 24 hours after light curing, which is different from what happens in the oral environment. Clinically, the oral environment is subjected to different kinds of foods, beverages, and pH changes due to disorders such as bulimia or gastroesophageal reflux disease; alternatively, the samples in the current study were only submitted to an artificial saliva challenge, meaning that the clinical results will likely be different.[51]

Therefore, clinicians should know the features of LED curing units and select the best LCU possible for their clinic. The battery level may influence the properties of the composite resin; therefore, the LCU should be fully charged to avoid any failures. The beam profile may not be homogeneous throughout the tip area; therefore, photopolymerization should be carried out in more than one location to ensure that the entire area receives sufficient irradiance to obtain optimum physical and mechanical properties. Further clinical and laboratory studies should be performed with different devices and different light-activated materials to prove the

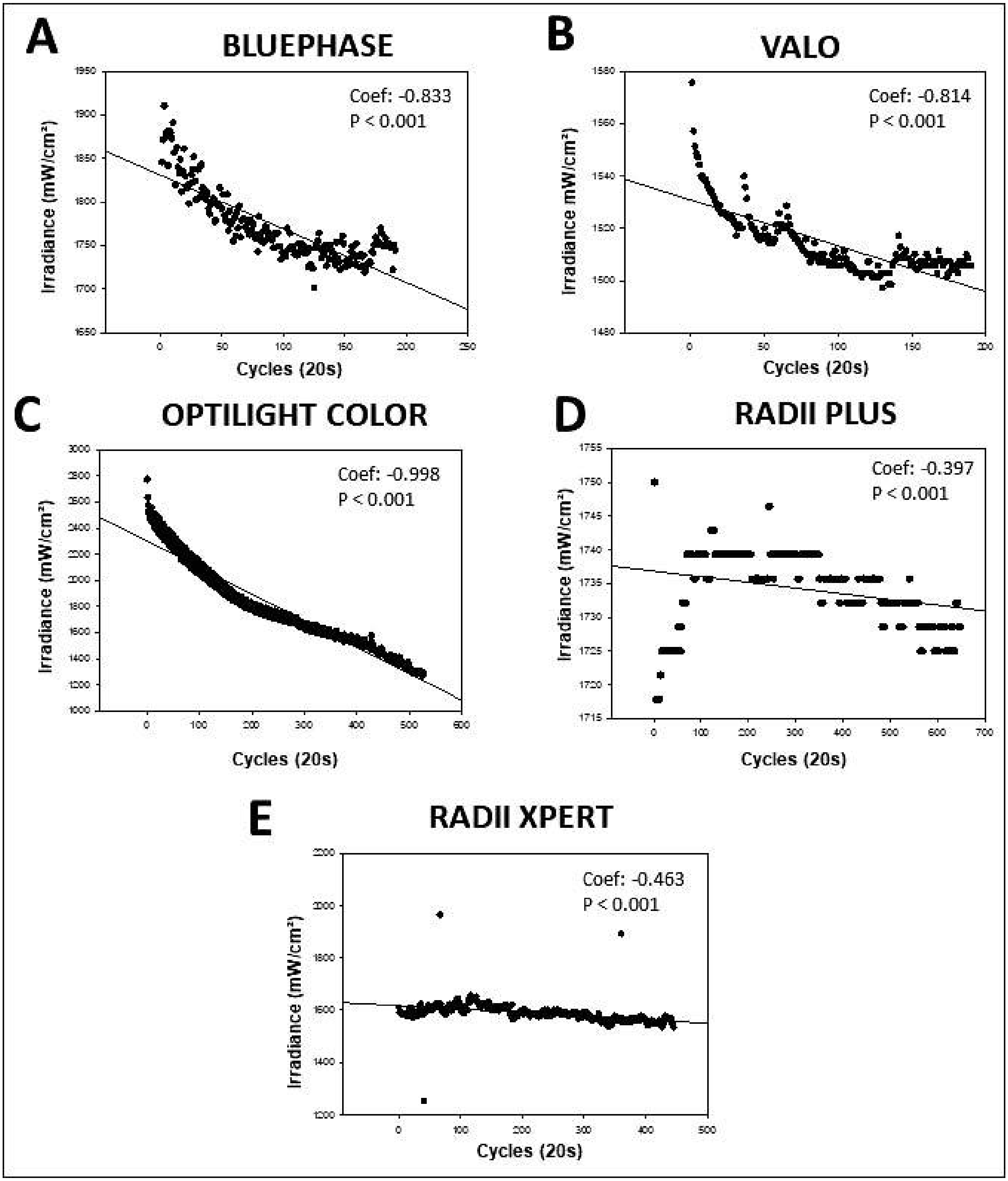


Figure 1. *Correlation graphs of irradiance (mW/cm$^2$) and cycles (20 seconds) of LCU. (A): Bluephase, (B ): Valo, (C): Optilight Color, (D): Radii Plus, and (E): Radii Xpert.*

influence of the LCU and battery level on the properties of these materials.

## CONCLUSION

Within the limitations of the present study, some LEDs at different battery levels were found to significantly decrease the DC, diametral tensile strength, sorption, and solubility of composite resins. Valo and Radii Xpert were not influenced by the battery levels in any test performed.

### Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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# Effect of Preheating and Fatiguing on Mechanical Properties of Bulk-fill and Conventional Composite Resin

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### Clinical Relevance

Bulk-fill composite resins may have comparable mechanical properties to conventional composite resin. Preheating does not reduce the mechanical properties of composite resins.


## SUMMARY

**Statement of Problem: Bulk-fill composite resins are increasingly used for direct restorations. Preheating high-viscosity versions of these composites has been advocated to increase flowability and adaptability. It is not known what changes preheating may cause on the mechanical properties of these composite resins. Moreover, the mechanical properties of these composites after mastication simulation is lacking.**

**Purpose: The purpose of this study was to evaluate the effect of fatiguing and preheating on the mechanical properties of bulk-fill composite resin in comparison to its conventional counterpart.**

**Methods and Materials: One hundred eighty specimens of Filtek One Bulk Fill Restorative (FOBR; Bulk-Fill, 3M ESPE) and Filtek Supreme Ultra (FSU; Conventional, 3M ESPE) were prepared for each of the following tests: fracture toughness (International Organization for Standardization, ISO 6872), diametral tensile strength (No. 27 of ANSI/ADA), flexural strength, and elastic modulus (ISO Standard 4049). Specimens in the preheated group were heated to 68°C for 10 minutes and in the fatiguing group were cyclically loaded and thermocycled for 600,000 cycles and then tested. Two-/one-way analysis of variance followed by Tukey Honest Significant Difference (HSD) *post hoc* test was used to analyze data for statistical significance ($\alpha$=0.05).**

**Results: Preheating and fatiguing had a significant effect on the properties of both FSU and FOBR. Fracture toughness increased for FOBR specimens when preheated and decreased when fatigued ($p$=0.016). FOBR had higher fracture toughness value than FSU. Diametral tensile strength decreased significantly after fatiguing for FSU ($p$=0.0001). FOBR had a lower diametral tensile strength baseline value compared with FSU ($p$=0.004). Fatiguing**



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