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Effectiveness of Second-generation Light-emitting Diode (LED) Light Curing Units

Ulisses Bastos Campregher, DDS, MS;
Susana Maria Werner Samuel, DDS, MS, PhD;
Carmen Beatriz Borges Fortes, DDS, MS;
Alberth David Correa Medina, DDS, MS;
Fabrício Mezzomo Collares, DDS;
Fabrício Aulo Ogliari, DDS

Abstract

Aim: The purpose of this study was to evaluate the effectiveness of three commercially available light emitting diode (LED) light curing units (LCU) (Elipar FreeLight - 3M ESPE; UltraLume LED2 - Ultradent; and Single V - BioArt) for polymerizing Z250-A3 composite (3M ESPE) using Knoop hardness, polymerization depth, and flexural strength properties.

Methods and Materials: The XL 2500 (3M ESPE) LCU, which is a conventional halogen unit, was used as a control. In all cases the curing time was 20 seconds. Hardness was determined 24 hours after composite cure for 10 samples of 8 mm diameter and 2 mm height for each LCU tested. Samples were stored dry in a light-proof container prior to testing. The depth of cure of the composite was measured immediately after composite polymerization for each LCU using three samples 4 mm in diameter and 6 mm in height. Flexural strength was determined for five samples 24 hours after immersion in distilled water at 37ºC. Each sample measured 25 mm in length, 2 mm in width, and 2 mm in height for each LCU tested.

Conclusion: The results were treated statistically for comparison of the LCUs. In all cases the results obtained by LED LCUs were not different or were higher than a conventional halogen LCU.

Clinical Significance: Second generation LED LCUs were as effective as/or more effective than a halogen LCU for polymerization of the used composite. The present study shows second generation LEDs have the potential to replace halogen LCUs.

Keywords: LED, halogen, composites, polymerization

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Introduction

In a composite restorative procedure photopolymerization of the composite is of fundamental importance because adequate polymerization is a crucial factor for optimization of the physical and mechanical properties and clinical results of the composite material. Inadequate polymerization results in poor resistance to wear, poor color stability, increased rates of water sorption and solubility, as well as adverse and early restoration failure.[1-5] Furthermore, there may be greater deterioration at the margins of the restoration[6], decreased bond strength between the tooth and the restoration[7], greater cytotoxicity[8,9], and reduced hardness.[10] Therefore, the dentist must use a light curing unit (LCU) that delivers adequate and sufficient energy to optimize composite polymerization.[11,12]

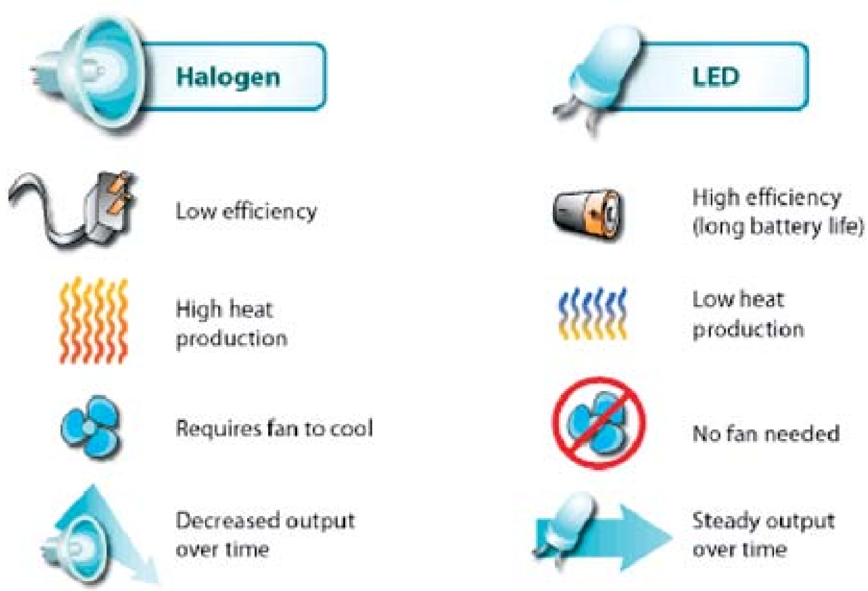
Halogen is the most widely used light source in LCUs. However, despite its popularity there are limitations inherent with this technology such as a limited lifespan of the bulb and low efficiency in the conversion of electric energy to light and high heat production and emission. The heat produced during use causes component degradation in the LCU resulting in a progressive decrease in light output which, in turn, compromises the degree of polymerization of the composite material.[13]

To overcome these shortcomings, the light emitting diode (LED) has been proposed as an alternative technology for curing light activated dental materials.

Unlike the halogen bulb, light generation in an LED does not involve a thermal process. Light is generated by electrons passing through holes then recombining at a junction of modified semiconductor material.[14-16]

The effective useful life of LEDs is estimated in terms of several thousand hours with a reduced light flux degradation over time.[17] Furthermore, the low energy consumption makes the production of cordless LED LCUs powered by rechargeable batteries feasable. LED LCUs require no filters because the spectral output of produced light falls within the absorption spectrum of camphorquinone which is the photoinitiator present in the majority of dental composites. Furthermore, LED LCUs thermal emission is significantly lower than conventional halogen LCUs.[18]

Early LED LCUs were built with an array of a large number of low power LEDs. Recently, second generation LED LCUs with high power LEDs ("Giga LEDs") were introduced to the market. These new LED LCUs consist of multiple



emitters on the same substrate and have an output power of up to 100 times higher than a first generation LED LCU.[19-21]

Several studies have documented the efficacy of first generation LED efficacy in terms of the polymerization of dental composites. However, there is limited published data about the behavior of second generation LED LCU's.[22-25] Therefore, the aim of the present study was to test the effectiveness of three commercial second generation LED LCUs on composite polymerization using Knoop hardness, the depth of polymerization, and flexural strength tests as measures of efficacy.

Materials and Methods

Four LCUs were used in the study. One conventional LCU with a quartz tungsten halogen bulb technology (XL 2500) served as the control (3M ESPE, St. Paul, MN, USA). The other three (Elipar FreeLight, 3M ESPE, St. Paul, MN, USA; ULtraLume LED2, Ultradent, South Jordan, Utah, USA; and Single V, BioArt, São Carlos, SP, Brazil) used LED technology. Their specifications are shown in Table 1.

For all LCUs, the light guide tips were 8 mm in diameter except for the UltraLume LED2 which has an oval shaped light footprint of 10x13 mm. A standard 20 second curing time was used for all LCUs according to composite manufacturers' recommendations.

The LCUs light irradiance was verified before each test using a hand-held Demetron 100 radiometer (Demetron Research, Danberry, CT, USA) and showed equivalency within manufacturers' specifications.

Filtek Z250 (3M, St. Paul, MN, USA) visible light-cured composite was used for all tests (Table 2).

The Knoop Hardness Test

A stainless steel split mold with a cylindrical cavity 2 mm in diameter and 8 mm in depth was slightly overfilled with composite material. The top and bottom of the composite were then covered by Mylar strips (Moyco Union Broach, Montgomeryville, PA, USA), leveled using a glass plate, and held under pressure for 30 seconds to allow any excess material to escape. After removing the top glass plate, the tip of the light guide of the LCU was positioned at the center

Table 1. Technical details of the halogen and LED LCU used in this study.

	XL 2500	Elipar FreeLight	UltraLume2	Single V
Light source	One halogen bulb	One LED	Two LED	One LED
Light emission spectrum (nm)	420-500	440-490	410-490	430-490
Output face light guide tip Ø (mm)	8	8	10x13mm oval	8
Irradiance (mW/cm2)	600	400	>400	600

Table 2. Restorative material used in this study.

Brand	Manufacturer
Product	250[a]
Manufacturer	3M Dental Products, St. Paul, MN, USA
Type	BIS-GMA, UDMA and Bis-EMA
Shade	A3
Filler particle size (µm)	0.01 to 3.5
Recommended curing time (s)	20
Filler type and loading (wt%)	Silica/Zirconia, 60%

[a] According to manufacturer 3M Dental Products, St. Paul, MN, USA

of the surface of the composite sample with the light passing through the Mylar strip while the tip remained in constant contact with the strip. Following photopolymerization, the specimens were removed from their molds and stored in a light proof container for 24 hours. Subsequently, the Knoop hardness was measured three times at the top of the sample using a Micromet 2001 hardness tester (Buehler, Lake Bluff, IL, USA). A 100 g load was applied through the indenter with a dwell time of 10 seconds. Three measurements were taken for each sample, and an average was calculated.

For each LCU in the study, ten samples were fabricated and tested.

Polymerization Depth Determination

A stainless steel split mold with a cylindrical cavity 4 mm in diameter and 6 mm in depth was slightly overfilled with composite material. The samples were polymerized as described previously for the Knoop hardness test. Immediately after photopolymerization depth of cure was measured using a penetrometer just in contact with the composite column similar to the suggestion by Harrington and Wilson.[26] This measurement is performed by lowering a needle rigidly connected to a weight of 1250 g onto the soft portion of the composite sample so the needle penetrates until it reaches the cured composite. Each of the three LCU samples were fabricated according ISO 4049 specification.[27]

Flexural Strength

Flexural strength was also evaluated according to the ISO 4049 specification. Specimens of 2 x 2 x 25 mm were prepared using a stainless steel split mold. The samples were polymerized as described previously for the Knoop hardness test except the light activation was performed by sequentially curing for a designated period with adjacent sections on either side being irradiated for the same period until the full length of the specimen had been photoactivated. The cured specimens were then stored in distilled water at 37ºC for 15 minutes followed by a careful polish under water with 2000 grit silicon paper in a longitudinal direction. Prior to mechanical testing, the specimens were stored in distilled water for 24 hours. The final dimensions of the specimens were then measured and recorded. The specimens were tested on a computer-controlled EMIC Model DL2000 universal testing machine (EMIC, São José do Pinhais, PR, Brazil) at a crosshead speed of 0.75 mm/min. Calculations were made using the following formula:

$$FS = 3PL/2WT^2$$

Where **P** is the load at fracture, **L** is the distance between two supports (which was set to be 20 mm), **W** is the width of the specimen, and **T** is the thickness of the specimen.

Five specimens were prepared for each LCU according to the ISO 4049 specification.

Statistical Analysis

Depth of cure and flexural strength data were compared using the requirements of ISO 4049, and a minimal significant difference was determined using the Kruskall Wallis test at a significance level of 0.05. For Knoop hardness, data was subjected to statistical analysis using one-way analysis of variance (ANOVA), and a 5% significance level was used to determine significant differences. A Tukey post hoc test was used to indicate a significant difference between the LCUs.

Results

Knoop Hardness

Table 3 shows the Knoop hardness values obtained with curing units used in the study. The values were higher for the three LED LCUs than for the halogen LCU. There were statistically no differences between LED LCUs.

Depth of Cure

Table 4 shows the depth of polymerization obtained with curing units used in the study. The Single V LED LCU had a significantly higher depth of polymerization than did the XL 2500 halogen LCU. There were no statistical differences between the Elipar FreeLight and the UltraLume LED2 LCUs.

Flexural Strength

The mean flexural strength values (MPa), standard deviations, and statistical results of the restorative materials are given in Table 5.

No significant differences were obtained between the four LCUs.

Table 3. Hardness.

Curing unit	Mean(S.D.)*
XL2500	64.15 (0.53)[a]
Manufacturer	67.65 (1.58)[b]
Type	66.39 (1.34)[b]
Single V	67.35 (0.46)[b]

* Values with the same superscript were not statistically different at p = 0.

Table 4. Depth of polymerization.

Curing unit	Mean(S.D.)*
XL2500	4.08(0.02)[b]
Elipar Freelight	4.72(0.02)[ab]
UltraLume LED2	4.10(0.04)[b]
Single V	4.75(0.02)[a]

* Values with the same superscript were not statistically different at p = 0.

Table 5. Flexural strength.

Curing unit	Mean(S.D.)*
XL2500	160.95 (16.83)[a]
Elipar Freelight	172,95 (20,86)[a]
UltraLume LED2	159.38 (5.91)[a]
Single V	174.53 (26.10)[a]

* Values with the same superscript were not statistically different at p = 0.

Discussion

The primary purpose of the present study was to compare the efficacy of second generation LED LCUs with a halogen LCU. The tests were chosen for their clinical relevance because they provide data about physical properties considered essential for the favorable performance of dental composites.[23]

In general the present study showed commercial LED LCUs achieved higher results or values for the three properties tested that were the same as the halogen LCU. In all cases ISO 4049 requirements were met.

Hardness is defined as the resistance to permanent penetration or indentation. Knoop hardness is widely used in scientific studies as an indirect method of determining the composite degree of conversion as it has been shown to have good correlation with infrared spectroscopy.[28-29]

The hardness values obtained using the three LED LCUs investigated were higher than the value obtained using the halogen LCU (Figure 1). Tests showed adequate polymerization was obtained in all cases. Higher hardness values are in general indicative of more extensive polymerization.[30] There were no differences between values achieved by the three LED LCUs.

In order to conduct a depth of cure test in accordance with the ISO 4049 specification any uncured material must be scraped away with a plastic spatula after use of the LCU before the measurement is done. Due to the impossibility of standardization of the scrapping force, a penetrometer, suggested by Harrington and Wilson[26], was used to enhance the accuracy of the test.

Of the three LED LCUs investigated, two of them (Elipar FreeLight and UltraLume LED2) showed a lower irradiance than halogen LCU, and the third (Single V) showed no difference. However, the depth of cure values for the Single V unit were significantly higher than with the XL 2500 while those obtained with the UltraLume LED2 and Elipar FreeLight LCUs showed no statistical differences (Figure 2).

The reason for this finding is the wavelength of light being near 470 nm which corresponds to blue light and matches the peak absorption of the camphorquinone photoinitiator. The number of photons emitted by the LED LCUs is higher than the halogen LCU.[31] In the present study the results of depth of cure showed all LCUs investigated fulfill ISO 4049 requirements.

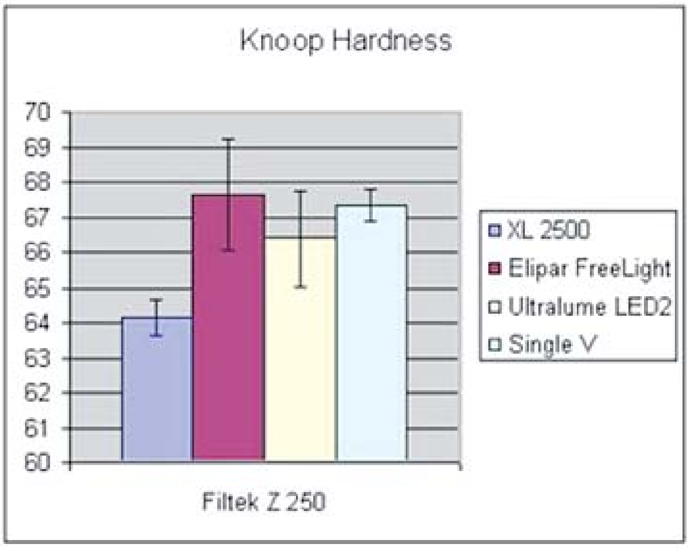


Figure 1. Knoop hardness of the composite polymerized with the three LED LCUs and the halogen LCU.

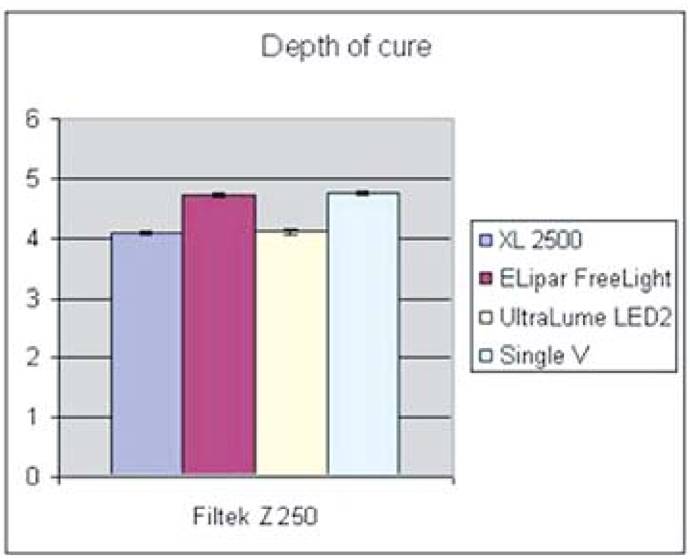


Figure 2. Depth of cure of the composite polymerized with the three LED LCUs and the halogen LCU.

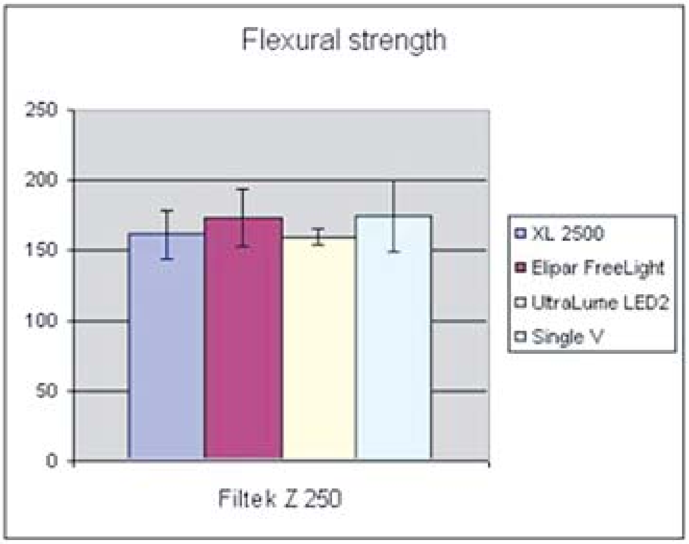


Figure 3. Flexural strength of the composite polymerized with the three LED LCUs and the halogen LCU.

Since all LCUs achieved ISO 4049 it may seem the differences found have no clinical relevance because, according to the resin composite manufacturers, the increments should not exceed 2 mm. However, in some clinical situations the LCU light guide tip cannot be placed in close contact to the restoration surface as was the case during this study. Therefore, any rise on the depth of cure obtained by a LCU should be considered important for daily clinical practice.

For the flexural strength test, the obtained results showed there were no statistical differences for all LCUs investigated, and in all cases the obtained values were much higher than the minimal ISO 4049 requirement (80 MPa) as shown in Figure 3.

The homogeneity obtained in the strength tests is related to the way the samples were fabricated. Due to the sample length, several photopolymerization cycles are realized. As a result, at the end of the process, almost all of the superficial area of the sample has actually been irradiated for a longer period of time than suggested by the manufacturer to achieve adequate polymerization of the composite. This demonstrates extending the irradiation time could compensate for reduced irradiance and might ensure adequate polymerization of light cured composite resin.

Perhaps the next generation of LED's with even higher power (i.e., Freelight 2, UltraLume 5, LE Demetron II, and BluePhase 16i) could be expected to have even better performance than the LCU's used in the present study.

Conclusion

Within the limitations of this experiment, second generation LED LCUs are either as effective as or more effective than a halogen LCU for polymerization of the composite used (Filtek Z250) in this study.

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About the Authors

Ulisses Bastos Campregher, DDS, MS

Dr. Campregher is a PhD student in the Department of Conservative Dentistry at the Federal University of Rio Grande do Sul in Porto Alegre, Rio Grande do Sul, Brazil.

e-mail: ubcampre@ufrgs.br

Susana Maria Werner Samuel, DDS, MS, PhD

Dr. Samuel is a Professor in the Department of Conservative Dentistry at the Federal University of Rio Grande do Sul in Porto Alegre, Rio Grande do Sul, Brazil.

e-mail: samuelsp@adufrgs.ufrgs.br

Carmen Beatriz Borges Fortes, DDS, MS

Dr. Fortes is a Professor in the Department of Conservative Dentistry at the Federal University of Rio Grande do Sul in Porto Alegre, Rio Grande do Sul, Brazil.

e-mail: fortes@ufrgs.br

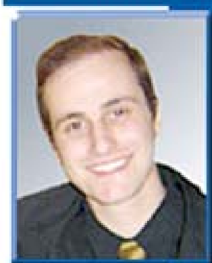
Alberth David Correa Medina, DDS, MS

Dr. Medina is a PhD graduate student in the Department of Operative Dentistry at the State University of Campinas in Campinas, São Paulo, Brazil.

Fabrício Mezzomo Collares, DDS

Dr. Collares is a MS student in the Department of Conservative Dentistry at the Federal University of Rio Grande do Sul in Porto Alegre, Rio Grande do Sul, Brazil.

Fabrício Aulo Ogliari, DDS



Dr. Ogliari is a MS student in the Department of Operative Dentistry at the Federal University of Pelotas in Pelotas, Rio Grande do Sul, Brazil.

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