REPES
REVISTA DE ENSINO, PESQUISA E EXTENSÃO EM SAÚDE

Beyond light: evaluating the characteristics of lower-cost LED Curing Units for resin composite polymerization

Laís da Mata Almeida[2]
Stella Sueli Lourenço Braga[3]
Maria Tereza Hordones Ribeiro[3]
Rayssa Ferreira Zanatta[2]
Carlos José Soares[3]
Crisnicaw Verissimo*[1]

[1] Universidade Federal de Goiás - UFG, Brasil
[2] Universidade de Brasília - UnB, Brasil
[2] Universidade Federal de Uberlândia - UFU, Brasil

*Autor Correspondente
crisnicaw.verissimo@ufg.br

Recebido: 08/05/2025 | Aceito: 25/06/2025 | Publicado: 14/09/2026

Palavras-chave

curing lights; light; polymerization; mechanical tests; composite resins.

ABSTRACT

Objective: This study aimed to evaluate the irradiance (mW/cm2), emission spectrum (mW/nm), radiant exposure (J/cm²), beam profile, and depth of cure of a resin composite light-cured using different low-cost LED light-curing units (LCUs). Materials & Methods: It was tested the following devices: Dental Wireless; LY-A180; LY-B200. The VALO (polywave) and Elipar DeepCure-L (monowave) were used as control groups. Irradiance, emission spectrum, and radiant exposure were evaluated using the MARC Resin Calibrator. The Knoop microhardness test evaluated the depth of cure and elastic modulus. Depth of cure data was analyzed using the Shapiro-Wilk test, Levene's test, ANOVA, Tukey HSD (α=0.05), and multiple linear regression analysis. Results: VALO and Elipar DeepCure-L showed a homogeneous radiant exitance. ANOVA showed that LCUs and restoration depth ($p<.001$) were significant, but the interaction was not. Multiple linear regression showed a significant relation between Elastic modulus, Irradiance, and depth of restoration ($p=.350$). Conclusions: Depth of cure tests showed that lower-cost LCUs tested showed satisfactory results; however, when all the variables were compared, they showed an inferior performance compared to the LCUs used as control.

CLINICAL SIGNIFICANCE: Budget LCUs are being frequently used in dental clinicians and by students. These Budgets LCUs are easily found directly over the Internet with attractive prices but without realizing their effectiveness. A non-satisfactory polymerization may interfere in clinical treatments, like negative consequences on durability and aesthetics of restorations.

INTRODUCTION

Since the early 90s, Light-Emitting Diode (LED) has become popular in dental practice serving as the technology behind the light-curing units (LCUs) used to initiate the process of photopolymerization of resin-based composites (RBCs). Since their introduction, these devices have replaced the well-established Quartz-tungsten-halogen (QTH) LCUs, due to advantages such as solid-state, lightweight, and efficient high power (Jandt; Mills, 2013). Typically, the LED devices exhibit an emission spectrum ranging from 438nm-501nm, with a peak at 465nm (Jandt *et al*., 2000), which is the one absorbable by camphorquinone, the most common photoinitiator used in the RBCs nowadays (Jandt; Mills, 2013).

The light-curing process is crucial when placing a direct or indirect resin-based restoration. The energy delivered to the RBCs by the LCUs significantly influences their mechanical properties (Price; Shortall; Ferracane, 2015; Tichy *et al*., 2020), which can result in clinical problems, such as fractures, caries lesions adjacent to restoration, and early surface wear (André *et al.*, 2018; Emmler *et al.*, 2008; Ferracane; Moser; Greener, 1985; Imazato *et al.*, 1995; Tongtaksin; Leevailoj, 2017). Therefore, the importance of using an effective LCU and employing proper techniques for energy delivery has been discussed (André *et al*., 2018; Rueggeberg *et al*., 2017; Soares *et al.*, 2018). The light emitted by an LCU should be uniformly distributed across the entire tip (Price *et al.*, 2010a; Price; Shortall; Palin, 2014; Vandewalle; Roberts; Rueggeberg, 2008), and key factors like power output, emission spectrum, and beam profile play a crucial role. Additionally, the relative position of the light-curing unit's tip over the cavity, its size, energy density, and light source can influence the proper cure of the material and be responsible for failures in the restorations (André *et al.*, 2018; Rueggeberg; Caughman; Curtis Junior, 1994; Price *et al.*, 2010a; Price; Shortall; Palin, 2014; Price, 2017; Yearn, 1985).

Differences in the light output among the dental LCUs are not easily detectable by visual inspection or a dental radiometer (Price; Shortall; Ferracane, 2015; Price, 2017). Considering the abundance of LCUs devices available in the current market, clinicians may be tempted to opt for lower-cost LCUs. While LCUs from certified dental manufacturers typically average around US$1000, alternatives can be found online at a significantly lower cost, ranging from US$224-US$470 (Soares; Braga; Price, 2021). Previous studies discussed that some lower-cost LCUs may interfere with the proper cure of RBCs and compromise the clinical performance of direct or indirect resin-based restorations (Alshaafi *et al.*, 2016; Soares; Braga; Price, 2021).

This study aimed to evaluate the irradiance, emission spectrum, radiant exposure, beam profile, and depth of cure of a resin composite light-cured using three lower-cost LCUs, comparing them with two well-established devices. The null hypothesis assumed no difference in any parameters among the tested LCUs. It was hypothesized that the depth of cure (measured by Knoop microhardness and Elastic modulus) of mesio-occlusal-distal (MOD) resin composite restorations would not be affected by the different LCUs.

MATERIALS & METHODS

Study Design

The following LED LCUs were selected: 1. VALO Cordless (polywave control); 2. Elipar DeepCure-L (monowave control); 3. Dental Wireless; 4. LY-A180; 5. LY-B200 (Figure 1). LCUs manufacturer’s information is shown in Table 1. LCUs were characterized using the MARC resin calibrator (BlueLight Analytics, Halifax, NS, Canada) to measure the emission spectrum (mW/nm), irradiance (mW/cm²), and radiant exposure (J/cm²). Light beam profiles were evaluated using a Laser Beam Profiler (Ophir-Spiricon, Logan, UT, USA). The depth of cure (expressed as the Knoop microhardness (KHN) and elastic modulus) of MOD restored human molars with Filtek Supreme (A2E shade, 3M Oral Care, St Paul, MN, USA) was evaluated.

Table 1 – LCUs manufacturer information

Light Cure Unit (LCU)	Light-Emitting Diode (LED) classification	Serial number	Manufacturer
VALO cordless	LED Polywave	C63964	Ultradent, Salt Lake City, Utah, EUA.
Elipar DeepCure-L	LED Monowave	R04549	3M Oral Care, Saint Paul, Minnesota, EUA.
Dental Wireless	LED Monowave	*Serial number not provided by the manufacturer*	Dental Wireless, China.

Light Cure Unit (LCU)	Light-Emitting Diode (LED) classification	Serial number	Manufacturer
LY-A180	LED Monowave	*Serial number not provided by the manufacturer*	Lyang Ya, China.
LY-B200	LED Monowave	190330579	Lyang Ya, China.

Figure 1 – Light curing units (LCUs) that were used in this study

Irradiance, Emission Spectrum, and Radiant Exposure

Emission spectrum, irradiance, and radiant exposure were measured using the MARC Resin Calibrator (BlueLight Analytics, Halifax, NS, Canada) in the standard light-curing mode from the positioning of the tip of the LCU at 0 mm from the top sensor during testing five measurements times of 40 seconds each one. The energy density or radiant exposure (J/cm²) was obtained by multiplying the irradiance (mW/cm²) by the exposure time (seconds). The emission spectrum (mW/nm) was obtained by dividing the spectral irradiance (mW/cm²/nm) by the wavelength (nm) as previously described (Price; Shortall; Ferracane, 2015).

Beam Profile

Light beam profiles were evaluated using a Laser Beam Profiler (Ophir-Spiricon, Logan, UT, USA) with a charge-coupled device (CCD) digital camera with a 50-mm focal distance lens (SP928, Ophir-Spiricon, Logan, UT, USA). Two blue filters (HOYA UV-VIS colored glass bandpass filters, Edmund Optics, Barrington, NJ, USA) were used to plan the spectral response of the CCD camera. LEDs were positioned at a fixed distance from the diffusi glass target (60-degree holographic screen, Edmund Optics, Barrington, NJ, USA). All images were obtained with the same characteristics, making the images comparable. The bi-dimensional images were collected using the beam analyzer software (BeamGage Professional version 6.14, Ophir-Spiricon, Logan, UT, USA).

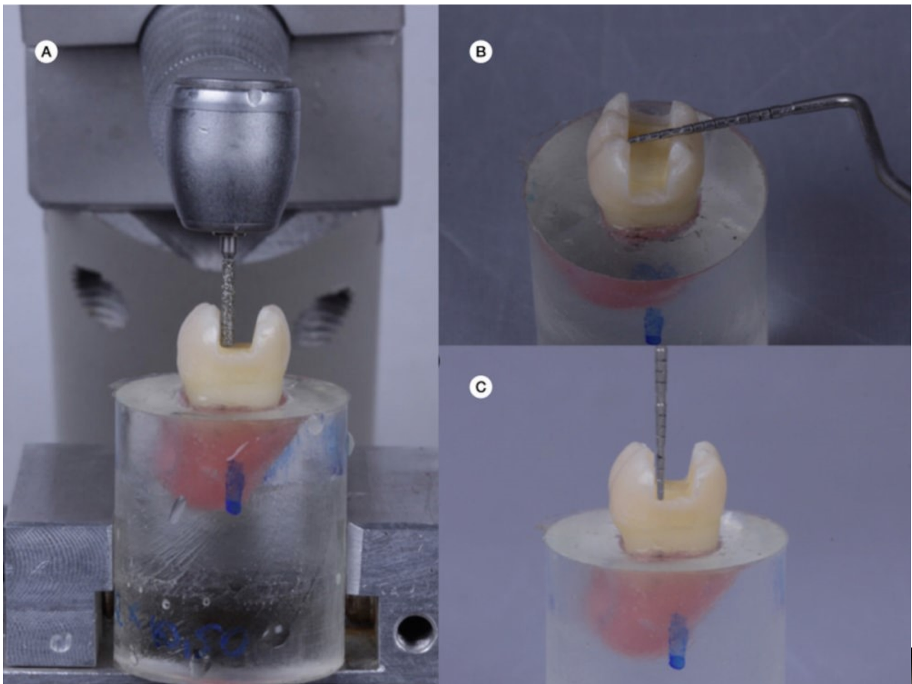
Depth of cure, Microhardness, and Elastic Modulus assessment

Twenty-five extracted intact caries-free human mandibular molars were obtained at the Dental Clinic of the School of Dentistry, Federal University of Goias, after approval of the local Ethics Committee in Human Research (CAAE 25583719.4.0000.5083). The molars had a mesial-distal width of 10 mm and a buccal-lingual width of 11mm (maximum deviation of 10%). The teeth had their roots covered with melted wax (Lysanda, São Paulo, SP, Brazil) and they were positioned individually in plastic cylinders (Tigre, Joinville, SC, Brazil), which were embedded in polystyrene resin (Polipox, São Paulo, SP, Brazil). The number of samples was based on a previous study (Haenel *et al.*, 2015).

Standard class II MOD cavities were prepared with diamond burs #3099 (KG Sorensen, Cotia, SP, Brazil), 4 mm depth from the highest cusp and 4 mm wide (buccal-lingual), with a preparation machine using a high-speed handpiece (Kavo, Joinville, SC, Brazil) (Figure 2A). Depth was measured with a millimeter probe (Golgran, São Caetano do Sul, SP, Brazil) along the entire length of the occlusal cavity. Depth was standardized from the highest molar cusp. (Figure 2B/2C). The teeth were etched with 35% phosphoric acid (Ultra-etch, Ultradent Products, South Jordan, UT, USA), and the Scothbond Multi-Purpose (3M Oral Care, St Paul, MN, USA) was applied following the manufacturer's instructions. The teeth were divided according to each LCU group (n=5). Each LCU was fully charged before the restorative procedure. The restorations were made using an incremental filling technique with the Filtek Supreme (A2E shade, 3M Oral Care, St Paul, MN, USA) and light-activated for 40 seconds in the center of the specimens.

Each specimen was sectioned in the buccal-lingual direction into two halves using a precision saw (Labcut 1010, Extec, Enfield, CT, USA). One was randomly selected for the Knoop microhardness and Elastic modulus tests and embedded in epoxy resin (Polipox, São Paulo, SP, Brazil). The teeth/restoration surface was finished with silicon-carbide papers (#600 grit – 5 minutes, #1200 grit – 10 minutes, and # 2000 grit – 10 minutes) and polished with metallographic diamond pastes (3, 1, and ¼- µm for 3 minutes each (Arotec, São Paulo, SP, Brazil).

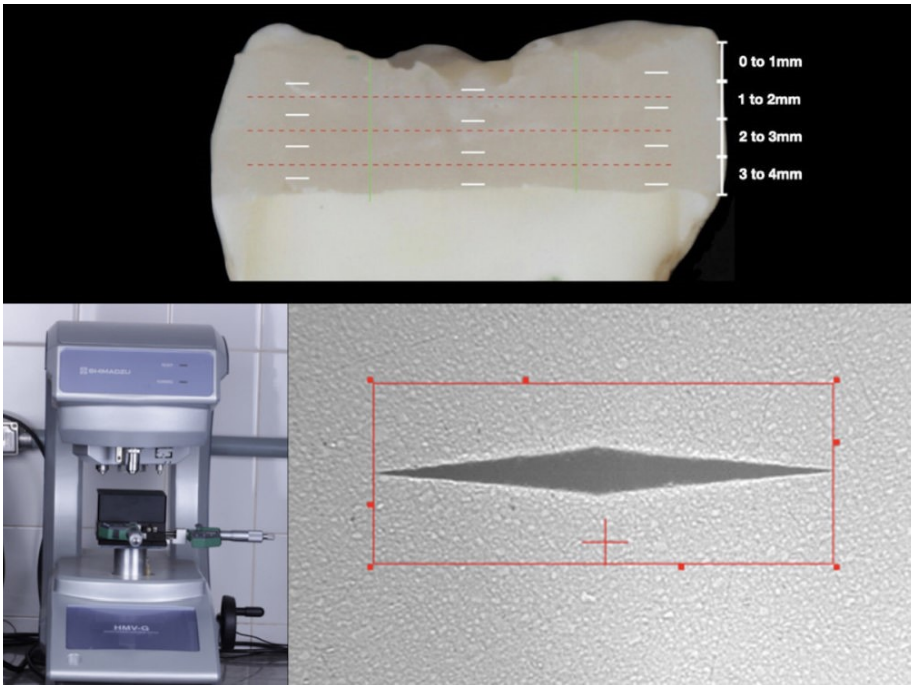
Figure 2 – Sample preparation. A) Preparation machine for sample preparation. B) Cavity measurement by width based on the highest cusp. C) Cavity measurement by 4mm depth



REPES
REVISTA DE ENSINO, PESQUISA E EXTENSÃO EM SAÚDE

Twelve indentations per specimen were performed using a Knoop tip (500g for 15 s - Shimadzu Microhardness Tester HMV G20, Tokyo, Japan). These indentations were made at 1 mm intervals from 1 mm to 4 mm, and measured from the occlusal surface of the restorations, and repeated at the mesial, center, and distal regions to obtain an average value (Figure 3). Besides the microhardness values, the Knoop indentations (large and small diagonals) were also used to determine the elastic modulus. The decrease in the length of the indentation diagonals caused by the elastic recovery of a material is related to the hardness/modulus ratio (H/E) and calculated using the equation: $b'/a' = b/a - (H/E)$. The equation relates the elastic recovery parameters, b'/a', with the relationship imposed by the geometry of the Knoop impression, $b/a = 0.1406$ and the constant $\alpha = 0.45$ obtained by linear interpolation, proposed by Marshall. Where b' = minor diagonal of the indentation, a' = major diagonal of the indentation, H = Knoop microhardness number and E = elastic modulus (Dewaele *et al.*, 2009; Marshall; Noma; Evans, 1982).

Figure 3 – Model of indentations along the samples



Statistical analysis

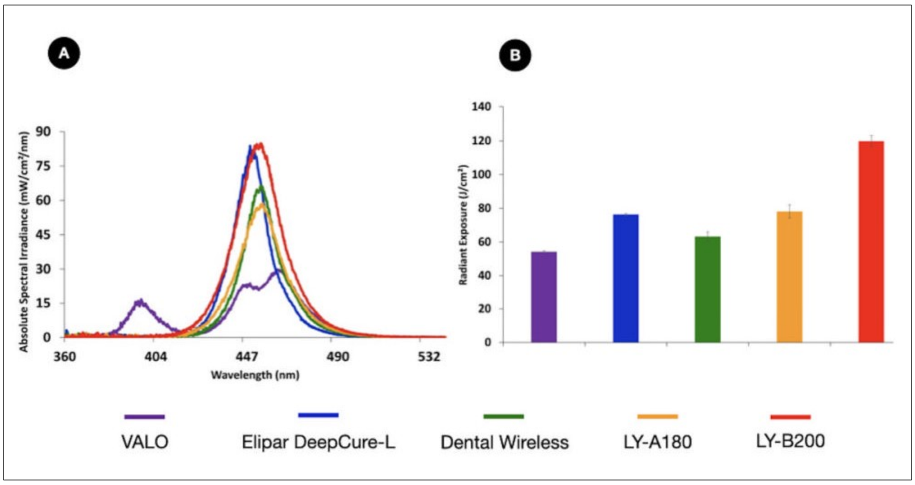
Knoop microhardness and elastic modulus data (depth of cure) were submitted to the Shapiro-Wilk test and equality of variance (Levene test). ANOVA was performed with a split-plot arrangement with one plot defined as the LCUs and the depth of restoration (1, 2, 3, 4 mm) defined as a subplot. Tukey HSD test was used for multiple comparisons between groups. Multiple linear regression analysis evaluated the influence of elastic modulus and irradiance on the Knoop microhardness values and the influence of depth of restoration and irradiance on the elastic modulus and Knoop microhardness. Analyzes were carried out using SPSS 15.0 for Windows program (SPSS Inc, Chicago, Illinois, USA) with a probability level set at 95% ($p < 0.05$). Irradiance, emission spectrum, radiant exposure, and beam profile were qualitatively analyzed.

RESULTS

Irradiance, Emission Spectrum, and Beam Profile Emitted by Different LCUs

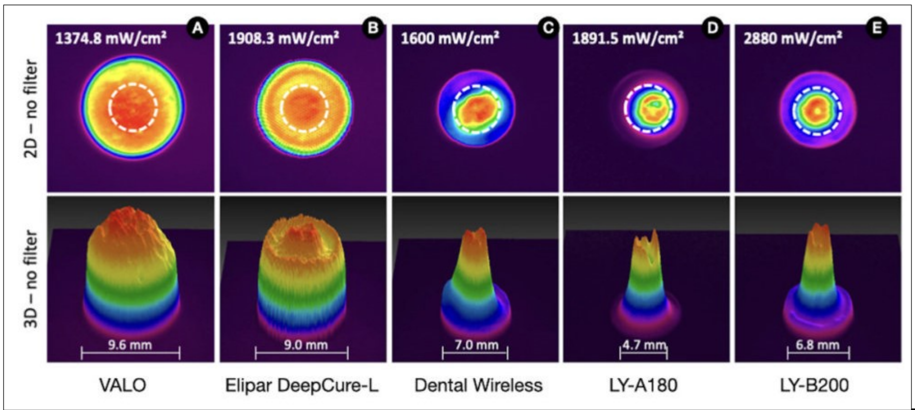
Emission spectrum (mW/cm²/nm) and radiant exposure (J/cm²) are shown in Figure 4 and were different in the LCUs tested. All LCUs were monowave, except VALO which was a polywave unit. LY-B200 had the higher radiant exposure. Radiant exitance (tip irradiance in mW/cm²), tip diameters (mm), and calibrated 2D and 3D beam profiles of the LCUs are reported in Figure 5. VALO showed a lower irradiance. The effective tip diameters of the lower-cost LCUs were lower than those of the control groups, ranging from 4.7mm to 7.0mm.

Figure 4 – Emission spectrum (mW/nm) and radiant exposure (J/cm^2) from the tested LCUs



Each LCU had its unique scale standardized for the maximum irradiance value. The lower-cost LCUs showed a non-uniform distribution of light across the optical tip. All LCUs also delivered the greatest radiant exitance very close to the center of their tip. VALO and Elipar DeepCure-L showed a more homogenous radiant exitance across a larger area of the optical tip compared with the other units tested.

Figure 5 – 2D and 3D Beam profiles from the LCUs showing the tip diameter and averaged radiant exitance (tip irradiance in mW/cm^2). Abbreviations 2D, two-dimensional; 3D, three-dimensional. Note the regions of nonuniform output delivered by the budget LCUs (C, D, and E) in contrast with the homogeneous output delivered by the LCUs produced by the major manufacturers (A and B)



Depth of cure

Knoop microhardness mean values (SD) and the results of the Tukey test are shown in Table 2. ANOVA with a split-plot arrangement showed that LCUs (p=.003) and restoration depth (p<.001) were significant, but the interaction between them was not (p=.975). VALO provided higher Knoop microhardness values than Dental Wireless (p=.009) and LY-A180 (p=.006). Elipar DeepCure-L and LY-B200 were statistically equal to VALO, Dental Wireless, and LY-A180 (p>.005). 1mm depth (near the occlusal surface) had the highest values of Knoop microhardness. Lower values were observed for 4mm depth.

Table 2 – Knoop hardness mean values (SD) and Tukey test results (HSD)

Depth of Restoration	VALO Cordless (SD)	Elipar DeepCure-L (SD)	Dental Wireless (SD)	LY-A180 (SD)	LY-B200 (SD)	Pooled average
1mm	78.0 (1.6)	76.6 (1.3)	75.2 (1,3)	75.2 (1.2)	75.9 (1.7)	76.2 (1.7) a
2mm	77.6 (0.3)	76.3 (1.0)	75.2 (0.6)	74.6 (1.5)	75.9 (2.0)	75.9 (1.5) a
3mm	77.2 (1.4)	76.3 (1.0)	73.5 (0.8)	74.3 (2.7)	75.4 (1.5)	75.3 (2.0) a
4mm	75.8 (1.3)	75.2 (1.0)	72.4 (1.4)	72.8 (3.4)	73.5 (3.0)	74.1 (2.4) b
Pooled average	77.1 (1.4) A	76.1 (1.1) AB	74.3 (1.3) B	74.2 (2.4) B	75.2 (2.2) AB	

Different upper letters indicate difference in the columns. Different lower letters indicate difference in the lines (p <0.05).

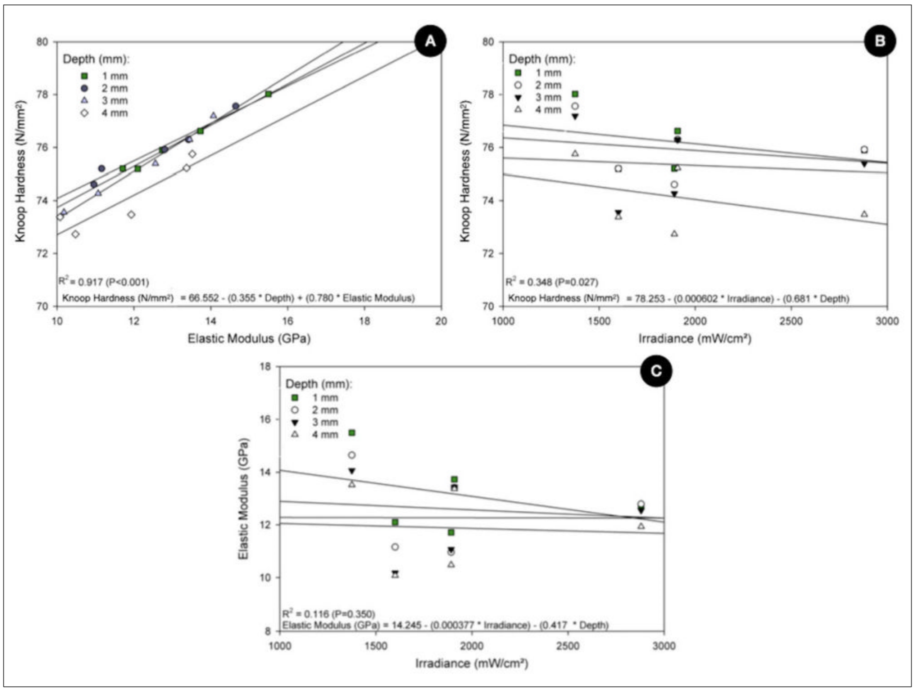
Elastic moduli mean values (SD) and the results of the Tukey test are shown in Table 3. ANOVA with a split-plot arrangement showed that LCUs (p<.001) and restoration depth (p<.001) were significant but the interaction between them was not (p=.120). VALO had the highest elastic modulus value through the restoration. Dental Wireless and LY-A180 had the lowest values and were statistically similar (p=.967). 1mm depth had the highest values of Elastic Modulus, 2mm and 3mm depth were similar (p=.300) and 4mm depth was the lower.

Multiple Linear Regression Analysis

Multiple linear regression analysis between variables: Elastic modulus, Knoop microhardness, Irradiance, and depth of restoration are shown in Figure 6. The analysis between Knoop microhardness, Elastic modulus, and depth of restoration was significant (p<.001) and showed that Knoop microhardness was correlated to Elastic modulus (R^2=.917) (Fig 6A). The analysis showed that Elastic modulus exhibited more influence on Knoop microhardness (β_2=.780) than the depth of restoration (β_1=.355) (Fig. 6A). Multiple linear regression between Knoop microhardness, Irradiance, and depth of restoration was significant (p=.027) and showed that Knoop microhardness had a weak correlation to irradiance (R^2=.348) (Fig 6B). Knoop microhardness values were more influenced by the depth of restoration (β_2=.681) than irradiance (β_1=.000602). The relation between Elastic modulus, Irradiance, and depth of restoration was not significant (p=.350) (Fig 6C).

REPES
REVISTA DE ENSINO, PESQUISA E EXTENSÃO EM SAÚDE

Figure 6 – Multiple linear regression analysis. A) Multiple linear regression model between the Knoop hardness and Elastic modulus (R^2=0.917; p<.001); B) Multiple linear regression model between the Knoop hardness and irradiance (R^2=0.348; p=.027); C) Multiple linear regression model between the Elastic modulus and irradiance (R^2=0.116; p=.350)



DISCUSSION

Nowadays, a wide range of LCUs is available for online shopping across several platforms, whether specifically designed for the dental market or not, and often offered at highly competitive prices. However, the legislation governing the production and regulation of these devices varies among countries, and it may lead to many entering dental offices without undergoing comprehensive safety and efficacy tests or even receiving proper approval from competent health authorities (Price, 2017). Evaluation of irradiance, emission spectrum, radiant exposure, and beam profile among the LCUs are important clinical parameters, usually not provided. The null hypothesis tested was rejected since there were differences between these parameters. Although all the LCUs had satisfactory irradiance, this is not sufficient to affirm that the LCUs are satisfactory for use (Price; Shortall; Palin, 2014; Price, 2017).

The lower-cost LCUs tested presented the peak of absorption of the camphorquinone exactly at 470 nm, while the Elipar DeepCure-L and VALO were not at this value (Figure 4). Although all of them presented satisfactory absorption, this is valid for composite resins containing camphorquinone, and materials presenting different photoinitiators might not be properly cured using the lower-cost units tested in this study. This is the kind of information that must be presented in the user's guide for better inform the dentist regarding the limitation or range of composites that can be used with the product. The introduction of polywave LCUs in dentistry was made in attempting to include devices with wider spectral output ranges, enabling greater options for the absorption of photoinitiators of different wavelengths when compared to monowave LCUs (Jandt; Mills, 2013; Price; Shortall; Ferracane, 2015).

The LY-B200 radiant exposure was significantly higher among the LCUs with smaller tip diameter (Figure 4 and Figure 5). Price (2017) showed that, usually, lower-cost LCUs have smaller diameter tips than higher-cost ones. The divergence between a higher energy density and a small diameter tip can lead to non-uniform polymerization of RBCs, and elevated radiant exposure may increase their polymerization shrinkage stress (Feitosa *et al.*, 2012). The beam profile is used to characterize irradiance distribution across the entire tip diameter. Our results, as shown in Figure 5, corroborate with previous findings indicating that lower-cost LCUs concentrate light beams in the center of the tips, reducing the tip diameter to achieve the minimum necessary irradiance (Alshaafi *et al.*, 2016). Although all the LCUs had satisfactory irradiance, the irradiance value provides limited information about the effectiveness and is not sufficient to decide on a unit for use (Dewaele *et al.*, 2009; Price, 2017). In our study, the LCUs used as control groups showed a more homogenous light distribution across a larger area of the optical tip, following previous findings in the literature (Feitosa *et al.*, 2012). This may allow a more homogeneous polymerization in a higher area, decreasing the necessity for multiple exposures in larger restorations (Alshaafi *et al.*, 2016; Vandewalle; Roberts; Rueggeberg, 2008).

The lower-cost LCUs tested showed a non-uniform light distribution across the entire tip on the beam profile. This could interfere with the energy dose received by the composite resulting in a non-satisfactory polymerization (Price; Shortall; Ferracane, 2015). The lower-cost LCUs tested delivered the light next to the center of the optical tips and these results are in accordance with other studies that showed that usually lower-cost devices show a higher radiant exitance in the center of the optical tip (Alshaafi *et al.*, 2016; Price, 2017). When the light is distributed across the entire tip it allows a better and more uniform polymerization in a larger area, while a light more centralized results in a non-uniform polymerization (Haenel *et al.*, 2015; Price; Shortall; Ferracane, 2015). This situation can bring several disadvantages, such as interference with the resin's mechanical properties, microhardness, polymerization stress, and restoration failure (André *et al.*, 2018; Haenel *et al.*, 2015; Price; Shortall; Ferracane, 2015; Rueggeberg; Caughman; Curtis Junior, 1994; Yearn, 1985). It is worth mentioning that dentists cannot measure the light distribution of their devices in their offices, using radiometers, for example. Inputting this information and the bean profile of the equipment on the user guide would be very beneficial in terms of information and a better decision-making process during the acquisition of equipment.

The second hypothesis was also rejected since ANOVA with a split-plot arrangement showed that the LCUs and restoration depth were significantly different. Depth of cure tests by Knoop microhardness are used to evaluate the performance of the LCUs (Price; Shortall; Palin, 2014; Vandewalle; Roberts; Rueggeberg, 2008) lights and the quality of the resin polymerized (Price *et al.*, 2010b). Results showed that the occlusal surface had higher Knoop microhardness values (1mm) than the bottom surfaces (4mm). This happened because occlusal surfaces were next to the optical tip, being areas of high-intensity exposure. This situation creates a significant number of free radicals allowing a higher polymerization in the region when compared to the regions with lower exposure (Soares et al., 2017; Vandewalle; Roberts; Rueggeberg, 2008). A study conducted by Dewaele *et al.* (2009) showed that the distance from the optical tip to the occlusal surface can interfere with polymerization, creating a non-satisfactory quality in the formed polymeric chain (Dewaele *et al.*, 2009; Feitosa *et al.*, 2012; Price, 2017). Elastic modulus and microhardness are related (Marshall; Noma; Evans, 1982) since they identify the relation between resin and light performance. However, the microhardness evaluation does not provide information on resistance to shear, the possibility of fractures, stress after restoration, stress analysis, and, mainly, the degree of conversion by the analysis of free radicals and quality of polymers formed during photopolymerization and amount of free radical's polymerization (Calheiros *et al.*, 2006; Dewaele *et al.*, 2009).

According to the literature, composite areas receiving higher irradiance usually exhibit enhanced polymerization and mechanical properties, which is in agreement with the present results (Table 3) that demonstrated higher elastic modulus on the composite surface in closer contact with the tip of LCU device in comparison to those located a few millimeters further away of its (Magalhães Filho *et al.*, 2016). The results suggest a certain proximity between the values of microhardness and the elastic modulus obtained regardless of the type of light-curing unit tested. The values of microhardness found in this study are inferior to the values found in the literature (Ritter *et al.*, 2006). Lower-cost LCUs showed lower values when compared to certified ones. This can be explained by Price 2017, which suggests the need for successive light curing along an area so that light curing occurs in the entire sample.

Table 3 – Elastic Modulus mean values (SD) and Tukey test results (HSD)

Depth of restoration	VALO Cordless (SD)	Elipar DeepCure-L (SD)	Dental Wireless (SD)	LY-A180 (SD)	LY-B200 (SD)	Pooled average
1mm	15.5 (0.8)	13.7 (0.9)	12.1 (1.2)	11.7 (0.4)	12.7 (0.8)	13.1 (1.6) a
2mm	14.7 (0.4)	13.4 (0.3)	11.2 (1.0)	11.0 (0.3)	12.8 (0.6)	12.6 (1.5) b

Depth of restoration	VALO Cordless (SD)	Elipar DeepCure-L (SD)	Dental Wireless (SD)	LY-A180 (SD)	LY-B200 (SD)	Pooled average
3mm	14.1 (0.6)	13.4 (0.3)	10.2 (0.9)	11.1 (0.4)	12.6 (1.0)	12.3 (1.6) bc
4mm	13.7 (0.7)	13.4 (0.3)	10.2 (0.9)	10.5 (0.4)	11.9 (0.7)	11.9 (1.6) c
Pooled average	14.5 (0.9) A	13.5 (0.5) B	10.9 (1.3) D	11.0 (0.6) D	12.5 (0.8) C	

Different upper letters indicate difference in the columns. Different lower letters indicate difference in the lines ($p < 0.05$).

The first graph of multiple linear regression comparison shows a high relation between elastic modulus and Knoop microhardness (R^2=.917), but the relation between elastic modulus and depth of restoration was not satisfactory. The relation between elastic modulus and Knoop microhardness is widely known (Marshall; Noma; Evans, 1982) and is in agreement with this study. While hardness represents the mechanical resistance of the material in relation to penetration and wear, the elastic modulus is the elastic stiffness of the material and presents the ability of a material to resist deformation through masticatory stresses. These properties are not sufficient to characterize a material as satisfactory or not for use (El-Safty *et al.*, 2012). However, the non-relation between elastic modulus and depth of restoration can be explained by the quality of the polymer chain made during the curing process (Dewaele *et al.*, 2009; Michaud *et al.*, 2014).

Although some studies have shown that the interaction between Knoop microhardness and irradiance exists (Price; Shortall; Palin, 2014; Price; Shortall; Ferracane, 2015; Vandewalle; Roberts; Rueggeberg, 2008), surprisingly, the present study showed that microhardness and depth-of-cure (p<.001) were not directly associated with LCUs irradiance (p=0.100). Although unusual, this lack of association between these properties might be explained by the fact that all the LCUs were placed in the center of the samples. As most of the low-cost LCUs have a light tip diameter relatively smaller than most of the high-cost LCUs, this allowed the light beam of those low-cost devices to be very focused on the very center of the samples. Accordingly, as the microhardness test was done on the whole sample surface, the results may have been interfered by the non-uniform light distribution throughout the entire sample and by the variety of the LCUs evaluated (Haenel *et al.*, 2015; Vandewalle; Roberts; Rueggeberg, 2008).

The elastic modulus is associated with the mechanical properties of the RBC, and Figure 6 shows no association between elastic modulus, depth of restoration and irradiance (p=0.350). The non-association between these factors occurred because Filtek Supreme is a nanoparticle composite with inorganic filler presenting greater distribution and contact area with the organic matrix. This structure requires satisfactory irradiance to perform adequate polymerization at a given depth of restoration. If a satisfactory irradiance distribution does not exist, it becomes difficult to have a proper polymerization. The microhardness value may decrease if a resin-based material is not well polymerized. As the light from the curing units loses intensity as the depth of a restoration increases, at greater depths, the microhardness values also tend to decrease in regions far from the tip of the unit, and this is exemplified in Figure 3. The same concept happens with the elastic modulus, obtained in this study using the method described by Marshall, Noma and Evans (1982). This relationship between microhardness, elastic modulus and the performance of the light curing units had already been presented in the literature (Grazioli *et al.*, 2022), showing that the radiant exposure and irradiance have a significant effect on the following chemical–mechanical performance of a resin composite: depth of cure, degree of polymerization, flexural strength, and elastic modulus. Other studies also showed the relationship between the light curing units and the mechanical properties of the resin composites (Correr-Sobrinho *et al.*, 2000; Ferracane, 1985; Grazioli *et al.*, 2022; Stansbury, 2012).

The result of our study raises the importance of testing LCUs before they are made available for sale. Information about the characteristics, irradiance, radiant exposure, and beam profile could help dental professionals to choose the best LCU and reduce the frequency of undercured restorative material, improving the chance of having a successful restoration. The clinician should always keep in mind that dental instruments should not only be effective for what they are designed for but do so within a safe and standardized fashion.

CONCLUSION

Within the limitations of this current study, it was concluded that:

1. When all the variables of the LCUs were compared, the lower-cost LCUs tested had a satisfactory irradiance value, but the beam profile was highly non-uniform.
2. They also presented a small tip diameter without light distribution across the entire tip.
3. These are factors that can interfere with resin polymerization.
4. Knoop microhardness and elastic modulus decreased as the depth of restoration increased.

REFERENCES

ALSHAAFI, M. M.; HARLOW, J. E.; PRICE, H. L.; RUEGGEBERG, F. A.; LABRIE, D.; ALQAHTANI, M. Q.; PRICE, R. B. Emission characteristics and effect of battery drain in “budget” curing lights. **Operative Dentistry**, Seattle, vol. 41, no. 4, p. 397-408, 2016. DOI: https://doi.org/10.2341/14-281-L. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/41/4/article-p397.xml. Accessed on: aug. 17, 2026.

ANDRÉ, C. B.; NIMA, G.; SEBOLD, M.; GIANNINI, M.; PRICE, R. B. Stability of the light output, oral cavity tip accessibility in posterior region and emission spectrum of light-curing units. **Operative Dentistry**, Seattle, vol. 43, no. 4, p. 398-407, 2018. DOI: https://doi.org/10.2341/17-033-L. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/43/4/article-p398.xml. Accessed on: aug. 17, 2026.

CALHEIROS, F. C.; KAWANO, Y.; STANSBURY, J. W.; BRAGA, R. R. Influence of radiant exposure on contraction stress, degree of conversion and mechanical properties of resin composites. **Dental Materials**, Amsterdam, vol. 22, no. 9, p. 799-803, 2006. DOI: https://doi.org/10.1016/j.dental.2005.11.008. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564105002915?via%3Dihub. Accessed on: aug. 17, 2026.

CORRER-SOBRINHO, L.; GOES, M. F.; CONSANI, S.; SINHORETI, M. A. C.; KNOWLES, J. C. Correlation between light intensity and exposure time on the hardness of composite resin. **Journal of Materials Science**: Materials in Medicine, Dordrecht, vol. 11, no. 6, p. 361-364, 2000. DOI: https://doi.org/10.1023/A:1008981907601. Available at: https://link.springer.com/article/10.1023/A:1008981907601. Accessed on: aug. 17, 2026.

DEWAELE, M.; ASMUSSEN, E.; PEUTZFELDT, A.; MUNKSGAARD, E. C.; BENETTI, A. R.; FINNÉ, G.; LELOUP, G.; DEVAUX, J. Influence of curing protocol on selected properties of light-curing polymers: degree of conversion, volume contraction, elastic modulus, and glass transition temperature. **Dental Materials,** Amsterdam, vol. 25, no. 12, p. 1576-1584, 2009. DOI: https://doi.org/10.1016/j.dental.2009.08.001. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564109002681?via%3Dihub. Accessed on: aug. 17, 2026.

EL-SAFTY, S.; AKHTAR, R.; SILIKAS, N.; WATTS, D. C. Nanomechanical properties of dental resin-composites. **Dental Materials**, Amsterdam, vol. 28, no. 12, p. 1292-1300, 2012. DOI: https://doi.org/10.1016/j.dental.2012.09.007. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564112004083?via%3Dihub. Accessed on: aug. 17, 2026.

EMMLER, J.; SEISS, M.; KREPPEL, H.; REICHL, F. X.; HICKEL, R.; KEHE, K. Cytotoxicity of the dental composite component TEGDMA and selected metabolic by-products in human pulmonary cells. **Dental Materials**, Amsterdam, vol. 24, no. 12, p. 1670-1675, 2008. DOI: https://doi.org/10.1016/j.dental.2008.04.001. Available at: https://www.sciencedirect.com/science/article/abs/pii/S010956410800105X?via%3Dihub. Accessed on: aug. 17, 2026.

FEITOSA, V. P.; FUGOLIN, A. P. P.; CORRER, A. B.; CORRER-SOBRINHO, L.; CONSANI, S.; WATSON, T. F.; SINHORETI, M. A. C.; SAURO, S. Effects of different photo-polymerization protocols on resin-dentine µTBS, mechanical properties and cross-link density of a nano-filled resin composite. **Journal of Dentistry**, Amsterdam, vol. 40, no. 10, p. 802-809, 2012. DOI: https://doi.org/10.1016/j.jdent.2012.05.014. Available at: https://doi.org/10.1016/j.jdent.2012.05.014. Accessed on: aug. 17, 2026.

FERRACANE, J. L. Correlation between hardness and degree of conversion during the setting reaction of unfilled dental restorative resins. **Dental Materials**, Amsterdam, vol. 1, no. 1, p. 11-14, 1985. DOI: https://doi.org/10.1016/S0109-5641(85)80058-0. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0300571212001455?via%3Dihub. Accessed on: aug. 17, 2026.

FERRACANE, J. L.; MOSER, J. B.; GREENER, E. H. Ultraviolet light-induced yellowing of dental restorative resins. **The Journal of Prosthetic Dentistry**, St. Louis, vol. 54, no. 4, p. 483-487, 1985. DOI: https://doi.org/10.1016/0022-3913(85)90418-4. Available at: https://www.thejpd.org/article/0022-3913(85)90418-4/abstract. Accessed on: aug. 17, 2026.

GRAZIOLI, G.; CUEVAS-SUÁREZ, C. E.; MEDEROS, M.; DE LEON, E.; GARCIA, A.; ZAMARRIPA-CALDERÓN, E.; PIVA, E. Evaluation of irradiance and radiant exposure on the polymerization and mechanical properties of a resin composite. **Brazilian Oral Research**, São Paulo, vol. 36, e082, 2022. DOI: https://doi.org/10.1590/1807-3107bor-2022.vol36.0082. Available at: https://www.scielo.br/j/bor/a/mFst9f765YhpQrvh8JHvcGm/?lang=en. Accessed on: aug. 17, 2026.

HAENEL, T.; HAUSNEROVÁ, B.; STEINHAUS, J.; PRICE, R. B. T.; SULLIVAN, B.; MOEGINGER, B. Effect of the irradiance distribution from light curing units on the local micro-hardness of the surface of dental resins. **Dental Materials**, Amsterdam, vol. 31, no. 2, p. 93-104, 2015. DOI: https://doi.org/10.1016/j.dental.2014.11.003. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564114006551?via%3Dihub. Accessed on: aug. 17, 2026.

IMAZATO, S.; TARUMI, H.; KOBAYASHI, K.; HIRAGURI, H.; ODA, K.; TSUCHITANI, Y. Relationship between the degree of conversion and internal discoloration of light-activated composite. **Dental Materials** Journal, Tokyo, vol. 14, no. 1, p. 23-30, 1995. DOI: https://doi.org/10.4012/dmj.14.23. Available at: https://www.jstage.jst.go.jp/article/dmj1982/14/1/14_1_23/_article. Accessed on: aug. 17, 2026.

JANDT, K. D.; MILLS, R. W. A brief history of LED photopolymerization. **Dental Materials**, Amsterdam, vol. 29, no. 6, p. 605-617, 2013. DOI: https://doi.org/10.1016/j.dental.2013.02.003. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564113000328?via%3Dihub. Accessed on: aug. 17, 2026.

JANDT, K. D.; MILLS, R. W.; BLACKWELL, G. B.; ASHWORTH, S. H. Depth of cure and compressive strength of dental composites cured with blue light-emitting diodes (LEDs). **Dental Materials**, Amsterdam, vol. 16, no. 1, p. 41-47, 2000. DOI: https://doi.org/10.1016/S0109-5641(99)00083-4. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564199000834?via%3Dihub. Accessed on: aug. 17, 2026.

MAGALHÃES FILHO, T. R.; WEIG, K. M.; COSTA, M. F.; WERNECK, M. M.; BARTHEM, R. B.; COSTA NETO, C. A. Effect of LED-LCU light irradiance distribution on mechanical properties of resin based materials. **Materials Science and Engineering**: C, Amsterdam, vol. 63, p. 301-307, 2016. DOI: https://doi.org/10.1016/j.msec.2016.02.060. Available at: https://www.sciencedirect.com/science/article/pii/S0928493116301527?via%3Dihub. Accessed on: aug. 17, 2026.

MARSHALL, D. B.; NOMA, T.; EVANS, A. G. A simple method for determining elastic-modulus-to-hardness ratios using Knoop indentation measurements. **Journal of the American Ceramic Society**, Hoboken, vol. 65, no. 10, p. C175-C176,

1982. DOI: https://doi.org/10.1111/j.1151-2916.1982.tb10357.x. Available at: https://ceramics.onlinelibrary.wiley.com/doi/10.1111/j.1151-2916.1982.tb10357.x. Accessed on: aug. 17, 2026.

MICHAUD, P. L.; PRICE, R. B. T.; LABRIE, D.; RUEGGEBERG, F. A.; SULLIVAN, B. Localised irradiance distribution found in dental light curing units. **Journal of Dentistry**, Amsterdam, vol. 42, no. 2, p. 129-139, 2014. DOI: https://doi.org/10.1016/j.jdent.2013.11.014. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0300571213003114?via%3Dihub. Accessed on: aug. 17, 2026.

PRICE, R. B. T.; LABRIE, D.; RUEGGEBERG, F. A.; FELIX, C. M. Irradiance differences in the violet (405 nm) and blue (460 nm) spectral ranges among dental light-curing units. **Journal of Esthetic and Restorative Dentistry**, Hoboken, vol. 22, no. 6, p. 363-377, 2010a. DOI: https://doi.org/10.1111/j.1708-8240.2010.00368.x. Available at: https://onlinelibrary.wiley.com/doi/10.1111/j.1708-8240.2010.00368.x. Accessed on: aug. 17, 2026.

PRICE, R. B. T.; RUEGGEBERG, F. A.; LABRIE, D.; FELIX, C. M. Irradiance uniformity and distribution from dental light curing units. **Journal of Esthetic and Restorative Dentistry**, Hoboken, vol. 22, no. 2, p. 86-101, 2010b. DOI: https://doi.org/10.1111/j.1708-8240.2010.00318.x. Available at: https://onlinelibrary.wiley.com/doi/10.1111/j.1708-8240.2010.00318.x. Accessed on: aug. 17, 2026.

PRICE, R. B.; SHORTALL, A. C.; PALIN, W. M. Contemporary issues in light curing. **Operative Dentistry**, Seattle, vol. 39, no. 1, p. 4-14, 2014. DOI: https://doi.org/10.2341/13-067-LIT. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/39/1/article-p4.xml. Accessed on: aug. 17, 2026.

PRICE, R. B. T.; FERRACANE, J. L.; SHORTALL, A. C. Light-curing units: a review of what we need to know. **Journal of Dental Research**, Thousand Oaks, vol. 94, no. 9, p. 1179-1186, 2015. DOI: https://doi.org/10.1177/0022034515594786. Available at: https://journals.sagepub.com/doi/10.1177/0022034515594786. Accessed on: aug. 17, 2026.

PRICE, R. B. T. Light curing in dentistry. **Dental Clinics of North America**, Philadelphia, vol. 61, no. 4, p. 751-778, 2017. DOI: https://doi.org/10.1016/j.cden.2017.06.008. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0011853217300745?via%3Dihub. Accessed on: aug. 17, 2026.

RITTER, A. V.; CAVALCANTE, L. M.; SWIFT JUNIOR, E. J.; THOMPSON, J. Y.; PIMENTA, L. A. F. Effect of light-curing method on marginal adaptation, microleakage, and microhardness of composite restorations. **Journal of Biomedical Materials Research Part B: Applied Biomaterials**, Hoboken, vol. 78B, no. 2, p. 302-311, 2006. DOI: https://doi.org/10.1002/jbm.b.30488. Available at: https://onlinelibrary.wiley.com/doi/10.1002/jbm.b.30488. Accessed on: aug. 17, 2026.

RUEGGEBERG, F. A.; CAUGHMAN, W. F.; CURTIS JUNIOR, J. W. Effect of light intensity and exposure duration on cure of resin composite. **Operative Dentistry**, Seattle, vol. 19, no. 1, p. 26-32, 1994. PMID: 8183730. Available at: https://pubmed.ncbi.nlm.nih.gov/8183730/. Accessed on: aug. 17, 2026.

RUEGGEBERG, F. A.; GIANNINI, M.; ARRAIS, C. A. G.; PRICE, R. B. T. Light curing in dentistry and clinical implications: a literature review. **Brazilian Oral Research**, São Paulo, vol. 31, suppl. 1, e61, 2017. DOI: https://doi.org/10.1590/1807-3107BOR-2017.vol31.0061. Available at: https://www.scielo.br/j/bor/a/nHcRprCrTjDnP7VMXh7PDBD/?lang=en. Accessed on: aug. 17, 2026.

SOARES, C. J.; RODRIGUES, M. P.; OLIVEIRA, L. R. S.; BRAGA, S. S. L.; BARCELOS, L. M.; SILVA, G. R.; GIANNINI, M.; PRICE, R. B. An evaluation of the light output from 22 contemporary light curing units. **Brazilian Dental Journal**, Ribeirão Preto, vol. 28, no. 3, p. 362-371, 2017. DOI: https://doi.org/10.1590/0103-6440201601466. Available at: https://www.scielo.br/j/bdj/a/SLdH9z5L7gW6pCYNWD5Hqhy/?lang=en. Accessed on: aug. 17, 2026.

SOARES, C. J.; FERREIRA, M. S.; BICALHO, A. A.; RODRIGUES, M. P.; BRAGA, S. S. L.; VERSLUIS, A. Effect of light activation of pulp-capping materials and resin composite on dentin deformation and the pulp temperature change. **Operative Dentistry**, Seattle, vol. 43, no. 1, p. 71-80, 2018. DOI: https://doi.org/10.2341/16-325-L . Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/43/1/article-p71.xml. Accessed on: aug. 17, 2026.

SOARES, C. J.; BRAGA, S. S. L.; PRICE, R. B. Relationship between the cost of 12 light-curing units and their radiant power, emission spectrum, radiant exitance, and beam profile. **Operative Dentistry**, Seattle, vol. 46, no. 3, p. 283-292, 2021. DOI: https://doi.org/10.2341/19-274-L. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/46/3/article-p283.xml. Accessed on: aug. 17, 2026.

STANSBURY, J. W. Dimethacrylate network formation and polymer property evolution as determined by the selection of monomers and curing conditions. **Dental Materials**, Amsterdam, vol. 28, no. 1, p. 13-22, 2012. DOI: https://doi.org/10.1016/j.dental.2011.09.005. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0109564111008335?via%3Dihub. Accessed on: aug. 17, 2026.

TICHY, A.; HOSAKA, K.; ABDOU, A.; NAKAJIMA, M.; TAGAMI, J. Degree of conversion contributes to dentin bonding durability of contemporary universal adhesives. **Operative Dentistry**, Seattle, vol. 45, no. 5, p. 556-566, 2020. DOI: https://doi.org/10.2341/19-165-L. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/45/5/article-p556.xml. Accessed on: aug. 17, 2026.

TONGTAKSIN, A.; LEEVAILOJ, C. Battery charge affects the stability of light intensity from light-emitting diode light-curing units. **Operative Dentistry**, Seattle, vol. 42, no. 5, p. 497-504, 2017. DOI: https://doi.org/10.2341/15-294-L. Available at: https://operative-dentistry.kglmeridian.com/view/journals/odnt/42/5/article-p497.xml. Accessed on: aug. 17, 2026.

VANDEWALLE, K. S.; ROBERTS, H. W.; RUEGGEBERG, F. A. Power distribution across the face of different light guides and its effect on composite surface microhardness. **Journal of Esthetic and Restorative Dentistry**, Hoboken, vol. 20, no. 2, p. 108-117, 2008. DOI: https://doi.org/10.1111/j.1708-8240.2008.00160.x. Available at: https://onlinelibrary.wiley.com/doi/10.1111/j.1708-8240.2008.00160.x. Accessed on: aug. 17, 2026.

YEARN, J. A. Factors affecting cure of visible light activated composites. **International Dental Journal**, London, vol. 35, no. 3, p. 218-225, 1985. PMID: 2932391. Available at: https://pubmed.ncbi.nlm.nih.gov/2932391/. Accessed on: aug. 17, 2026.