©Operative Dentistry, 2021, **46-1**, 63-74

# Effect of LED Light-Curing Spectral Emission Profile on Light-Cured Resin Cement Degree of Conversion

RQ Ramos • RR Moraes • GC Lopes

**Clinical Relevance**

The use of multipeak LED light-curing guarantees efficiency on light activation of Ivocerin-containing light-cured resin cement.


## SUMMARY

**Objectives: This study evaluated the degree of conversion (DC) of an Ivocerin-containing light-cured resin cement activated through different thicknesses of a lithium disilicate glass ceramic using two LED light-curing units (LCUs). It also evaluated the influence of the glass ceramic interposition on irradiance and the spectral emission profile of the LED LCUs.**

**Methods and Materials: Medium-translucency lithium disilicate glass ceramic specimens of 0.3-, 1.0-, and 2.0-mm thickness were heat pressed. A single-peak and a multipeak LED LCU were selected. Irradiance and spectral emission profile were assessed, the light transmittance was calculated, and the translucency parameter was determined for each thickness. DC was calculated after 20, 40, or 60 seconds of light activation by attenuated total reflection/Fourier-transform infrared spectroscopy. DC data were analyzed using three-way analysis of variance (ANOVA) and the Tukey honestly significant difference (HSD) test, irradiance and light transmittance data were analyzed using two-way ANOVA and the Tukey HSD. Spearman's correlation test was performed between the translucency parameter and light transmittance ($\alpha$=0.05).**

**Results: DC ranged from 71.1% to 80.1%, increasing significantly from light activation of 20 to 60 seconds. Irradiance ranged from 186.1 to 2013.5 mW/cm$^2$. Multipeak LED LCU showed higher DC and irradiance than single-peak LED LCU. Light transmittance ranged from 13.3% to 61.5%. Irradiance and light transmittance decreased as lithium disilicate glass ceramic thickness increased. The translucency parameter and light transmittance showed a significant correlation.**

**Conclusions: Multipeak LED LCU allows higher C=C conversion with shorter light activation time of Ivocerin-containing light-cured resin cement with an interposed medium-translucency lithium disilicate glass ceramic.**


Renato Q Ramos, DDS, MS, graduate student, Department of Dentistry, Federal University of Santa Catarina, Florianópolis, Brazil

Rafael R Moraes, DDS, MS, PhD, associate professor, Department of Dentistry, Federal University of Pelotas, Pelotas, Brazil

*Guilherme C Lopes, DDS, MS, PhD, associate professor, Department of Dentistry, Federal University of Santa Catarina, Florianópolis, Brazil

*Corresponding author: R Delfino Conti, 1240, Campus Trindade, Florianópolis, SC, Brazil;

e-mail: guilherme.lopes@ufsc.br

https://doi.org/10.2341/19-234-L

## INTRODUCTION

The demand for ceramic esthetic restorations has increased over the past years.[1-4] The continuous development of ceramic materials improves their indications of use and esthetics.[3,5-7] Among ceramic options, lithium disilicate glass ceramics are often the restorative material of choice since they combine fracture resistance and esthetics.[3,8,9] An innovative manufacturing technology was introduced in 2016, designed to further enhance the properties of lithium disilicate glass ceramics.[8,10] Described as high-density micronization, this process results in smaller crystals that are better distributed and in higher density in the glassy matrix, leading to a ceramic (GC Initial LiSi Press, GC Co, Tokyo, Japan) with better physical properties, superior esthetics, lower wear potential to antagonist teeth, and higher polishability compared to any other lithium disilicate glass ceramic.[8,10]

However, ceramic materials with excellent mechanical properties do not necessarily imply better clinical performance.[11,12] The success of ceramic restorations relies on the adhesion of the luting agent to tooth structure.[13,14] Resin-based cements are used to lute glass ceramic restorations.[11] The polymerization process of resin cements can be initiated by the application of a light source (light-cured resin cements), by a chemical redox reaction (chemical-cured resin cements), or by the combination of these two processes (dual-cured resin cements).[13,15,16] Light-cured resin cements have two major advantages: working time is controlled by clinicians, and better color stability is attained compared to both dual- and chemical-cured resin cements.[7,17] However, ceramic type[12,17-21] and its thickness,[4,12,13,17,22,23] translucency,[2,7,12,24] and color[23] may attenuate the light emitted by a light-curing unit (LCU). Thus, the light source must be powerful enough to be transmitted through the ceramic restoration and reach the resin cement with sufficient irradiance to carry out the polymerization process appropriately.[7,17,19,21,25,26]

One way of quantifying the polymerization of resin cements is to measure their degree of conversion (DC), which represents the percentage of monomers converted into polymers.[11,15] A high DC of resin cements has usually been linked to better physical and mechanical properties,[7,19,21,27] clinical performance,[7,23,27] biocompatibility,[16,28] color stability,[13] and adhesion to tooth structure[25] in addition to lower solubility in the oral environment.[13,24] Light activation can be achieved by many light sources,[1,29,30] but LED LCUs are currently the "gold standard" to perform this process.[29] Camphorquinone is the most common photoinitiator present in resin cements, with a light absorption spectrum ranging from about 425 to 495 nm and thus compatible with the spectral emission profile of LED LCUs.[26,29,30] However, materials formulated with camphorquinone tend to be slightly yellowish.[26,30,31] The search for resin composite materials with lighter colors has led manufactures to develop alternative photoinitiators to circumvent this limitation,[26] the most common being Lucirin TPO, PPD, and Ivocerin.[26,30] The counterpoint to using alternative photoinitiators is the occasional need for a shorter light wavelength than that emitted by a single-peak LED LCU (420 to 480 nm), also classified as a first- or second-generation LED LCU.[26,30] Recently, third-generation LED LCUs (also classified as multipeak LED LCUs) have been developed that have a broader spectral emission profile (390 to 490 nm) compared to single-peak LED devices.[26,29-31]

Ivocerin is a patented photoinitiator considered more reactive than camphorquinone with a light absorption spectrum ranging from about 390 to 445 nm (absorption peak at 408 nm).[30,32] It can be used alone, that is, without any additional coinitiator; this ensures better color stability of the materials that use it.[32,33] An example of a light-cured resin cement that contains this photoinitiator is Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein). For reasons of industrial protection, its manufacturer does not describe the entire formulation of this light-cured resin cement, omitting the types and concentrations of the photoinitiators. Therefore, the characteristics that the LED LCU should have to light activate this material are unclear.[30,34] To date, literature is scarce regarding the use of different LED LCUs in Ivocerin-containing light-cured resin cements as well as the interaction of the light produced by these LED LCUs with lithium disilicate glass ceramics. Thus, the objective of the present study was to evaluate the DC of an Ivocerin-containing light-cured resin cement light activated with progressive exposure times (20, 40, or 60 seconds) through different thicknesses of a lithium disilicate glass ceramic using two LED LCUs and to evaluate the influence of the interposition of glass ceramic on irradiance and on spectral emission profile of the light emitted by the LED LCUs. The null hypotheses were that DC would not be influenced by the interposition of the glass ceramic, exposure time, or the LED LCU.

## METHODS AND MATERIALS

### Preparation of Glass Ceramic Specimens

A castable CAD/CAM acrylic resin block (Vipi Block VBS, Dentsply Sirona, York, PA, USA) was sectioned with a double-faced diamond disk (IsoMet Blade 15LC, Buehler, Lake Bluff, IL, USA) coupled to a precision cutting machine (IsoMet 1000, Buehler) at a speed of 350 rpm under constant water cooling. The cuts were performed perpendicular to the outer surface of the block, yielding rectangular specimens (19×16 mm) with 0.3-, 1.0-, and 2.0-mm thicknesses. The specimens were reduced to quadrangular plates with square bases measuring 10 mm using a diamond disk at low speed. All the dimensions were checked with a digital caliper (Mitutoyo CD-6″ CSX, Mitutoyo, Kawasaki, Japan).

A wax cylinder (sprue #2.5, Kota, Cotia, Brazil) was attached to the center of one side of each specimen of acrylic resin. Groups of six specimens, two of each thickness, were positioned on an investment ring system (IPS Investment Ring System, 300 g, Ivoclar Vivadent) for investing (Bellavest SH, Bego, Bremen, Germany). After setting for 20 minutes, the investment ring was placed into a burnout furnace (3000 10P, EDG, São Carlos, Brazil). The furnace was heated from room temperature to 600°C at a heating rate of 20°C/min, and left at this temperature for 10 minutes. Then it was heated to 900°C and cooled to 850°C and left at this temperature for 30 minutes. Following this, the investment ring was placed in a press furnace (EP 5000, Ivoclar Vivadent) to press the glass ceramic ingot (GC Initial LiSi Press, MT-A1, GC Co; initial temperature 700°C, heating rate 60°C/min, remaining at 917°C for 25 minutes and then pressed). After completing the press cycle, the investment ring was sectioned with a sintered diamond disk at low speed; the specimens were then divested using air abrasion at 1.5 bar. Sprues were cut with a diamond disk at low speed. Both bases of glass ceramic specimens were wet ground manually with #180 grit SiC abrasive papers (231Q, 3M Corp, St Paul, MN, USA), obtaining five glass ceramic specimens of each thickness (0.3±0.01, 1.0±0.01, and 2.0±0.01 mm).

Ceramic glaze (IPS Ivocolor Glaze Powder Fluo, Ivoclar Vivadent) was brushed on one side of each glass ceramic specimen to fill any irregularities. The specimens covered with glaze were positioned on a firing tray and fired in a ceramic furnace (P510, Ivoclar Vivadent; initial temperature of 403°C, heating rate of 60°C/min, remaining at 770°C for 90 seconds). Then all glazed surfaces were abraded with #600 grit SiC abrasive papers (211Q, 3M Corp) until they had exactly 0.3-, 1.0-, and 2.0-mm thickness and checked with a digital caliper. The nonglazed surfaces were etched with 9% hydrofluoric acid gel (Porcelain Etch, Ultradent, South Jordan, UT, USA) for 20 seconds and then washed with water spray for 30 seconds. Any residue was removed by ultrasonic cleaning for 10 minutes in distilled water. After air drying for 30 seconds, one coat of a silane coupling agent (Silane, Ultradent) was applied to the etched surface for 60 seconds and air-dried for 15 seconds.

### Silicone Guide Preparation

The following procedure was used to standardize the thickness and obtain a resin cement film thickness (~50 μm) representative of a luted ceramic restoration in a clinical situation.[35] A Mylar strip was positioned on a glass plate; a small portion of the light-cured resin cement (Variolink Esthetic LC, shade Light+, Ivoclar Vivadent) was placed on the Mylar strip, and the glazed surface of a glass ceramic specimen was positioned on the resin cement. A load of 250 gf was applied for two minutes at the center of the glass ceramic specimens with a custom device containing a flat rubber point 10 mm in diameter.[22] Excess resin cement was removed with a small brush, and the resin cement was light activated for 40 seconds through the glass ceramic specimen. Afterward, equal parts of vinyl polysiloxane (VPS) base and catalyst putty impression material (Express XT, 3M Oral Care, St Paul, MN, USA) were hand mixed for 30 seconds. The mixture was positioned on the stack, and another glass plate was placed on the VPS impression material. Manual pressure was exerted on the latter glass plate until it came into full contact with the glass ceramic specimen. After VPS polymerization was complete, the upper glass plate was removed, the excess silicone guide was cut with a knife, and the resin cement in contact with the glass ceramic specimen was removed with a #12 scalpel blade. This procedure was performed for one glass ceramic specimen of each thickness.

### Degree of C=C Conversion

The DC of the light-cured resin cement (Variolink Esthetic LC, shade Light+) was measured at room temperature by attenuated total reflection/Fourier-transform infrared (ATR-FTIR) spectroscopy (IR-Prestige-21, Shimadzu, Kyoto, Japan). The silicone guide was positioned on the center of the ATR module (DuraSamplIR II, Smiths Detection Inc, Edgewood, MD, USA), leaving the diamond crystal at the center of a space corresponding to the glass ceramic specimen. The light-cured resin cement was applied directly from its application syringe to the diamond crystal. A Mylar strip was positioned on the resin cement, and the glass ceramic specimen was placed on the stack with its glazed surface facing upward. Specimen thickness was standardized by positioning a microscope slide on the stack and pressing gently until it made full contact with the silicone guide. The microscope slide was removed, and the resin cement was light activated for 20, 40, or 60 seconds through the different glass ceramic specimens of 0.3-, 1.0-, or 2.0-mm thickness. Light activation was performed with the tip of the LED LCU immediately above the glass ceramic specimens (n=5). Control groups were evaluated by positioning the resin cement directly on the diamond crystal, being light activated for 20, 40, or 60 seconds without the interposition of the glass ceramic specimens.

The infrared spectra collected between 1500 and 1800 $cm^{-1}$ in absorbance mode at 4 $cm^{-1}$ spectral resolution over 12 scans was plotted on a software program (IRsolution, v1.60, Shimadzu) and analyzed. The DC of each specimen was calculated using the standard baseline method, which is based on changes in the ratios between the absorbance peak heights corresponding to the aliphatic (1637 $cm^{-1}$) and aromatic (1608 $cm^{-1}$) C=C prior to and after resin cement light activation. The absorbance intensity of aromatic C=C was used as an internal reference, as its intensity does not change during the polymerization reaction.[12] The DC was evaluated immediately after light activation of the light-cured resin cement and calculated according to the following equation:

$$DC(\%) = \left[1 - \frac{\left(\frac{abs(C{=}C_{aliphatic})}{abs(C{=}C_{aromatic})}\right)_{cured}}{\left(\frac{abs(C{=}C_{aliphatic})}{abs(C{=}C_{aromatic})}\right)_{uncured}}\right] \times 100,$$

where $abs(C{=}C)_{aliphatic}$ refers to the aliphatic absorbance peak and $abs(C{=}C)_{aromatic}$ refers to the aromatic absorbance peak for both cured and uncured resin cements.

### Irradiance, Spectral Emission Profile, and Light Transmittance Through Ceramic

Two LED LCUs with similar irradiance of approximately 1000 $mW/cm^2$, measured by a curing radiometer (Demetron L.E.D. Radiometers, KaVo Kerr, Brea, CA, USA), were selected: a second-generation LED LCU, also classified as a single-peak LED LCU,[30,31,36] with spectral emission between 440 and 480 nm, presenting only one emission peak (Radii Plus, SDI, Melbourne, Australia),[37] and a third-generation LED LCU, also classified as a multipeak LED LCU,[30,31,36] with spectral emission between 395 and 480 nm, presenting two distinct emission peaks (VALO on its standard power mode, Ultradent).[38] The irradiance and the spectral emission profile of each LED LCU through glass ceramic specimens with different thicknesses were evaluated using a light spectrometer (MARC-RC, BlueLight Analytics, Halifax, NS, Canada). The LED LCUs were held by a clamp (benchMARC, BlueLight Analytics), and their tips were positioned at the center of the top surface sensor. The measurements were performed with and without interposition of the glass ceramic specimens between the sensor and the LED LCU tip (n=5). All glass ceramic specimens of each thickness were evaluated with their glazed surfaces facing the LED LCU tip. The LED LCUs were activated for 20 seconds in all evaluations, and both irradiance and spectral emission profile data were recorded in a software program (MARC, v4.01, BlueLight Analytics). The light transmittance (%) was calculated as the percentage ratio between light irradiance through glass ceramic specimens and light irradiance without interposition of glass ceramic specimens.

### Translucency Parameter

The translucency parameter of glass ceramic specimens was evaluated with a sphere spectrophotometer (SP60, X-rite, Grand Rapids, MI, USA). The spectrophotometer was calibrated with a ceramic disk for white calibration measurements and with the trap opening for black calibration measurements, as recommended by the manufacturer. Color data were represented by CIE L*a*b* coordinates: the L* parameter represents the lightness, where 100 is pure white and 0 pure black; the a* parameter represents red-green coordinates, where positive values represent red and negative values green; and the b* parameter represents yellow-blue coordinates, where positive values represent yellow and negative values blue. Three consecutive readings were performed over a white background (L*=94.7, a*=–0.89, and b*=–0.38) and over a black background (L*=0.20, a*=0.23, and b*=–0.94) at the center of the glazed surface of each glass ceramic specimen, and the average was considered. The mean translucency parameter of each glass ceramic specimen was calculated by the following equation:[39]

Table 1: *Degree of C=C Conversion (%) of the Light-Cured Resin Cement According to Glass Ceramic Thickness and Exposure Time for Each LED Light-Curing Unit (LCU) (Mean ± SD) (n=5)*[a,b]

| Thickness (mm) | Exposure Time | | | | | |
|---|---|---|---|---|---|---|
| | Multipeak LED | | | Single-Peak LED | | |
| | 20 s | 40 s | 60 s | 20 s | 40 s | 60 s |
| 0.0 (control) | 74.0 ± 1.0 Aa | 80.1 ± 0.9 Ab* | 80.1 ± 0.6 Ab* | 74.3 ± 1.6 BCa | 75.5 ± 1.2 ABb* | 78.0 ± 1.7 ABb* |
| 0.3 | 76.6 ± 1.0 Ba* | 79.9 ± 0.2 Ab* | 80.0 ± 0.4 Ab | 73.4 ± 1.7 Aba* | 77.4 ± 1.7 Bb* | 79.4 ± 1.0 Bb |
| 1.0 | 75.8 ± 1.2 ABa | 77.2 ± 1.1 Ba | 79.9 ± 0.9 Ab | 76.4 ± 1.8 Ca | 78.1 ± 2.1 Bb | 79.4 ± 2.0 Bb |
| 2.0 | 74.0 ± 0.9 Aa* | 76.8 ± 0.5 Bb* | 77.0 ± 0.9 Bb | 71.1 ± 1.2 Aa* | 74.6 ± 0.5 Ab* | 75.7 ± 1.0 Ab |

[a] *Different letters (uppercase for rows, lowercase for columns) indicate statistical differences for a specific LED LCU (p<0.05).*
[b] *Asterisk (*) indicates statistical differences between LED LCUs at each exposure time (p<0.05).*

$$TP = [(L*_w - L*_b)^2 + (a*_w - a*_b)^2 + (b*_w - b*_b)^2]^{1/2},$$

where w refers to color values of each specimen over a white background and b to the values over a black background.

### Statistical Analysis

All the data were submitted to the Kolmogorov-Smirnov test to confirm normal distribution. DC (%) data were submitted to three-way analysis of variance (ANOVA) (glass ceramic thickness × exposure time × LED LCU) and the Tukey honestly significant difference (HSD) test. Irradiance and light transmittance data were submitted to two-way ANOVA (glass ceramic thickness × LED LCU) and the Tukey HSD test. The Spearman correlation was performed for the translucency parameter and light transmittance. All analyses were performed using a statistical software program (SPSS, v21.0, IBM, Armonk, NY, USA) with $\alpha = 0.05$.

## RESULTS

### Degree of C=C Conversion

DC showed a statistically significant difference for LED LCU ($p<0.001$), glass ceramic thickness ($p<0.001$), and exposure time ($p<0.001$). The interaction between LED LCU and glass ceramic thickness ($p<0.001$) and the interactions between the three factors were statistically significant ($p<0.001$). Results for DC are shown in Table 1. DC increased significantly from 20 to 60 seconds of light activation in all ceramic thicknesses for both LED LCUs ($p<0.05$). Increasing light activation from 40 to 60 seconds was statistically significant only when the multipeak LED LCU was used on a 1.0-mm-thick ceramic specimen ($p<0.05$). For the multipeak LED LCU, DC for 20 seconds of light activation was statistically higher in the 0.3-mm-thickness group than the control and the 2.0-mm-thickness groups ($p<0.05$). Regarding 40 seconds of light activation, the control and the 0.3-mm-thickness groups presented the highest DC. As for 60 seconds of light activation, the lowest DC was for the 2.0-mm-thickness group. For the single-peak LED LCU, DC for 20 seconds light activation was statistically higher in the 1.0-mm-thickness group than the 0.3- and the 2.0-mm-thickness groups ($p<0.05$). Regarding 40 and 60 seconds of light activation, DC for the control and the 2.0-mm-thickness groups were statistically similar.

Comparing the LED LCUs, multipeak LED LCU showed higher DC than single-peak LED LCU. The multipeak LED LCU showed higher DC for 20 seconds of light activation for both the 0.3- and the 2.0-mm-thickness groups ($p<0.05$). Regarding 40 seconds of light activation, the multipeak LED LCU showed higher DC for the control, the 0.3-mm-thickness, and the 2.0-mm-thickness groups ($p<0.05$). As for 60 seconds of light activation, the multipeak LED LCU showed higher DC only for the control group ($p<0.05$).

### Irradiance, Spectral Emission Profile, and Light Transmittance

Irradiance showed a statistically significant difference between LED LCUs and thicknesses ($p<0.001$). The interaction between the factors was also statistically significant ($p<0.001$). Irradiance results are shown in Table 2. The irradiance of both LED LCUs decreased significantly as the glass ceramic specimen thickness increased ($p<0.05$). The multipeak LED LCU showed the highest irradiance values ($p<0.05$) for all thicknesses. The spectral emission profiles of the single-peak LED LCU and the multipeak LED LCU are shown in Figure 1 and Figure 2, respectively. The multipeak LED LCU showed a spectral emission profile with two distinct peaks at 394 and 459 nm; the single-peak LED LCU had only one peak at 457 nm.

Table 2: *LED Light-Curing Unit Irradiance According to Glass Ceramic Thickness (Mean ± SD; n=5)*[a]

| Thickness (mm) | Multipeak | | Single-Peak | |
|---|---|---|---|---|
| | Irradiance (mW/cm$^2$) | Attenuation (%)[b] | Irradiance (mW/cm$^2$) | Attenuation (%)[b] |
| 0.0 (control) | 2013.5 ± 10.7 Aa | — | 1400.7 ± 3.1 Ab | — |
| 0.3 | 1168.6 ± 46.2 Ba | 42.0 | 861.9 ± 22.6 Bb | 38.5 |
| 1.0 | 662.3 ± 7.3 Ca | 67.1 | 428.8 ± 18.3 Cb | 69.4 |
| 2.0 | 298.8 ± 9.7 Da | 85.2 | 186.1 ± 8.2 Db | 86.7 |

[a] *Different letters (uppercase for rows, lowercase for columns) indicate statistical differences* ($p<0.05$).
[b] *Attenuation of irradiance compared with the control.*

No statistically significant difference in light transmittance was observed for the LED LCUs ($p=0.894$), only for the different glass ceramic specimen thicknesses ($p<0.001$). The light transmittance mean values are shown in Table 3. The light transmittance for both LED LCUs decreased significantly as the glass ceramic specimen thickness increased ($p<0.05$).

## Translucency Parameter

The glass ceramic translucency parameter according to thickness was 0.3 mm (27.2±4.2), 1.0 mm (12.9±0.5), and, 2.0 mm (7.9±0.2). The translucency parameter and light transmittance showed a significant nonlinear correlation ($p<0.05$) for multipeak LED LCU ($r_s=0.887$) and single-peak LED LCU ($r_s=0.900$).

## DISCUSSION

The null hypotheses were rejected. DC was influenced by the interposition of glass ceramic, exposure time, and LED LCU.

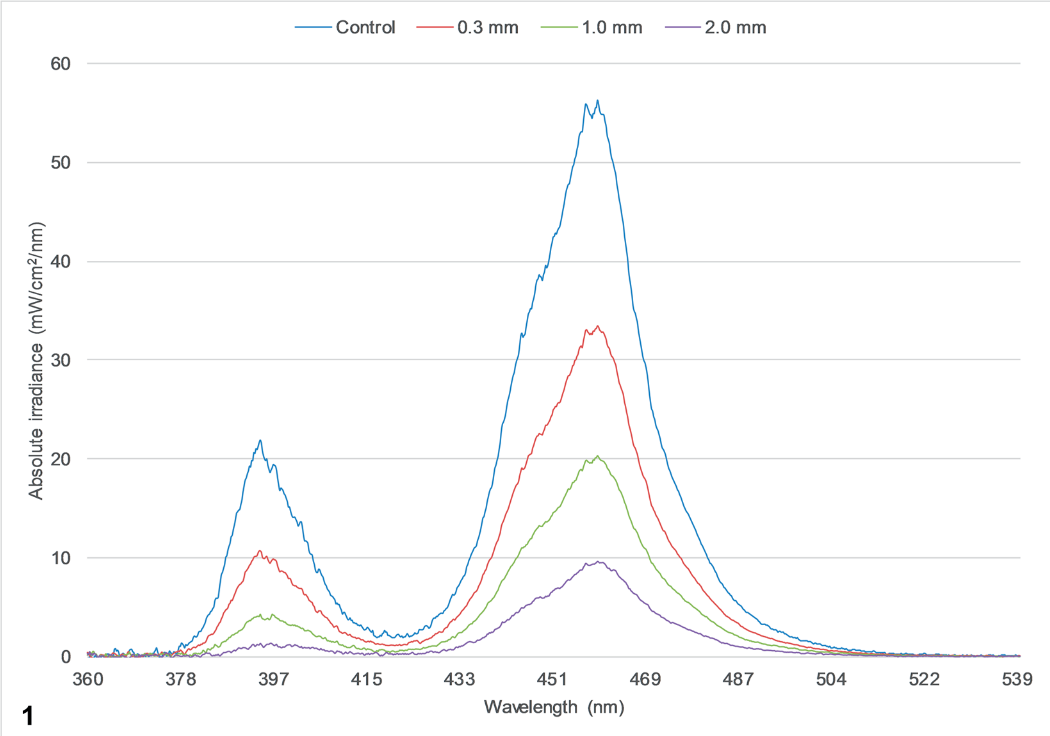
The glass ceramic ingot translucency selected in the present study was medium translucency due to its vast indications for use (thin veneers, veneers, inlays, onlays, crowns, and three-unit bridges).[8] Following the preparation design guidelines for this ceramic material, the following minimum thicknesses are recommended: 0.3 mm for thin veneers; 1.0 mm for table tops, inlays, and onlays; and 1.5 mm for incisal/occlusal crown surfaces.[8] This is the ultimate reason for evaluating the interposition of glass ceramic specimens of 0.3- and 1.0-mm thickness and its effect on the DC of the light-cured resin cement (Variolink Esthetic LC). This light-cured resin cement is indicated for luting glass ceramic restorations up to 2.0 mm in thickness.[33] This indication led glass ceramic specimens with 2.0-mm thickness to be included in the present study. The Light+ shade of light-cured resin cement was chosen due to its higher opacity among the five available shades.[33] Leloup and others[40] found that an increased opacity of a light-cured composite may reduce its DC. Thus, selecting the Light+ shade to lute a 2.0-mm glass ceramic thickness restoration would represent an extreme indication for the studied light-cured resin cement. A limitation of the present study was the evaluation of only one level of translucency of a single glass ceramic brand and only one shade of an Ivocerin-containing light-cured resin cement. Future investigations should consider comparing other glass ceramic shades and opacities as well as light-cured resin cements with other alternative photoinitiators.

The selection of the LED LCUs to be tested in the present study was performed by measuring the irradiance of LED LCUs by a handheld curing radiometer (Demetron L.E.D. Radiometers), a device used by clinicians and some researchers to monitor the output from their LCUs.[41] Two LED LCUs with similar irradiance of approximately 1000 mW/cm$^2$ were selected. However, according to the results of the present study, a discrepancy was noticed between the irradiance measured by the handheld curing radiometer to those measured by the MARC-RC device; thus, the selection of the LED LCU was a major limitation of the present study, as ideally both

Table 3: *Light Transmittance According to Glass Ceramic Thickness for Each LED Light-Curing Unit (Mean ± SD; n=5)*[a]

| | LED LCU | Thickness (mm) | | |
|---|---|---|---|---|
| | | 0.3 | 1.0 | 2.0 |
| Light transmittance (%) | Multipeak | 58.0 ± 2.3 Aa | 32.9 ± 0.9 Ab | 14.8 ± 0.5 Ac |
| | Single-peak | 61.5 ± 1.6 Aa | 30.6 ± 1.3 Ab | 13.3 ± 0.6 Ac |

[a] *Different letters (uppercase for rows, lowercase for columns) indicate statistical differences* ($p<0.05$).



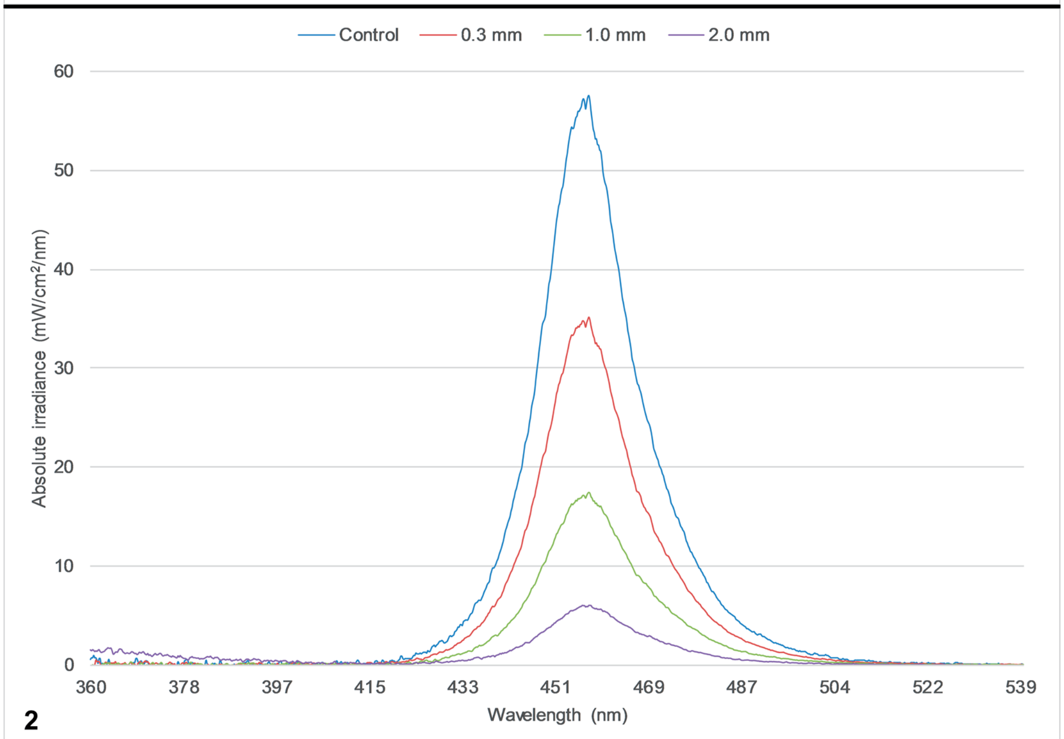




Figure 1. *Spectral emission profile of multipeak LED light-curing units according to wavelength for each glass ceramic thickness (n=5).*

Figure 2. *Spectral emission profile of the single-peak LED light-curing units according to wavelength for each glass ceramic thickness (n=5).*

LED LCUs should have the same irradiance measured by a MARC-RC device.

Several studies have shown that interposition of a restorative material may[4,12,17,19,42,43] or may not[15,17,24,27,42] be able to reduce the DC of light-cured resin cements. In the present study, there was no consensus for the influence of glass ceramic interposition on DC since the increase in the glass ceramic specimen thickness did not necessarily result in worse results. It is noteworthy to mention that there was a situation in which the interposition of a glass ceramic specimen with 0.3-mm thickness did not reduce but actually increased the DC compared to the control. This apparent abnormality may be explained by slower and smaller formation of free radicals due to light absorption by and diffusion into the structure of glass ceramic, reducing the polymerization rate, delaying the light-cured resin cement viscosity, and extending time for free radical diffusion, thus allowing greater conversion of monomers into polymers.[26,42] A similar result was found by Faria-e-Silva and Pfeifer,[42] where a 0.5-mm-thick glass ceramic interposition tended to present higher DC than the control (without glass ceramic interposition).

A 40-second light activation (except in one group) was enough to obtain the highest DC for both LED LCUs. The increase in exposure time of a light-cured resin cement yielded similar results in other studies.[2,18] Alshaafi and others[18] showed an increase in DC by increasing light activation not only from 20 to 40 seconds but also from 40 to 60 seconds. This can be partially explained by the greater thickness of the light-cured resin cement specimen (0.5 mm) and by the use of another light-cured resin cement (Variolink II base past, shade A1, Ivoclar Vivadent) in that study. Archegas and others[2] tested different exposure times (40, 80, and 120 seconds) and did not find any significant difference between 40 and 80 seconds, whereas differences between 40 and 120 seconds were significant. That study also used another light-cured resin cement (RelyX Veneer, shade A3, 3M Oral Care) specimens with 0.5-mm thickness.

When the light from the LED LCU reaches the surface of a glass ceramic, a considerable portion of its energy is lost (absorbed by and diffused into the structure of the material) and another portion transmitted.[44] It was observed that light transmittance of different glass ceramic thicknesses was statistically similar between LED LCUs, showing that there is no relation between light transmittance and emission profile of LED LCU. Thus, the tested multipeak LED LCU presented higher irradiance in all thicknesses since the value of its irradiance without glass ceramic interposition was higher than that of the single-peak LED LCU. The irradiance transmitted by the multipeak LED LCU through glass ceramic in the present study as well as that by Faria-e-Silva and Pfeifer[42] was measured by the same light spectrometer (MARC-RC; however, the light transmittance that they found was slightly higher than that of the present study, probably because they evaluated a glass ceramic with higher translucency (IPS Empress Esthetic, shade ET1, Ivoclar Vivadent).

The silicone guides made for DC measurement ensured that only light transmitted through the glass ceramic specimen would reach the light-cured resin cement. Thus, an interesting finding was that DC was not always related to the irradiance received by the resin cement. There were situations in which the DC was not reduced compared to the control despite a significant reduction in light irradiance. This indicates that the irradiance received by the resin cement was sufficient to perform an acceptable monomeric conversion. Similar results have been found in other studies.[15,21,42]

The visible light absorption spectrum of Ivocerin corresponds approximately to a wavelength ranging between 390 and 445 nm with an absorption peak at 408 nm.[30,33] Both LED LCUs emitted light with a spectrum within this range. Since the multipeak LED LCU has a spectral emission profile with two distinct peaks (at 394 and 459 nm), it was able to activate the photoinitiator better.[26,30] However, it did not necessarily result in higher DC. In some groups, the single-peak LED LCU—with only one emission peak at 457 nm and transmitting lower irradiance to the light-cured resin cement—presented results statistically similar to those of the multipeak LED LCU. This can probably be explained by the higher reactivity of Ivocerin than camphorquinone, thus optimizing the polymerization reaction.[30,33] Therefore, a lower irradiance—even though not at Ivocerin's absorption peak—would be able to result in enough DC. Another possible explanation may be the presence of other photoinitiators with an absorption spectrum about 457 nm, such as camphorquinone or PPD.[26] However, the manufacturer classifies the resin cement used in the present study as amine free,[32,33] and the CQ-amine combination is the most commonly used photoactivation system in light-cured composites.[45,46]

The glass ceramic used in the present study behaved as a filter for neutral density, meaning that the spectral emission profile of LED LCUs though the three glass ceramic thicknesses did not change. Alshaafi and others[18] and Faria-e-Silva and Pfeifer[42] found similar results. However, LED LCU spectral emission profiles did not prove to be a decisive factor to improve Ivocerin-containing light-cured resin cement DC. AlQahtani and others[1] also evaluated the influence of different LED LCUs on DC. These authors found similar results regarding the spectral emission profile effect on DC using another light-cured resin cement (Variolink II base paste, shades A1 and A4).

Light transmittance and the translucency parameter presented a near perfect positive nonlinear correlation for both LED LCUs; that is, increased translucency parameter of the tested glass ceramic was associated with increased light transmittance. However, since this correlation is nonlinear, the value of one of these parameters cannot be established when the other is known. This finding differs from that of the study by Oh and others,[12] in which the evaluated glass ceramics presented a near perfect linear positive correlation between these parameters. Thus, in that case, it would be possible to determine the value of one parameter knowing the value of the other. However, it is worth mentioning that the methodology used by Oh and others[12] to evaluate light transmittance and the translucency parameter differs from that used in the present study.

Although DC was evaluated at room temperature, a higher temperature, such as human body temperature (37°C), would probably not result in higher DC. Another study demonstrated that increasing the temperature from 23°C to 54°C did not result in statistically higher DC for a light-cured resin cement (RelyX Veneer).[47] In the present study, the DC was measured immediately after resin cement light activation. No new DC measurement was performed 24 hours after light activation because the specimens could not be repositioned on the diamond crystal of the ATR module as they were for the initial measurement. In spite of that, in another study,[12] it was reported that there was no significant increase in DC of a light-cured resin cement (Variolink N base paste, Ivoclar Vivadent) when measured immediately and 24 hours after light activation, probably because the resin cement specimens were about 50 μm thick (same thickness as in the present study), thus allowing enough light irradiation to reach maximal DC.

The success of ceramic restorations depends not only on the mechanical properties of the ceramic system but also on the resin cement's mechanical properties and adequate polymerization reaction.[7,13,16,19,21,23,27,28] Thus, since mean DC ranged from 71.1% to 80.1%, Ivocerin-containing light-cured resin cements can be selected for luting lithium disilicate glass ceramic restorations of medium translucency using either a single- or multipeak LED LCU. Several studies have evaluated light- and/or dual-cured resin cements DC through ceramic;[a] however, methodological differences (such as the use of another resin cement, ceramic type, LED LCU, DC measurement method, and/or spectrometer to measure light transmittance and light irradiance) do not allow an adequate comparison with the present study.

A recently published systematic review and meta-analysis selected 13 clinical trials of laminate veneers by methodology quality with a median follow-up period of nine years. Laminate veneers resulted in a high estimated overall cumulative survival rate (89%).[48] Laminate veneers resulted in low complication rates; the following clinical outcomes of interest were debonding (2%), ceramic fracture/chipping (4%), secondary caries (1%), severe marginal discoloration (2%), and endodontic problems (2%).[48] The present article's authors speculate that most of these complication outcomes might be partially attributed to ineffective light activation during the luting procedure that could have resulted in low DC. Light-activation luting procedure protocols still need to be investigated in further laminate veneer clinical trials.

Although the multipeak LED LCU proved to be superior to the single-peak LED LCU in the present study, it is difficult to state whether differences between mean DC using these two LED LCUs could have clinical implications. However, the use of a multipeak LED appears to reduce light-activation time of Ivocerin-containing resin cement, reducing chair time.

## CONCLUSIONS

The results of this laboratory study seem to indicate that the interposition of medium translucency lithium disilicate glass ceramic has a minor effect on degree of conversion for the analyzed light-cured resin cement. In spite of that, using a multipeak LED light-curing unit seems to achieve a higher degree of conversion in a shorter light-activation time.

[a] *References 1, 2, 11, 12, 15, 17-21, 24, 25, 27, 42.*

**Acknowledgements**

The authors would like to thank GC South America for providing the glass ceramics used in the present study as well as Leina Nakanishi, Josiane Rutz, Carlos Enrique Cuevas Suárez, Cristina Isolan, Fabíola Jardin Barbon, and Verônica Pereira de Lima, graduate students of the Graduate Program in Dentistry of the Federal University of Pelotas (UFPel), for their help in conducting the present study and Felipe Hilgert Seadi, Henrique Waltrick, and Ney Paulo, dental technicians, for helping with the glass ceramic specimens.

**Conflict of Interest**

The authors of this article 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.

*(Accepted 27 November 2019)*

**REFERENCES**

1. AlQahtani MQ, AlShaafi MN, & Price RB (2013) Effects of single-peak vs polywave light-emitting diode curing lights on the polymerization of resin cement *Journal of Adhesive Dentistry* **15(6)** 547-551, https://dx.doi.org/10.3290/j.jad.a29634
2. Archegas LRP, de Menezes Caldas DB, Rached RN, Soares P, & Souza EM (2012) Effect of ceramic veneer opacity and exposure time on the polymerization efficiency of resin cements *Operative Dentistry* **37(3)** 281-299, https://dx.doi.org/10.2341/11-134-L
3. Heintze SD, Albrecht T, Cavalleri A, & Steiner M (2011) A new method to test the fracture probability of all-ceramic crowns with a dual-axis chewing simulator *Dental Materials* **27(2)** e10-e19, https://dx.doi.org/10.1016/j.dental.2010.09.004
4. Martins FV, Vasques WF, & Fonseca EM (2019) How the variations of the thickness in ceramic restorations of lithium disilicate and the use of different photopolymerizers influence the degree of conversion of the resin cements: A systematic review and meta-analysis *Journal of Prosthodontics* **28(1)** e395-e403, https://dx.doi.org/10.1111/jopr.12920
5. Aboushelib MN & Sleem D (2014) Microtensile bond strength of lithium disilicate ceramics to resin adhesives *Journal of Adhesive Dentistry* **16(6)** 547-552, https://dx.doi.org/10.3290/j.jad.a33249
6. Shenoy A & Shenoy N (2010) Dental ceramics: An update *Journal of Conservative Dentistry* **13(4)** 195-203, https://dx.doi.org/10.4103/0972-0707.73379
7. Zhang L, Luo XP, & Tan RX (2019) Effect of light-cured resin cement application on translucency of ceramic veneers and light transmission of LED polymerization units. *Journal of Prosthodontics* **28(1)** e376-e382, https://dx.doi.org/10.1111/jopr.12910
8. GC Europe (2019) GC Initial LiSi Press: Technical manual; Retrieved online June 18, 2019 from: https://cdn.gceurope.com/v1/PID/initiallisipress/manual/MAN_Initial_LiSi_Press_en.pdf
9. Ivoclar Vivadent (2011) IPS e.max Press: Scientific documentation; Retrieved online June 19, 2019 from: http://www.ivoclarvivadent.com/zoolu-website/media/document/9808/IPS+e-max+Press
10. GC Europe (2019) GC Initial LiSi Press: Lithium disilicate redefined; Retrieved online June 18, 2019 from https://cdn.gceurope.com/v1/PID/initiallisipress/leaflet/LFL_Initial_LiSi_Press_-_for_dentists_en.pdf
11. Novais VR, Raposo LH, Miranda RR, Lopes CC, Simamoto PC Júnior & Soares CJ (2017) Degree of conversion and bond strength of resin-cements to feldspathic ceramic using different curing modes *Journal of Applied Oral Science* **25(1)** 61-68, https://dx.doi.org/10.1590/1678-77572016-0221
12. Oh S, Shin SM, Kim HJ, Paek J, Kim SJ, Yoon TH, & Kim SY (2018) Influence of glass-based dental ceramic type and thickness with identical shade on the light transmittance and the degree of conversion of resin cement *International Journal of Oral Science* **10(1)** 5, https://dx.doi.org/10.1038/s41368-017-0005-7
13. Furuse AY, Santana LOC, Rizzante FAP, Ishikiriama SK, Bombonatti JF, Correr GM, & Gonzaga CC (2016) Delayed light activation improves color stability of dual-cured resin cements *Journal of Prosthodontics* **27(5)** 449-455, https://dx.doi.org/10.1111/jopr.12509
14. Tian T, Tsoi JK, Matinlinna JP, & Burrow MF (2014) Aspects of bonding between resin luting cements and glass ceramic materials *Dental Materials* **30(7)** e147-e162, https://dx.doi.org/10.1016/j.dental.2014.01.017
15. Cho SH, Lopez A, Berzins DW, Prasad S, & Ahn KW (2015) Effect of different thicknesses of pressable ceramic veneers on polymerization of light-cured and dual-cured resin cements *Journal of Contemporary Dental Practice* **16(5)** 347-352, http://dx.doi.org/10.5005/jp-journals-10024-1688
16. Souza G, Braga RR, Cesar PF, & Lopes GC (2015) Correlation between clinical performance and degree of conversion of resin cements: A literature review *Journal of Applied Oral Science* **23(4)** 358-368, https://dx.doi.org/10.1590/1678-775720140524
17. Runnacles P, Correr GM, Baratto Filho F, Gonzaga CC, & Furuse AY (2014) Degree of conversion of a resin cement light-cured through ceramic veneers of different thicknesses and types *Brazilian Dental Journal* **25(1)** 38-42, http://dx.doi.org/10.1590/0103-6440201302200
18. AlShaafi MM, AlQahtani MQ, & Price RB (2014) Effect of exposure time on the polymerization of resin cement through ceramic *Journal of Adhesive Dentistry* **16(2)** 129-135, https://dx.doi.org/10.3290/j.jad.a30756
19. Calgaro PA, Furuse AY, Correr GM, Ornaghi BP, & Gonzaga CC (2013) Influence of the interposition of ceramic spacers on the degree of conversion and the hardness of resin cements *Brazilian Oral Research* **27(5)** 403-409, https://dx.doi.org/10.1590/S1806-83242013000500004
20. Lanza MDS, Andreeta MRB, Pegoraro TA, Pegoraro LF, & Carvalho RM (2017) Influence of curing protocol and ceramic composition on the degree of conversion of resin cement *Journal of Applied Oral Science* **25(6)** 700-707, https://dx.doi.org/10.1590/1678-7757-2016-0270
21. Pick B, Gonzaga CC, Junior WS, Kawano Y, Braga RR, & Cardoso PE (2010) Influence of curing light attenuation

caused by aesthetic indirect restorative materials on resin cement polymerization *European Journal of Dentistry* **4(3)** 314-323.

22. Moraes RR, Correr-Sobrinho L, Sinhoreti MA, Puppin-Rontani RM, Ogliari FA, & Piva E (2008) Light-activation of resin cement through ceramic: Relationship between irradiance intensity and bond strength to dentin *Journal of Biomedical Materials Research Part B: Applied Biomaterials* **85(1)** 160-165, https://dx.doi.org/10.1002/jbm.b.30928
23. Pereira CN, De Magalhães CS, Daleprane B, Peixoto RT, Ferreira Rda C, Cury LA, & Moreira AN (2015) LED and halogen light transmission through a CAD/CAM lithium disilicate glass-ceramic *Brazilian Dental Journal* **26(6)** 648-653, https://dx.doi.org/10.1590/0103-6440201300367
24. Ganjkar MH, Hesmat H, & Ahamgari RH (2017) Evaluation of the effect of porcelain laminate thickness on degree of conversion of light cure and dual cure resin cements using FTIR *Journal of Dentistry, Shiraz University of Medical Sciences* **18(1)** 30-36.
25. Lohbauer U, Pelka M, Belli R, Schmitt J, Mocker E, Jandt KD, & Müller FA (2010) Degree of conversion of luting resins around ceramic inlays in natural deep cavities: A micro-raman spectroscopy analysis *Operative Dentistry* **35(5)** 579-586, https://dx.doi.org/10.2341/10-012-L
26. Rueggeberg FA, Giannini M, Arrais CAG, & Price RBT (2017) Light curing in dentistry and clinical implications: A literature review *Brazilian Oral Research* **31(Supplement 1)** 64-91, https://dx.doi.org/10.1590/1807-3107BOR-2017.vol31.0061
27. Scotti N, Comba A, Cadenaro M, Fontanive L, Breschi L, Monaco C, & Scotti R (2016) Effect of lithium disilicate veneers of different thickness on the degree of conversion and microhardness of a light-curing and a dual-curing cement *International Journal of Prosthodontics* **29(4)** 384-388, https://dx.doi.org/10.11607/ijp.4811
28. Santos RL, Sampaio GAM, Carvalho FG, Pithon MM, Guênes GMT, & Alves PM (2014) Influence of degree of conversion on the biocompatibility of different composites in vivo *Journal of Adhesive Dentistry* **16(1)** 15-20, https://dx.doi.org/10.3290/j.jad.a29704
29. Jandt KD & Mills RW (2013) A brief history of LED photopolymerization *Dental Materials* **29(6)** 605-617, https://dx.doi.org/10.1016/j.dental.2013.02.003
30. Price RBT (2017) Light curing in dentistry *Dental Clinics of North America* **61(4)** 751-778, https://dx.doi.org/10.1016/j.cden.2017.06.008
31. Rueggeberg FA (2011) State-of-the-art: Dental photocuring—A review *Dental Materials* **27(1)** 39-52, https://dx.doi.org/10.1016/j.dental.2010.10.021
32. Burtscher P (2013) Ivocerin in comparison to camphorquinone *Ivoclar Vivadent Report* **19** 11-15.
33. Ivoclar Vivadent (2014) Variolink Esthetic: Scientific Documentation; Retrieved online June 15, 2019 from https://www.ivoclarvivadent.com/zoolu-website/media/document/26983/Variolink+Esthetic
34. Hadis M, Leprince JG, Shortall AC, Devaux J, Leloup G, & Palin WM (2011) High irradiance curing and anomalies of exposure reciprocity law in resin-based materials *Journal of Dentistry* **39(8)** 549-557, https://dx.doi.org/10.1016/j.jdent.2011.05.007
35. Reich S, Gozdowski S, Trentzsch L, Frankenberger R, & Lohbauer U (2008) Marginal fit of heat-pressed vs CAD/CAM processed all-ceramic onlays using a milling unit prototype *Operative Dentistry* **33(6)** 644-650, https://dx.doi.org/10.2341/07-162
36. Soares CJ, Rodrigues MP, Oliveira LRS, Braga SSL, Barcelos LM, Silva GRD, Gianini M, & Price RB (2017) An evaluation of the light output from 22 contemporary light curing units *Brazilian Dental Journal* **28(3)** 362-371, https://dx.doi.org/10.1590/0103-6440201601466
37. SDI (2017) Radii Plus Technical Data; Retrieved online July 1, 2019 from https://www.sdi.com.au/downloads/brochures/Radii_plus_Bro_EN.pdf
38. Ultradent (2018) VALO Cordless Product Instruction; Retrieved online July 1, 2019 from https://downloads.ctfassets.net/wfptrcrbtkd0/d9d85c84-455f-48e9-89c2-a5dcf5a77c76/2ed7881db10965379aabbaccacd98091/VALO_Cordless.pdf
39. Johnston WM, Ma T, & Kienle BH (1995) Translucency parameter of colorants for maxillofacial prostheses *International Journal of Prosthodontics* **8(1)** 79-86.
40. Leloup G, Holvoet PE, Bebelman S, & Devaux J (2002) Raman scattering determination of the depth of cure of light-activated composites: Influence of different clinically relevant parameters *Journal of Oral Rehabilitation* **29(6)** 510-515, https://dx.doi.org/10.1046/j.1365-2842.2002.00889.x
41. Shimokawa CA, Harlow JE, Turbino ML, & Price RB (2016) Ability of four dental radiometers to measure the light output from nine curing lights *Journal of Dentistry* **54** 48-55, https://dx.doi.org/10.1016/j.jdent.2016.08.010
42. Faria-e-Silva AL & Pfeifer CS (2017) Effectiveness of high-power LEDs to polymerize resin cements through ceramics: An in vitro study *Journal of Prosthetic Dentistry* **118(5)** 631-666, https://dx.doi.org/10.1016/j.prosdent.2016.12.013
43. Kilinc E, Antonson SA, Hardigan PC, & Kesercioglu A (2011) The effect of ceramic restoration shade and thickness on the polymerization of light- and dual-cure resin cements *Operative Dentistry* **36(6)** 661-669, https://dx.doi.org/10.2341/10-206-L
44. Ilie N & Hickel R (2008) Correlation between ceramics translucency and polymerization efficiency through ceramics *Dental Materials* **24(7)** 908-914, https://dx.doi.org/10.1016/j.dental.2007.11.006
45. Bouzrati-Zerelli M, Maier M, Dietlin C, Fabrice MS, Fouassier JP, Klee JE, & Lalevée J (2016) A novel photoinitiating system producing germyl radicals for the polymerization of representative methacrylate resins: Camphorquinone/R3GeH/iodonium salt *Dental Materials* **32(10)** 1226-1234, https://dx.doi.org/10.1016/j.dental.2016.07.006
46. Song L, Ye Q, Ge X, Misra A, & Spencer P (2016) Tris(trimethylsilyl)silane as a co-initiator for dental adhesive: Photo-polymerization kinetics and dynamic mechanical property *Dental Materials* **32(1)** 102-113, https://dx.doi.org/10.1016/j.dental.2015.10.013

47. Lima MO, Catelan A, Marchi GM, Lima DA, Martins LR, & Aguiar FH (2018) Influence of pre-heating and ceramic thickness on physical properties of luting agents *Journal of Applied Biomaterials and Functional Materials* **16(4)** 252-259, https://dx.doi.org/10.1177/2280800018782842

48. Morimoto S, Albanesi RB, Sesma N, Agra CM, & Braga MM (2016) Main clinical outcomes of feldspathic porcelain and glass-ceramic laminate veneers: A systematic review and meta-analysis of survival and complication rates *International Journal of Prosthodontics* **29 (1)** 38-49, https://doi.org/10.11607/ijp.4315