article ORIGINAL

Luis Felipe Jochims **SCHNEIDER**[1]
Ana Carolina **CARMELLO**[2]
Leonardo Duarte Eiras **PEREIRA**[2]
Mário Pereira **COUTO NETO**[2]
Rodrigo Antonio **MODENA**[3]
Larissa Maria **CAVALCANTE**[4]

Influence of light-curing units on the activation potential of bulk-fill composites

ABSTRACT: Objectives: To determine: (a) the influence of the light-curing unit (LCU) type ("monowave" vs. "polywave") on the degree of conversion (GC) as a function of depth, for different formulations of bulk-fill composites; (b) which light evaluation parameter is able to predict photoactivation as a function of depth of bulk-fill composites; and (c) verify whether these parameters are related to the cost of the light source. **Methods:** Four LED-based sources were used (Poly Wireless/Kavo; Radii-Cal/SDI; Bluephase G2/Ivoclar; and Valo Cordless/Ultradent) and three bulk-fill composites (Aura BF/SDI, regular viscosity and conventional initiator; Tetric N-Ceram BF/Ivoclar, regular viscosity and alternative initiator; and Surefill SDR /Dentsply, flowable viscosity). For each material, the activation time was that indicated by the manufacturer and GC (%) was determined by FTIR spectroscopy (n = 5) at the subsurface (0.1mm) and 4mm depth. The results were submitted to analysis of variance and Tukey test (95%). Pearsons' correlation analyzes were performed (a) between the light source irradiance data and the degree of conversion and (b) among the irradiance values and the cost of the light sources. **Results:** For Aura BF the light source did not influence the subsurface GC, but the use of the RadiCall reduced GC at 4mm. For Tetric BF, Bluephase G2 and Valo polywave devices produced higher values than Poly Wireless and Radii-Cal. For SDR, the conversion was uniform across the material's depth, regardless of the apparatus used. There was a positive correlation between the irradiance values and the activation capacity when considering the data obtained with the tip of the curing device distanced from the analysis sensor. There was a positive correlation between the LCUs' cost and its collimation capacity. **Conclusions:** The LCU had little influence on the DC at the subsurface. The GC was dependent on the LCU at a depth of 4 mm for regular-viscosity bulk-fill composites, and the behavior of the SDR resin was homogeneous as a function of depth and not dependent on the light source employed. A positive correlation was observed (a) between activation capacity and light source collimation and (b) collimation capacity and LCU cost. **KEYWORDS:** Photoactivator. Photoinitiator. Degree of conversion. Bulk-fill resin.

Introduction

Bulk-fill composites is a term with the meaning of mass filling, available in regular and low-viscosities and has been standing out due to the possibility of photoactivation of 4-5 mm increments and consequent reduction in clinical time.[1-4]

In general, the extent of polymerization of composite resins may be affected by the type of composite, formulation and proportion of monomers employed; inorganic fraction, mass viscosity, increment thickness, reaction of the temperature and photoactivation protocol.[5-7] To ensure that a greater depth of polymerization is achieved in bulk-fill resins without compromising mechanical properties, a number of modifications have been made to the basic formulation of traditional composite resins, such as the use of new monomers, the use of chemical modulators in the polymerization reaction, the use of new photoinitiators systems and, most often than all, increased translucency.[8,9]

The degree of conversion (DC) is related to the amount of monomers converted in the polymer chain and, consequently, associated with the development of the mechanical properties of the composite.[10] In theory, low conversion may result in unreacted free monomers, which may dissolve and cause material degradation, consequently risking the restoration longevity. Thus, obtaining adequate conversion is of utmost importance. A fundamental part of the clinical success in the use of bulk-fill resins may be directly related to the use of appropriate photoactivating devices.[11]

Several light curing unit (LCU) are available in the market, with variations like shape, power (cable vs. battery), category of the tip of the source and size, emission spectrum, among others.[12] Depending on the equipment without comparison, large variations may occur in relation to the price of the device, which may result in doubt about its real benefit to the clinicians. An accurate analysis of the real benefit of these devices is still necessary.

Therefore, the present study aims to: a) determine the influence of LCU on the DC on the top and bottom regions of bulk-fill resins of three different formulations; b) determine which light evaluation parameter is capable of predicting photoactivation capacity on account of the depth; and c) verify if these parameters are related to the cost of the LCU.

The hypotheses tested throughout this research were:

1. that the LCU would not be determinant of the DC in the top region, but it would affect the bottom for regular consistency bulk-fill resin and conventional photoinitiator system;
2. that the LCU would not be determinant of the DC in the top region, but it would be determinant in the bottom for regular consistency bulk-fill resin and alternative photoinitiator system;
3. that the LCU would not be determinant of the DC in the top region, but it would be influence in the bottom for flowable consistency bulk-fill resin and conventional photoinitiator system;
4. that the activation potential of a LCU is related to its irradiance when considering direct measurement; and
5. that the ability to preserve the amount of light emission as it is moved away from the object (collimation) is not related to the cost of the LCU.

MATERIALS AND METHODS

Materials used and characterization of light curing unit

For the present study, four light emitting diodes (LED) LCUs were tested, being two LCU emitting light only of the blue spectrum (monowave) - Poly

Wireless (Kavo Kerr, Joinville, SC, Brazil) and Radii-Cal (SDI, Bayswater, Victoria, Australia) - and two LCU emitting blue and violet spectrum (polywave) - Bluephase G2 (Ivoclar Vivadent, Liechtenstein) and Valo Cordless (Ultradent, South Jordan, UT, United States). The irradiance (mW/cm2) of each device was measured by a digital radiometer (RD7, Ecel, Ribeirtão Preto, SP, Brazil). The irradiance was also determined by calculating power in mW with a potentiometer (Ophir Optronics Solutions, Jerusalem, Israel) divided by the area of the LCU (in cm^2). For the second method, the measurements were calculated with the tip of the LCU directly positioned over the sensors establishing a limit of 6 mm of spacing, aiming to verify the bottom/top ratio; therefore, establishing the collimation potential of that specific LCU.

Considering the proposal of this study, three commercially composites were analyzed: 1) Aura Bulk-fill (SDI, Bayswater, Victoria, Australia), representing a regular-viscosity bulk-fill resin and a traditional photoinitiator system; 2) Tetric N-Ceram Bulk-fill (Ivoclar Vivadent, Liechtenstein), representing a regular-viscosity bulk-fill resin and an alternative photoinitiator system; and 3) Surefill SDR (Dentsply), representing a low-viscosity bulk-fill resin and a traditional photoinitiator system.

Degree of conversion (DC) analysis

The DC of each material was determined on the top (0.1 mm) and bottom (4 mm) regions. In order to do so, plastic molds with thickness already mentioned before were used, with 6 mm in diameter. The reading was performed by Fourier transform infrared spectroscopy (FTIR) through the attenuated total reflectance technique (Alpha; Bruker Optics, Ettlingen, Germany; with 16 scans and $4cm^{-1}$ resolution). For spectrum analysis, the carbon chain vibratory modes at peaks of ~ 1638 cm^{-1} (aliphatic bonds) and peaks of ~ $1608cm^{-1}$ (aromatic bonds) were analyzed before and after the photoactivation process, which obeyed the manufacturers' recommended time (40 seconds for Aura Bulk-fill, 10 seconds for Tetric N-Ceram Bulk-fill and 20 seconds for Surefil SDR).

Thus, the degree of conversion (DC, in%) was determined by the formula:

$$GC = 100 \times \left\{1- \left[\frac{(C{=}C_{pol}/aromatica_{pol})}{(C{=}C_{npol}/aromatica_{npol})}\right]\right\}.$$

In which DC means degree of conversion, $C{=}C_{pol}$ means the value of the absorption peak area of the aliphatic bonds C=C of the polymerized sample, $aromatica_{pol}$ means the value of the aromatic ring absorption peak area of the polymerized sample, $C{=}C_{npol}$ means the value of the absorption peak area of the C=C alipha tic bonds of the unpolymerized sample and aromaticapol means the value of the aromatic ring absorption peak area of the unpolymerized sample.

Statistical analysis

In order to verify the influence of LCU on the DC of top/bottom, the normality of data distribution was verified and two-way analysis of variance was followed by Tukey's post-hoc test (95%). Independent analyzes were performed for each composite.

As for the irradiance analysis, the calculation of the bottom/top ratio was determined for the DC values. Pearson correlation analyzes (95%) were performed to calculate the possibility of a relation between the irradiance values (top, bottom and ratio) and those found for DC (top, bottom and ratio). Correlation analyzes were also calculated to analyze the possibility of a relation between the irradiance values in the different forms of analysis and the average cost of LCU, obtained through three online commerce platforms.

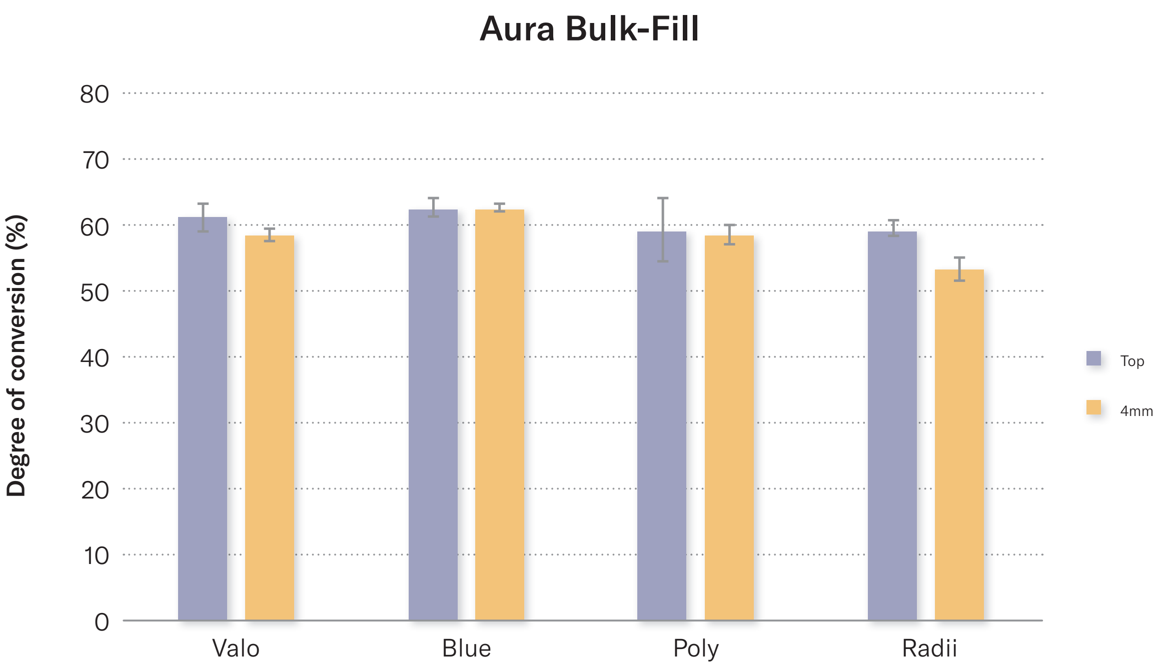
RESULTS

Table 1 shows the registration of the irradiance values found for the LCU tested with both radiometer and potentiometer analysis. Thus, it can be observed that the recorded irradiance value was of little variation, between the two polywave LCU - (Valo Cordless and Bluephase G2) - and one of the monowave LCU - (Poly Wireless) - when analyzing the top values. However, the analysis of the bottom/top ratio (% 6 mm/direct) indicates that the Bluephase G2 and Valo Cordless LCU presented higher collimation than the others.

Table 1: Irradiance values (mW/cm^2) determined by radiometer and potentiometer, as well as the ratio between the values found when the LCU is distanced from the sensor (6 mm) and those when the tips are in contact with it (direct).

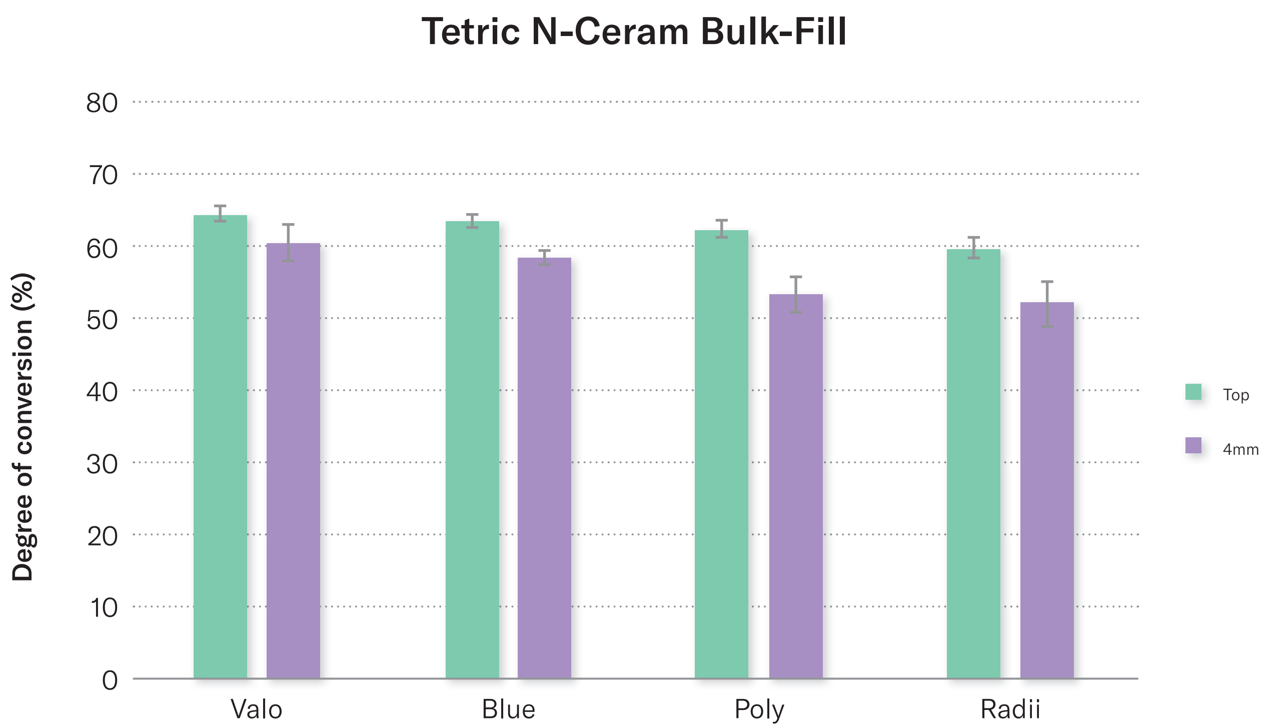
LCU	DIRECT RADIOMETER	POTENCIOMETER		6 MM/DIRECT (IN %)
		Direto	6 mm	
Valo Cordless	1250	1037	739	71
Bluephase G2	1450	1218	959	78
Poly Wireless	1400	849	521	61
Radii-Call	950	1177	553	47

The results from Aura Bulk-fill resin are presented in Figure 1. On the top region, there was no difference in the DC as a function of the LCU employed. When the bottom region was analyzed, the Radii-Cal LCU produced lower conversion values compared to the other tested devices. Related to Tetric N-Ceram Bulk-fill resin (Fig 2), the best results of DC in the top region were obtained by the Valo Cordless, Bluephase G2 and Poly Wireless confronted by Radii-Cal LCU. On the bottom region, Valo Cordless and Bluephase G2 showed the highest DC values when compared to Poly Wireless and Radii-Cal LCUs. Regarding the top-bottom values, the DC of bottom was always lower than the top, disregarding the LCU used. For the Surefill SDR composite (Fig 3), there was no significant difference between the top and bottom LCUs tested. When comparing the DC values of the top-bottom regions, there was no statistical difference.



Significance values (“p”): LCU, p = 0.048; depth, p = 0.032; LCU * depth, p = 0.021.

Figure 1: DC in samples of 0.1 mm (representing the top) and 4 mm thickness of Aura Bulk-fill resin when photoactivated by four LCU



Significance values ("p"): LCU, p = 0.012; depth, p = 0.002; LCU * depth, p = 0.001.

Figure 2: DC to 0.1 mm (representing the top) and 4 mm thickness samples of Tetric N-Ceram Bulk-fill resin when photoactivated by four LCU.

Table 2 shows the correlation coefficients obtained between the LCUs irradiance data and the composite resin conversion data. There is a greater possibility of relation between the characteristics of the LCUs and the consequent polymerization of the material when considering the distanced irradiance values of the sensor and also when considering the ratio 6 mm / direct.

The average cost (quoted on January 2019) of LCUs was $ 4,601 for Valo Cordless, $ 4,197 for Bluephase G2, $ 1,115 for Kavo Poly Wireless, and

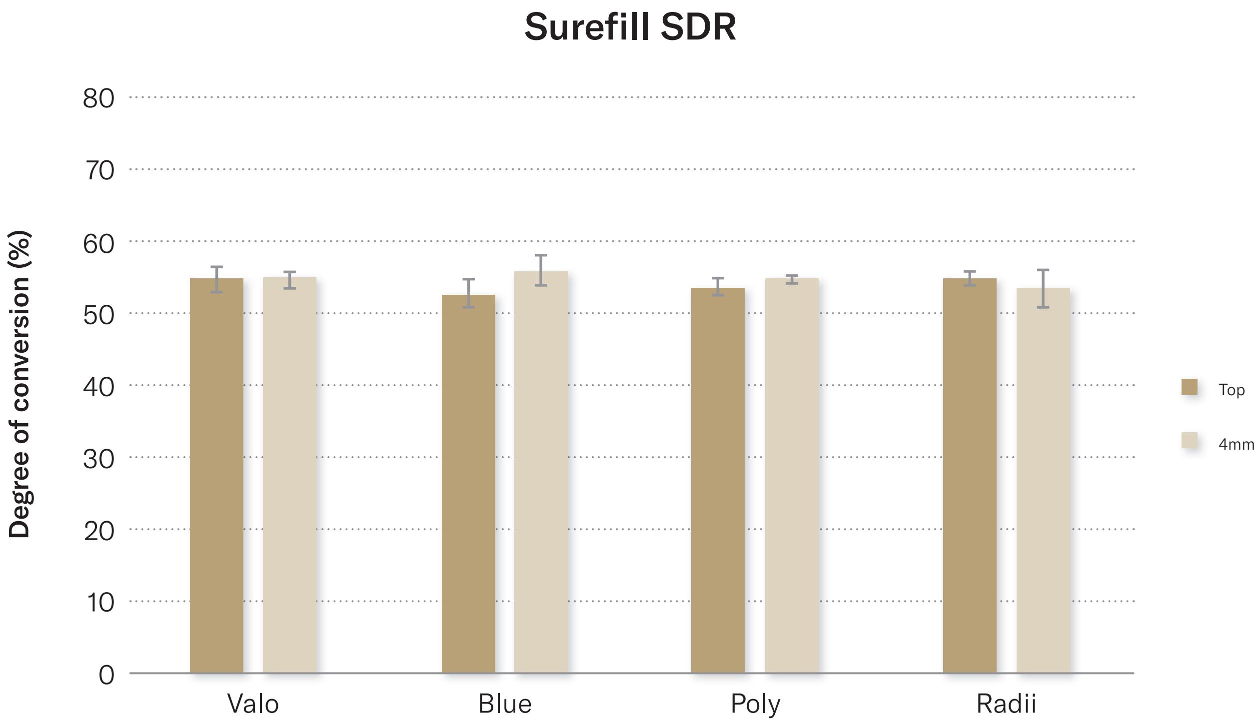


Figure 3: DC to 0.1 mm (representing top) and 4 mm thickness samples of Surefill SDR resin when photoactivated by four LCU.

$ 1,490 for the Radii-Cal. Based on these values, the possibilities of correlation with the irradiance values obtained in the mentioned situations were calculated. Thus, there was a positive and significant correlation ($p < 0.05$) when considering the irradiance values with the 6 mm spacer (r = 0.850801686) and also with the 6 mm / direct ratio (r = 0.817501837). There was no correlation between the irradiance values obtained by direct analyzes, either with the radiometer (r = 0.342945724) or with the potentiometer (r = 0.421342234), and the cost of LCUs.

Table 2: Correlation coefficients obtained between the LCU irradiance data and the composite resin conversion data.

	AURA BF			TETRIC BF			SUREFIL SDR		
	GC top	GC bottom	Reason	GC top	GC bottom	Reason	GC top	GC bottom	Reason
Radiometer	0,53086	***0,929554***	***0,905821***	***0,754371***	0,445916	0,472834	***0,907218***	-0,79302	0,856623
Potenciometer	0,502485	0,031076	-0,01155	-0,22133	0,206809	0,172004	***0,100459***	-0,15515	0,057107
Retractor 6mm	***0,980524***	***0,790961***	***0,788135***	0,595163	***0,766764***	***0,757185***	***0,821734***	-0,6213	***0,830240***
6mm/direct	***0,904549***	***0,949783***	***0,984916***	***0,906281***	***0,855009***	***0,865142***	***0,940907***	-0,62769	***0,997628***

Values highlighted in bold and italics call statistical significance ($p < 0.05$).

DISCUSSION

It is considered that the DC of a composite resin is directly linked to the properties of the final polymer formed, such as improved mechanical behavior and also greater degradation resistance.[10] Thus, it can be assumed that polymerization capacity may be associated with failure rates in retention of direct restorations and adverse pulp responses caused by unpolymerized monomers. Given that innovations are constantly introduced to the world, it is essential that independent studies be carried out - including to ascertain if the cost of any innovations entail real benefits. For this reason, four LCUs of recognized acceptance among Brazilian clinicians - which have significant price variations - in relation to the polymerization capacity of bulk-fill resins were evaluated. Due to variations in formulation between bulk-fill composites,[13] three representative brands were selected from different categories - with consistency and initiator system variations.

At first, the present study aimed to determine the influence of the LCU on the DC on the top and bottom regions of bulk fill resins of three different formulations. The first research hypothesis was that the LCU would not be determinant of the DC on the top region, but it would influence the bottom for regular consistency bulk fill resin and conventional photoinitiator system. Considering the results obtained with the Aura Bulk-fill composite, in which the results obtained by the Radii-Cal were inferior to the others on the bottom region - even after 40 seconds of activation - the hypothesis of the study was accepted. The discussion about the differences produced by LCUs follows the report of the findings found using the Tetric N-Ceram Bulk-fill composite.

The second research hypothesis was that the LCU would not be determinant of the DC on the top region, but it would influence the bottom region for regular consistency bulk-fill resin and alternative photoinitiator system. Thus, after analyzing the results obtained with the Tetric N-Ceram Bulk-fill composite, the Valo Cordless and Bluephase G2 produced higher conversion grade values than those produced by Poly Wireless and Radii-Cal on the 4 mm region. The second hypothesis of work was then also accepted. The lower conversion percentage on the bottom region of the Tetric N-Ceram Bulk-fill composite may be related to a photoinitiator present in its composition besides camphorquinone. Commercially named Ivocerin™, this photoinitiator is excited by light between 380-450nm and would be an interesting option when considering aesthetic aspects. However, studies indicate that this type of initiator is not able to provide adequate and deeper conversion due to the low penetration of short wavelength (violet) light within the composite.[14-16]

When analyzing the results obtained on the bottom region for the Tetric N-Ceram Bulk-fill composite, it was found that the LCU polywave produced higher conversion values than those promoted by LCU monowave. Thus, one can immediately believe that the behavior of this material is really dependent on violet light as some works show,[11] but it is essential to consider that the LCU polywave used presented a higher light collimation than monowave - this is the real cause of the difference between the LCU employed. A systematic review concludes that polywave LCU are useful but not essential to activate commercially available resins containing alternative primers.[17] In addition, 10s of photoactivation were employed, and despite being the manufacturer's recommendation, it is a relatively short time compared to traditionally employed materials.[17] A recent study by the research group conducting the present work shows that when this time is raised to 20s monowave LCU was able to activate the material similar to polywave LCU (unpublished data). Another fact that demonstrates how much the activation capacity due to depth may be associated with the potential for collimation is that the Radii-Cal produced statistically lower values than other LCU, even when long 40 seconds were used for Aura BF composite.

Among the bulk-fill composites tested, SureFill SDR composite presented the most uniform DC in all depth extension and did not depend on the LCU employed, rejecting the third hypothesis. Similar behavior has been presented in other analyzes[18] and this characteristic can be attributed to resin viscosity prior to light curing, which is influenced by monomer composition and charging content. The low-viscosity is an important parameter regarding the final kinetics reaction, as it affects the mobility of reactive species. A photoactive group integrated in urethane-based methacrylate monomers, which is capable of interacting with caforoquinone, is also present in the composition of these composite - it also makes it possible to modulate the fixation reaction, controlling the polymerization stress due to the greater flexibility of urethane groups, as well as conducting a more homogeneous network formation.[8]

The second objective of this study was to determine which light evaluation parameter is able of predicting the photoactivation capacity due to the depth of bulk-fill composites. The hypothesis tested worked with the possibility of this capacity be related to its irradiance when considering direct measurement, but it was rejected. Even though being useful in clinical practice as a way to verify the condition of the photoactivator, studies indicate that conventional radiometers should not be considered in the case of more accurate analysis and that other forms of evaluation should be employed to characterize LCUs.[19,20] As shown in Table 1, the values recorded by the radiometer and the power meter differ significantly. This is related to the reading area, which is not considered in the first one. Regardless of these differences, the correlation analyzes show that the irradiance values obtained from the direct analyzes were not related to the photoactivation capacity due to the depth. For greater predictability, it is necessary to calculate the irradiance when the LCU is moved away and, therefore, estimate the collimation capacity. Obviously, direct reading is fundamental for this analysis and does not exclude the need for the LCU to emit large amounts of light from its output.[21]

The third general objective of this study was to verify if the light analysis parameters that predict the activation capacity of a LCU are related to its cost. The hypothesis tested - that the collimation capacity is not related to the cost of the LCU - was rejected. It is difficult to establish the reason for the costs of a given LCU because several factors must be considered, such as technical and comercial variations that are not subject to discussion in a scientific article. In a simple rationale, it is possible to speculate that cost differences of fiber optic tips and output lenses may be associated with those differences observed between Bluephase G2 and Poly Wireless - involving differences in fiber optics - and Valo Cordless and Radii-Cal, where the first presentes a glass lens and less distortion while the second is made with an acrylic tip that negatively interferes the passage of light.

It is important to highlight that the cost for materials used in the health system have been considered in scientific studies, especially when the aim is to calculate the cost-benefit of a given treatment. At the moment of this publication, there is no evident record of similar comparison in databases of recognized importance for dental research. In this sense, this study is a pioneer in relation to the cost of LCUs and their real benefit in terms of their potential polymerization. Concerning limitations, it can be considered that the conversion analysis after 5 minutes may not be related to the final DC of the material. Although, studies show that bulk-fill composites with higher post-photoactivation conversion (late polymerization, “in the dark”) present a greater chance of degradation over time when exposed to solutions.[22]

CONCLUSIONS

1. The LCU employed had little influence on the DC on the subsurface.
2. The DC in reason of depth was dependent on the LCU for regular-viscosity bulk-fill composites. The behavior of Surefill SDR composite was homogeneous on all depth and it did not depend on the LCU employed.
3. There is a positive and significant correlation between the activation potential of a LCU and its collimation capacity.
4. The collimation capacity of the LCUs employed was associated with their respective costs.

ACKNOWLEDGMENT

To Prof. Dr. Mário Alexandre Coelho Sinhoreti, on behalf of the Piracicaba School of Dentistry of the State University of Campinas (FOP / UNICAMP) for the possibility of checking the photoactivating devices. LFS thanks FAPERJ for the financial support through the Young Scientist of Our State announcement and FUNADESP for the granting of research support.