



UNIVERSIDADE FEDERAL DE UBERLÂNDIA
FACULDADE DE ODONTOLOGIA



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**ABILITY OF LOW-COST GENERIC AND
REFERENCE LIGHT-CURE A BULK-FILL
RESIN-BASED COMPOSITE**

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Trabalho de conclusão de curso apresentado
a Faculdade de Odontologia da UFU, como
requisito parcial para obtenção do título de
Graduado em Odontologia

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Ability of low-cost generic and reference light-curing units to light-cure a bulk-fill resin-based composite

RESUMO

Para comparar a dureza Knoop da uma resina composta OPUS Bulk Fill APS (FGM) fotoativada por quatro fontes de luz, sendo 2 genéricos de baixo custo: VRN-VAFU Black e VRN-VAFU Purple (Guilin Veirun Medical Technology), comparadas às duas fontes de referência: VALO Grand e o VALO Cordless (Ultradent). As amostras de resina composta (n = 10) foram fotoativadas por 20 s no modo padrão ou 3 s no modo de alta potência. A potência, energia e o espectro de emissão foram medidos usando esfera integradora acoplada a espectrômetro de fibra óptica. A irradiância foi calculada e os perfis de feixe foram obtidos. A dureza Knoop foi medida no topo e base das amostras. Os dados foram analisados usando ANOVA 2-fatores e teste de Tukey ($\alpha = 0,05$). A irradiância e potência foram maiores no modo de alta potência, porém a energia fornecida foi significativamente maior no modo padrão, independentemente da fonte de luz. Os perfis dos feixes dos fotopolimerizadores genéricos foram heterogêneos, sem emissão de comprimento de onda violeta (400 nm). Os dois modos de fotoativação, e as fontes de luz produziram valores de dureza Knoop semelhantes no topo das amostras (>51,7 - Opus Bulk Fill). Porém, houve redução significativa da dureza Knoop na base no modo de alta potência para todas fontes de luz. O modo de alta potência forneceu menos energia e produziu menores valores de dureza na base. Portanto, tempos curtos de exposição com alta irradiância não devem ser usados com essa marca de resina composta.

ABSTRACT

The Knoop hardness (KH) of OPUS Bulk Fill APS (FGM) resin-based composite (RBC) was compared after it had been light-cured using four different light-curing units (LCUs). The VRNVAFU Black and VRN-VAFU Purple (Guilin Veirun Medical Technology Co., Ltd.) were classified as generic low-cost LCUs and were compared to the VALO Grand and VALO Cordless, (Ultradent). The RBC specimens ($n = 10$) were light-cured for 20 s in standard mode or 3 s in the high-power mode. Power, energy, and emission spectra were measured using an integrating sphere attached to a fiber optic spectrometer. Irradiance was calculated, and beam profiles were obtained. The KH was measured at the top and bottom surfaces. Data were analyzed using two-way ANOVA and the Tukey test ($\alpha = 0.05$). The irradiance and power were higher in the high-power 3 s mode, but the radiant exposures delivered to the RBCs were significantly higher in the standard mode, irrespective of LCU. The generic LCU's beam profile was heterogeneous and lacked violet light (400 nm). Both curing modes and LCUs produced similar top KH values, >52 in Opus Bulk fill (FGM), but there was a significant reduction in the KH at the bottom in the high-power 3 s mode for all four LCUs. The high-power 3 s mode delivered less energy and produced lower KH values at the bottom surfaces. Thus, short exposure times with high irradiance should not be used with this brand of RBC.

Keywords: light-curing units, energy, multiwave, Knoop hardness, resin-based composites.

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INTRODUCTION

The practice of dentistry in private and public dental services requires efficient, practical, and reliable treatment procedures. Since their introduction, bulk-fill resin-based composites (RBCs) have become popular for restoring posterior teeth (1). Their properties are now similar to those of conventional RBCs (2), and bulk-fill RBCs can be light-cured in increments of up to 4–5 mm (2). However, a good light-curing unit (LCU) and a good light-curing technique are required to deliver sufficient energy to reach the bottom of the RBC restoration (3, 4).

Contemporary light-emitting diode (LED) LCUs often offer several light-curing modes with different light outputs and exposures that deliver various radiant exposures to the RBC (5). The introduction of high-power LED chips (6) has enabled the manufacture of LCUs that now deliver greater power and higher irradiance modes than from quartz-tungsten (QTH) or even plasma arc lights (7). Following the trend of making dental procedures more efficient, many light manufacturers have included a curing mode in their LCUs that delivers a high irradiance for a short exposure time (8). However, the combination of these two parameters has caused confusion because most RBC manufacturers do not recommend using these short exposure times, instead they usually recommend using a 10 to 40 s exposure time. The longevity of RBC restorations depends on how well the resin is light cured (3), and it is well known that if the minimum required amount of energy is not delivered, the RBC will not reach the manufacturer's intended properties, and its mechanical properties will be compromised, especially at deeper locations of the restoration (3, 10). It has been suggested that to ensure proper light-curing, each 2-mm-thick RBC layer should receive approximately 16 J/cm² (9). However, to deliver a radiant exposure of 16 J/cm² in 10 s, the LCU must emit an irradiance of at least 1,600 mW/cm², and to deliver 16 J/cm² in 3 s the LCU must deliver 5,333 mW/cm² (4). Very few LCUs deliver this irradiance and unless the exposure time is increased, this may lead to problems such as debonding, postoperative discomfort, discoloration, or premature failure of the RBC restoration (5).

LCUs from dental manufacturers who manufacture RBCs can light-cure their RBCs if their manufacturer's instructions are followed (5). However, the LCUs from most major dental manufacturers are usually expensive (11). Chinese curing light manufacturers have copied curing lights made by major dental manufacturers, and they sell these curing lights at significantly lower costs. Consequently, many dentists

and students think that these generic LCUs are equivalent to LCU from major dental manufacturers, and they purchase these low cost LCUs based on their cost and marketing claims (11).

VALO LCUs (Ultradent Products, South Jordan, UT, USA) have consistently received good reports on their performance and ergonomic design (12) and they have become one of the best-selling LCUs (13). The Chinese manufacturer (Guilin Veirun Medical Technology Co., Ltd.) produces the VRN-VAFU, an LCU that appears to copy the VALO LCUs (Ultradent). The VAFU manufacturer claims that this LCU delivers wavelengths ranging from 385 to 515 nm and three light modes with irradiance levels ranging from 1,600 to 3,200 mW/cm². These specifications and the appearance of the VAFU are similar to those of the Valo.

LCUs are classified as Class II medical devices by the US Food and Drug Administration (FDA) and because they pose a potential moderate risk to patients, users, or both, LCUs must meet specific standards before they are sold in the USA (14). Other countries have similar standards. However, due to the unrestricted online availability of dental products, many unapproved LCUs are sold from online marketplaces, but it is unknown if these LCUs can photocure RBCs as well as the LCU that they have copied.

Therefore, this study compares the performance of such generic LCUs to reference multiwave LCUs from a major dental manufacturer (Ultradent) by measuring the Knoop hardness (KH, Kgf/mm²) of one bulk-fill RBC when photocured using the standard (20 s) or the high-power (3 s) curing modes. The null hypotheses were:

- (1) the light-curing mode on the LCU does not affect the Knoop hardness at the top and bottom of the tested bulk-fill RBC;
- (2) both reference and generic LCUs will produce comparable Knoop hardness results at the top and bottom surfaces of the RBCs;
- (3) the generic light sources will deliver a spectral emission that is similar to the reference light source they appear to have copied.

MATERIALS AND METHODS

Study design

Four multiwave (violet-blue) LCUs were used in this study (Table 1). Two were low-cost generic LCUs, VRN-VAFU Black and VRN-VAFU Purple (Guilin Veirun

Medical Technology Co., Ltd., Guilin, Guangxi, CHI) and two were popular LCUs from a major manufacturer (VALO Grand and VALO Cordless, Ultradent Products, South Jordan, Utah, USA). The power (mW), energy (J/cm^2), and spectral emission ($\text{mW}/\text{cm}^2/\text{nm}$) were measured, and the light beam profiles were recorded from all 4 LCUs using two different light output modes: standard 20 s and highpower 3 s. The Knoop hardness at the top and bottom of OPUS Bulk Fill APS (FGM, Joinville, SC, Brazil) RBC that had been light cured in 8 mm wide and 4 mm deep specimens was used to compare the ability of the LCUs to light cure a bulk fill RBC. The composition and information provided by the manufacturer of the RBC are listed in Table 2.

Characterization of Light-Curing Unit (LCU)

The power (mW), energy (J/cm^2), and spectral emission ($\text{mW}/\text{cm}^2/\text{nm}$) from the LCUs in both curing modes were recorded through a 12.5 mm aperture into a 6-in integrating sphere (Labsphere, North Sutton, NH, USA) attached to a fiber-optic spectrometer (USB 4000, Ocean Insight, Largo, FL, USA). Before use, the measurement system, which included a spectrometer, an optical fiber, and an integrating sphere, was calibrated. The light tip of each LCU was positioned at the aperture of the integrated sphere to capture all the light. A digital caliper (Mitutoyo, Tokyo, Japan) was used to measure the internal diameter (mm) of the light tip. The mean irradiance across the light-emitting surface of the tip was calculated as the quotient of the average of the five radiant power values (mW) and the internal optical area (mm^2) of the LCU tip (15). This provided the average single-irradiance value across the entire light tip. The light transmission through the 8- mm diameter 4-mm thick RBC specimens into the sphere was recorded for all the LCUs.

Light beam profiles of the LCUs were measured using a laser beam profiler (Ophir Spiricon, Logan, UT, USA), as previously described (13). The light tip diameter and the power emitted from the LCUs were inputted into BeamGage Professional 6.14.0.355 software (OphirSpiricon). Subsequently, the calibrated data file was exported to OriginPro 2018 software (OriginLab, Northampton, MA, USA) to produce calibrated two-dimensional beam profile images illustrating the irradiance (mW/cm^2) and radiant exposures (J/cm^2) delivered to the surface of the RBC for all the LCUs. Calibrated three-dimensional color-coded profile images were also made (BeamGage Professional) after the light from the LCU had passed through narrow bandpass filters that transmitted light with a 10 nm full-width half maximum bandwidth centered at either 400 nm (violet) or 460 nm (blue) (#65-132 and #88-010, Edmund

Industrial Optics, Barrington, NJ, USA) so that only the violet or blue light wavelengths were recorded. In the images, red indicates high irradiance (100% or maximum), and purple represents a low irradiance from the emitting tip of the light guide.

Knoop hardness (KH)

Opaque plastic ring molds with an internal diameter of 8 mm and 4 mm deep were used to prepare the specimens of each group ($n = 10$). A Mylar strip (Preven, Guapirama, PR, Brazil) was used to cover the mold to achieve a smooth surface. The RBC in the mold was then pressed flat between two glass plates, after which the plates were removed. All the RBC specimens were lightcured at a distance of 1 mm from the tip of the LCU under the same conditions in a controlled room temperature in a room that was illuminated with only yellow light. The Mylar strips were removed, and the specimens were stored in the dark for 24 h and at 37°C before they were subjected to KH testing. Five indentations with at least 1 mm between them were made on the top and bottom surfaces at standardized locations at the center of each surface and in each quadrant. The Knoop indentation values were determined using a microhardness tester (FM700; FutureTech Corp., Kawasaki, Japan) using a load of 50 g that was applied for 10 s.

Statistical analysis

KH data were analyzed for normal distribution (Shapiro–Wilk test) and homoscedasticity (Levene's test). The KH data were then analyzed using a two-way analysis of variance (ANOVA) with repeated measurements carried out based on the study factor of the LCU types (four levels), light-curing modes (two levels), and measurement locations on the top and bottom of the specimens (two levels), followed by Tukey post-hoc tests for multiple comparisons. All statistical analyses were conducted with the statistical package Sigma Plot version 13.1 (Systat Software, San Jose, CA, USA) using an $\alpha = 0.05$ significance level.

RESULTS

The tip diameter (mm), power (mW), irradiance (mW/cm^2) and radiant exposure (J/cm^2) of each LCU are reported in Table 3. The VALO Grand (Ultradent) had the largest tip diameter (11.8 mm), followed by VRN-VAFU Purple (9.8 mm), whereas

VALO Cordless (9.6 mm) and VRN-VAFU Black (9.6 mm) had the same tip size. The high-power 3-s modes delivered the highest power and irradiance, but the standard mode delivered the greatest radiant exposure (J/cm^2) when used for 20 s.

The radiant power (mW) and emission spectrum ($\text{mW}/\text{cm}^2/\text{nm}$) from the LCUs through the 8-mm diameter empty matrix are reported in Figure 1. As expected, all the LCUs delivered more power in the high-power 3-s mode, and this output was constant throughout the exposure time. Both generic LCUs emitted similar power values that were greater than the reference LCUs in terms of power (mW) in the standard mode (609 - 752 mW). But, in the high-power mode, the VALO Cordless emitted the highest power value (1607 mW), followed by VRN-VAFU Purple (1607 mW), VALO Grand (1421 mW), and VRN-VAFU Black (1318 mW).

Figure 2 reports the calibrated irradiance two-dimensional beam profile images, showing the tip diameter and average radiant exitance (irradiance at the tip in mW/cm^2) across the light tip. Notably, the irradiance values were consistently higher than $1,150 \text{ mW}/\text{cm}^2$ inside the 8 mm diameter dotted circle corresponding to the diameter of the RBC specimens. The generic LCUs delivered a more concentrated irradiance over a small area in the high-power 3-s mode that was greater than $4,000 \text{ mW}/\text{cm}^2$.

The radiant exposure (J/cm^2) images distributed across the light tip shown in Figure 3 were generated by multiplying the irradiance beam profile images by the exposure time. For all LCUs, the standard mode, in 20 s delivered at least $24 \text{ J}/\text{cm}^2$ inside the 8 mm diameter dotted circle representing the diameter of the RBC specimen. The LCUs from the manufacturer Guilin Veirun had a concentrated region of high radiant exposure that reached as high as $47 \text{ J}/\text{cm}^2$ (VRN-VAFU Black 42 and Purple 47 J/cm^2), while the VALO Grand and Cordless delivered a more uniform radiant exposure that was approximately $30 \text{ J}/\text{cm}^2$ (29 and 31 J/cm^2 respectively). In the highpower 3-s mode, the radiant exposure values were at least 5 J/cm^2 across the light tip, but only approximately $14 \text{ J}/\text{cm}^2$ was delivered in 3 s (VRN-VAFU Black 14 and Purple 14. J/cm^2 ; VALO Grand 11 and Cordless 12 J/cm^2).

Three-dimensional representations of the beam profile recorded from all LCUs through the narrow bandpass filters are shown in Figure 4. Note the absence of any light emitted through the 400 nm bandpass filter for the VRN-VAFU Black and VRN-VAFU Purple LCUs and the inhomogeneous distribution of violet light both Valos.

This was due to the location of the violet LED emitter in the Valos. However, some violet light was emitted across all of the Valo light tips.

The mean and standard deviation KH (Kgf/mm²) values at the top and bottom surfaces of the OPUS Bulk-fill RBC specimens light-cured using the four LCUs using the two light-curing modes are reported in Table 4. The two-way ANOVA results showed that the KH values in the standard mode at the top and bottom surfaces when light cured in the standard mode were not significantly different between the LCUs. Also, no significant differences were observed in the KH values between the LCUs in the high-power mode for both the top and bottom surfaces.

The KH values measured at the top surface were always significantly higher than those measured at the bottom for both the standard and high-power modes, irrespective of the LCU tested. No significant differences were observed between the activation modes for the top surface; however, when the RBC was light-cured using the standard 20-s mode, the difference was significantly higher. The ratios between the KH values measured at the top and bottom of the RBC used in this study were consistently below 80%, but the ratios were higher in standard mode.

DISCUSSION

The light-curing modes did not significantly affect the KH values at the top surface of the RBC for all the tested LCUs. The KH values were similar to those reported in previous studies that used the same bulk-fill RBC (3, 10, 16). However, both curing modes affected the KH values at the bottom surface of the 4 mm RBC specimens, resulting in a bottom-to-top KH ratio that was much lower than 80% (Table 3). When light-cured using the high-power 3-s mode, the decrease in the KH values at the bottom surface was even more significant. Therefore, the first null hypothesis that the light-curing mode would not affect the hardness at the top and bottom of the RBC specimens was rejected.

Other studies have also tested the effects of using a high irradiance for a short exposure time on the material properties of a bulk-fill RBC (4, 22). These studies detected a direct relationship between the properties and radiant exposure (J/cm²) delivered from the LCU (4, 22). The KH values shown in Table 4 are expected to be reduced from the top to the bottom of a photoactivated RBC; however, it has been recommended that this value should be at least 80% (3). When a high irradiance for a short exposure time was used, the bottom surface of the specimen was

compromised, resulting in KH values that were between 25.4 and 19.9 Kg/mm² and the bottom/top ratio reached under these conditions was only approximately 42–36%. The KH values support Figure 3, confirming that the radiant exposure delivered to the RBC is directly related to the KH values at the bottom of the RBC.

It is well known that the irradiance and exposure time affect the energy delivered to the RBC and they directly influence the polymerization process of the resin (3) compromise the bottom surface of the restoration, which may increase the chances of detachment of the restoration from gingival surfaces and lead to early failures. In addition, it can be clinically extrapolated to the development of secondary caries (21). Several studies have reported that an exposure time of 20 s at an irradiance of $\geq 1,000$ mW/cm² will deliver at least 20 J/cm², and this should be sufficient to light-cure most RBCs (17-20). The present study found that light-curing the tested bulk-fill RBC for 20 seconds was sufficient to achieve acceptable KH values at the top of this brand of RBC, but not at the bottom surface. Since other studies that tested the same RBC using 40 s exposure time obtained satisfactory top/bottom ratios for KH (3, 10), this unacceptable outcome can be attributed to the fact that the manufacturer's recommended irradiance/exposure time of 450-1,000 mW/cm² for 40 s, or 1,000-2,000 mW/cm² for 30 s were not followed. Instead, exposure times of 20 s or 3 s were used, and an insufficient radiant exposure was delivered in 3-s. The manufacturer of the RBC tested in this study recommends that at least 18 J/cm² be delivered at a minimum irradiance of 450 mW/cm² (450 mW/cm² for 40 s), but at 1,000 mW/cm² they recommend that 30 J/cm² be delivered at 1000 mW/cm² (1000 mW/cm² for 30 s). This is 66% more energy at the higher irradiance level.

As shown in Figure 3, none of the LCUs used in this study in high irradiance mode (3 s mode) achieved values greater than 15 J/cm². Table 3 shows how much time, approximately 9 to 11 s would be required to ensure the same radiant exposure as in standard mode in 20 s using the high irradiance mode. Therefore, at least three exposures of 3 s mode for VALO Grand and Cordless LCUs and 4 exposures for VRN-VAFU Black and Purple are required. Thus, it is recommended that the recommendations provided by RBC manufacturers for exposure time and irradiance levels should be used to ensure appropriate light-curing and achieve satisfactory properties. However, it is also known that the amount of energy delivered to RBC is related to the increase in temperature (6) and above 5.5°C may cause irreversible

damage to the pulp tissue (22). Thus, the brand of RBC used in this study may not be suitable for rapid 3-s curing.

The low-cost generic and the reference LCUs produced similar performances, with no significant differences in the KH values observed at the top or bottom of the LCUs, regardless of the light-curing mode. Therefore, the second null hypothesis was accepted. This may be because the irradiance values across the 8 mm diameter sample in the central region of all LCUs were higher than 1,150 mW/cm². Furthermore, the generic and reference LCUs delivered similar radiant exposure (J/cm²) values under the same conditions (Table 3 and Figure 3). However, Figure 2 shows that the LCUs used in this study had different irradiance distributions across the light tip, and the VALO Grand (Ultradent) had the widest tip diameter.

Although the VRN-VAFU manufacturer claims to be a broad-spectrum LCU delivering violet light, the violet peak was absent from the tested VRN-VAFU Black and Purple LCUs (Fig. 1C 1D, 4). Only the reference LCUs emitted detectable wavelengths in the violet emission spectrum. The beam profile analysis using a 400 nm filter confirmed the absence of the violet spectrum (Figure 4). Therefore, the third hypothesis was rejected.

This study has some limitations. The specimens were made in optimal environments, with the light-curing unit (LCU) tip positioned near and perpendicular to the lower surface. Such an ideal scenario occurs infrequently within the oral cavity owing to limitations in how wide the patient can open their mouth and the presence of matrix bands, clamps, the rubber dam, the LCU design, the technique used by the operator, and patient movements, which can all adversely affect how much energy is delivered to the RBC (23). Therefore, the clinical results may be even more adversely affected. Another limitation was that while the RBC manufacturer does not recommend using an irradiance greater than 2000 mW/cm² and they recommend using a 30 s exposure time, . However, this study followed the light manufacturer's instructions and used 20 s or a high irradiance 3 s exposure mode. These directions most likely were the cause of the lower KH values at the bottom surface. In addition, only one type of RBC was tested. Thus, it is recommended that further studies with a greater variety of RBCs including those formulated for shorter light-curing times and high irradiance, and using different examples of the generic LCUs, should be conducted. Of note, the generic LCUs, tested in this study, which have very similar design to the reference LCUs (Figure 5), they are not certified for use on patients and

have not been evaluated by key regulatory agencies (e.g., the FDA - U.S. Food and Drug Administration or ANVISA - Brazilian Health Regulatory Agency). Considering that many other LCUs that are available from online sellers also do not have the necessary certifications (24), it is important to recognize that purchasing and then using unapproved medical devices on patients is not recommended (25). The absence of certification and the inability to contact the manufacturer of the device could pose a hazard for patients and may detrimentally affect a dentist's career (24, 25). To combat this type of practice, government agencies and licensing bodies should enforce their regulations for this type of medical device (25). Clinicians and patients will be better protected if the RBC manufacturer's instructions for use are followed. The clinician should also use a certified LCU that emits a homogeneous light output at an irradiance higher than 1,000 mW/cm². The light must also emit the appropriate wavelengths of light required by the photoinitiator used in the RBC that they are using.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

- Using the standard mode (20 s) and the high-power mode (3 s) light-curing modes resulted in similar KH values at the top, regardless of which LCU was used.
- Regardless of the mode and LCU, the KH at the bottom surface was always significantly lower.
- Generic LCUs, despite not delivering any violet light, light-cured the tested RBC similarly to the reference LCUs.
- Sufficient radiant exposure must be delivered to light-cure the bulk-fill RBCs in depth.
- Short 3 s exposure times at a high irradiance should be used cautiously for the bulk-fill RBC tested in this study.

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Tables

Table 1. Light-curing units (LCU) used in the study. Information provided by the manufacturers.

LCU	LCU Serial Number	LCU Type-Wavelength Emission	Manufacturer
VRN-VAFU Purple	VFE-02448	LED- multi-peak	Guilin Veirun Medical Technology Co., Ltd., Guilin, Guangxi, CHI
VRN-VAFU Black	VFE-02158	LED- multi-peak	Guilin Veirun Medical Technology Co., Ltd., Guilin, Guangxi, CHI
VALO Grand	S05627	LED- multi-peak	Ultradent, South Jordan, Utah, USA
VALO Cordless	C33856	LED- multi-peak	Ultradent, South Jordan, Utah, USA

Table 2. Information provided by the manufacturer of the resin-based composite.

Material/Shade	Lot	Type	Composition*	Manufacturer
Opus Bulk Fill APS, A2	10221/60521	Bulk-fill	Monomers: Triethyleneglycol dimethacrylate, Bisphenol A polyethylene glycol diether dimethacrylate, Urethane-dimethacrylate Fillers (76.5 wt.%): Silica with urethane dimethacrylate, salinized silica dioxide, salinized barium glass, YbF₃ - ytterbium fluoride Initiators: Advanced Polymerization System (APS)	FGM Joinville, SC, Brazil

Table 3. Means and standard deviation values of the power (mW), irradiance (mW/cm²) delivered to an 8 mm diameter specimen and radiant exposure (J/cm²) received by the RBCs using the different light curing modes. The time (s) that would be required to deliver the same radiant exposure on the high-power 3-s setting as on the standard 20-s setting are also included.

LCU	Tip diameter (mm)	Power (mW)		Irradiance (mW/cm ²)		Radiant exposure (J/cm ²)		Time to deliver the same radiant exposure on the high-power setting (s)
		Standard (20s)	High-power (3s)	Standard (20s)	High-power (3s)	Standard (20s)	High-power (3s)	
VRN-VAFU Black	9.6	751.9 ± 3.0	1505.2 ± 3.0	1496.7 ± 6.0	2995.9 ± 6.0	29.90 ± 0.10	9.00 ± 0.01	10.0
VRN-VAFU Purple	9.8	740.0 ± 8.0	1318.0 ± 0.5	1472.9 ± 16.0	2623.7 ± 0.8	29.40 ± 0.30	7.90 ± 0.01	11.2
VALO Grand	11.8	609.0 ± 0.1	1421.2 ± 6.0	1214.3 ± 1.0	2836.9 ± 1.0	24.20 ± 0.03	8.50 ± 0.02	8.5
VALO Cordless	9.6	693.3 ± 1.0	1606.6 ± 3.0	1370.9 ± 2.0	3197.9 ± 6.0	27.60 ± 0.04	9.60 ± 0.02	8.6

Table 4. Mean and standard deviation KH values (Kgf/mm²) of the OPUS RBC light-cured with the two generic and the two reference LCUs using two light-curing modes.

LCUs	Standard (20 s)		Bottom/Top Ratio (%)	High power (3 s)	
	Top - KH	Bottom - KH		Top - KH	Bottom - KH
VRN-VAFU Black	64.5 ± 2.6 Aa	40.7 ± 2.2 Ab*	63	59.5 ± 5.8 Aa	25.4 ± 5.7 Ab**
VRN-VAFU Purple	58.8 ± 3.8 Aa	40.5 ± 3.8 Ab**	68	59.7 ± 5.0 Aa*	19.9 ± 2.7 Ab***
VALO Grand	66.8 ± 1.8 Aa	43.3 ± 2.9 Ac**	64	58.4 ± 2.9 Ab*	21.4 ± 2.5 Ad***
VALO Cordless	58.1 ± 3.4 Aa	38.1 ± 4.9 Ab*	65	60.5 ± 2.1 Aa	22.5 ± 1.9 Ac**

Different letters mean significant difference - uppercase letters for comparisons between the LCUs, lowercase letters for comparisons to the surface measured - top or bottom. * Indicates a significant difference between the light curing mode for each surface analyzed (p<0.05).

Figure Legends

Figure 1. Radiant power (mW) and spectral emission (mW/cm²/nm) from the LCUs through the empty matrix. A and B illustrate the radiant power emitted by the four LCUs in 20 and 3 s, respectively. C and D show the wavelengths delivered by the LCUs. Note the absence of the violet peak from the VRN-VAFU Black and Purple LCUs.

Figure 2. Calibrated beam profiles from the LCUs showing the tip diameter and averaged irradiance (mW/cm²) across the light tip. Note the irradiance values were always higher than 1,150 mW/cm² inside the 8 mm diameter dotted circle corresponding to the diameter of the RBC specimens.

Figure 3. Calibrated beam profiles from the LCUs showing the tip diameter and averaged radiant exposure (J/cm²) across the light tip. Note that the 8 mm diameter dotted circle corresponding to the diameter of the RBC specimens.

Figure 4. Three-dimensional representations of the beam profile recorded through a 400-nm bandpass filter (violet light), and through a 460-nm bandpass filter (blue light) based on the standard and high-power mode of the four LCUs tested. Note the images taken through the 400- and the 460-nm bandpass filters are on their individual percentage scales at each wavelength range.

Figure 5. Similar design verified among generic and reference LCUs. A. VRN-VAFU Black; B. VRN-VAFU Purple; C. VALO Grand; D. VALO Cordless.

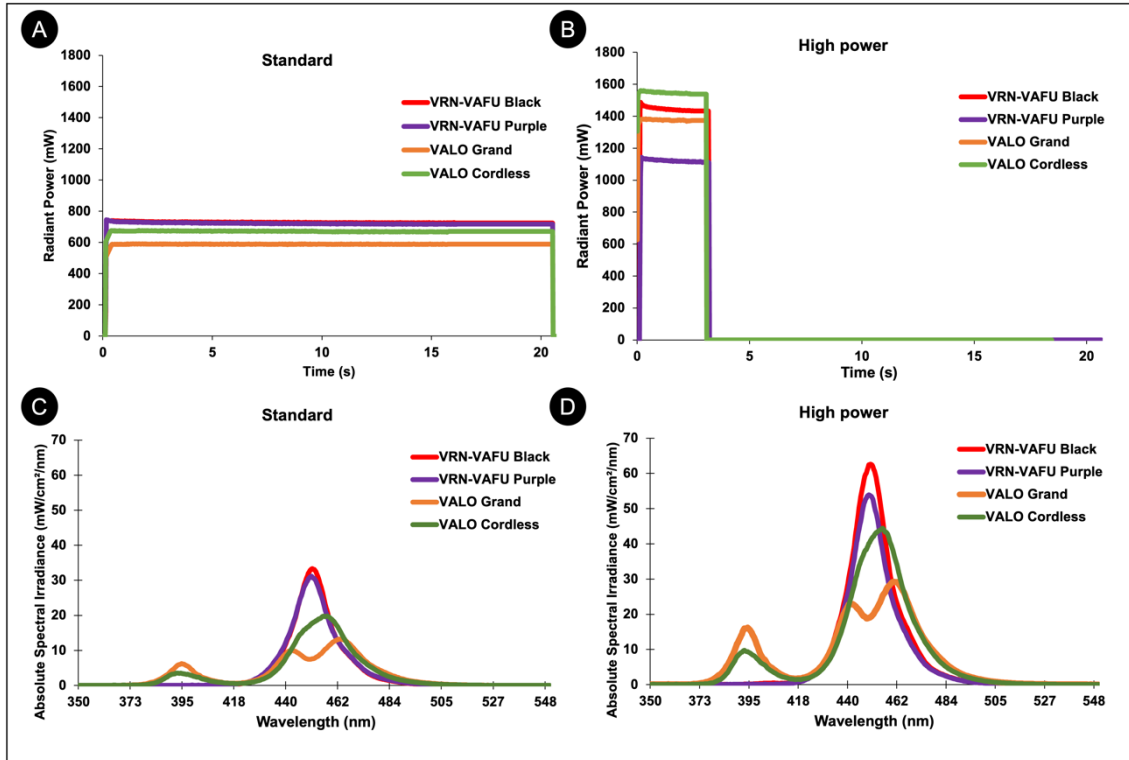


Figure 1. Radiant power (mW) and spectral emission (mW/cm²/nm) from the LCUs through the empty matrix. A and B illustrate the radiant power emitted by the four LCUs in 20 and 3 s, respectively. C and D show the wavelengths delivered by the LCUs. Note the absence of the violet peak from the VRN-VAFU Black and Purple LCUs. 160x108mm (300 x 300 DPI).

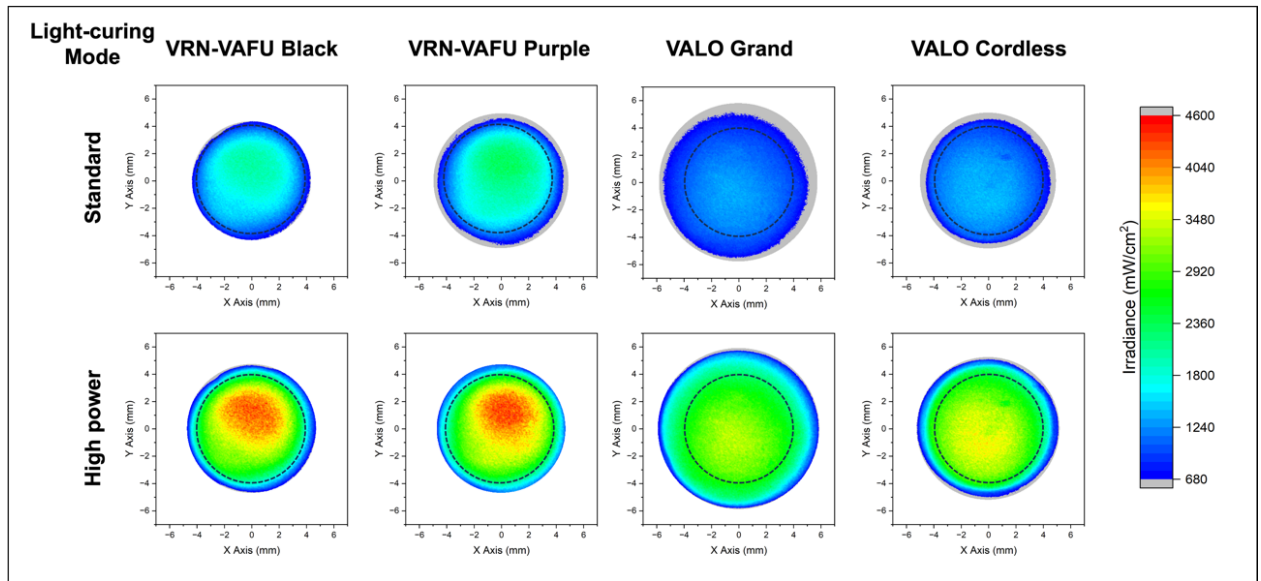


Figure 2. Calibrated beam profiles from the LCUs showing the tip diameter and averaged irradiance (mW/cm²) across the light tip. Note the irradiance values were always higher than 1,150 mW/cm² inside the 8 mm diameter dotted circle corresponding to the diameter of the RBC specimens. 159x74mm (300 x 300 DPI).

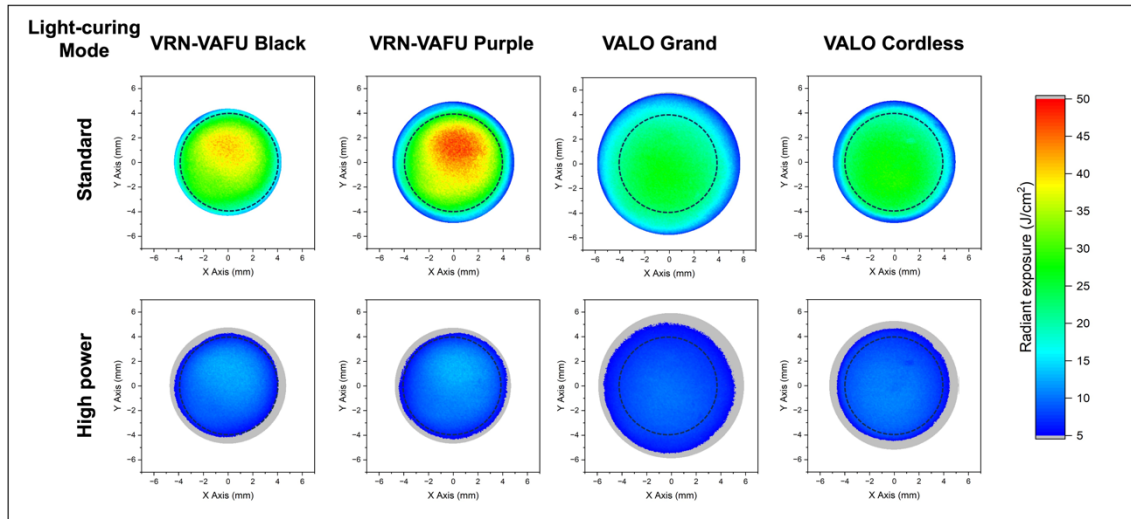


Figure 3. Calibrated beam profiles from the LCUs showing the tip diameter and averaged radiant exposure (J/cm^2) across the light tip. Note that the 8 mm diameter dotted circle corresponding to the diameter of the RBC specimens.

159x74mm (300 x 300 DPI).

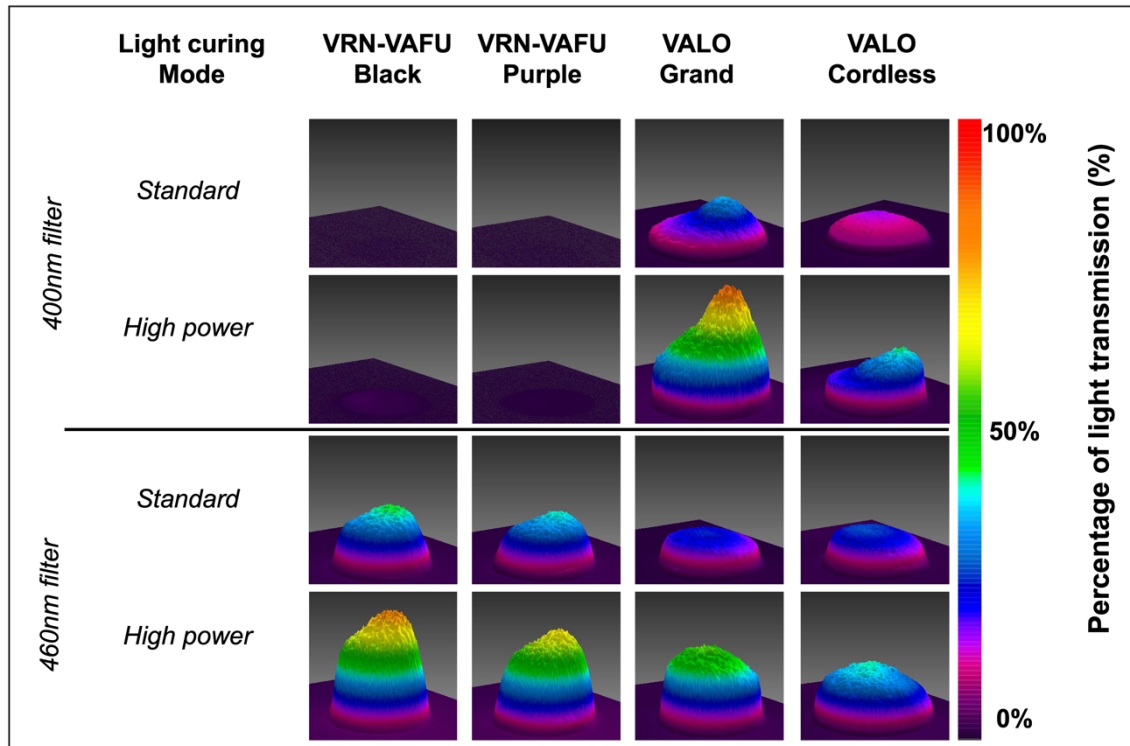


Figure 4. Three-dimensional representations of the beam profile recorded through a 400-nm bandpass filter (violet light), and through a 460-nm bandpass filter (blue light) based on the standard and high-power mode of the four LCUs tested. Note the images taken through the 400- and the 460-nm bandpass filters are on their individual percentage scales at each wavelength range.

159x105mm (300 x 300 DPI).



Figure 5. Similar design verified among generic and reference LCUs. A. VRN-VAFU Black; B. VRN-VAFU Purple; C. VALO Grand; D. VALO Cordless. 176x170mm (300 x 300 DPI).