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Light-emitting Diode Beam Profile and Spectral Output Influence on the Degree of Conversion of Bulk Fill Composites

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Clinical Relevance

The nonuniform emission of light-emitting diodes (LEDs) may provide a similar degree of conversion (DC) of a bulk fill composite with camphorquinone (CQ). However, the bulk fill composite with CQ and alternative photoinitiators may have a lower DC in depth as a result of lower wavelength absorption of alternative photoinitiators.

SUMMARY

Objectives: To evaluate the beam profile and the spectral output of monowave and polywave light-emitting diodes (LEDs) and their influence on the degree of conversion (DC) of bulk fill composites.

Methods: A monowave LED (Smartlite Focus, Dentsply) and a polywave LED (Valo Cordless, Ultradent) were characterized using a resin calibrator and a laser beam profile analyzer. Two bulk fill composites, Sonic Fill 2 (SF) containing camphorquinone (CQ) and Tetric EvoCeram Bulk Fill (TEB) containing CQ associated with alternative photoinitiators, were placed in custom-designed molds (n=3) and photoactivated by the monowave or polywave LED with 20 J/cm^2. To map the DC, longitudinal cross sections (0.5 mm thick) from the center of the restoration were evaluated using FT-NIR microscopy. SF and TEB light transmittances (n=3) through 4-mm-thick speci-

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mens were evaluated during curing. Data were analyzed using a split-plot analysis of variance and Tukey test (α=0.05; β=0.2).

Results: The monowave LED had a radiant emittance of 20 ± 0.5 J/cm^2 over 420-495 nm, and the polywave LED had an emittance of 15.5 ± 0.4 J/cm^2 over 420-495 nm and of 4.5 ± 0.2 J/cm^2 over 380-420 nm. The total radiant exposure at the bottom of TEB was 2.2 ± 0.2 J/cm^2 with the monowave LED and 1.6 ± 0.3 J/cm^2 with the polywave LED, and for SF it was 0.4 ± 0.1 J/cm^2 for both LEDs. There were no differences in the curing profiles produced either by the monowave or the polywave LED (*p*=0.9), according to the regions under influence of blue and/or violet emission at the same depth. There was no statistical difference in the DC for SF using the monowave or polywave LED at any depth (*p*=0.29). TEB had a higher DC at up to 2 mm in depth when the polywave LED was used (*p*<0.004), but no differences were found when starting at 2.5 mm.

Conclusions: Monowave and polywave LEDs emitted nonhomogeneous light beams, but this did not affect the DC homogeneity of bulk fill composites. For composites containing CQ associated with alternative photoinitiators, polywave LEDs had a higher DC, but only at the top part of the restoration; lower wavelength absorption photoinitiators were ineffective in deeper areas.

INTRODUCTION

The photoactivation of resin-based materials is always an important step in dentistry and still involves a concern for bulk fill composites.[1,2] An adequate radiant exposure is essential to produce biocompatible resin-based restorations with adequate physical properties to ensure clinical longevity.[2-4] However, the efficiency of photoactivation decreases with thickness as the radiant emittance is reduced because of the absorption and scattering of light within the composite.[5-7] The light attenuation is higher for the lower wavelengths (nm), such as violet (380-420 nm), in comparison to the higher blue wavelengths (420-495 nm) needed to activate the camphorquinone (CQ) photoinitiator used in all dental composites.

CQ has been partially substituted in some commercial products with alternative photoinitiators, such as diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (TPO), that are less yellow and have absorption peaks at wavelengths less than 420 nm.[8] As a result, polywave light-curing units with multiple light-emitting diodes (LEDs) possessing different wavelength range outputs (blue and violet) were designed.[9-11] However, the nonhomogeneity of the light beam emitted from these polywave units may affect the uniformity of the breadth and depth of the degree of conversion (DC) of resin-based materials, especially when CQ is used as the unique photoinitiator system.[12-14] Moreover, monowave units that emit only blue light may also be less efficient for curing resin-based materials containing CQ and alternative photoinitiators as a result of the absence of the appropriate wavelengths.[15-17]

A correlation between the nonhomogeneity of the emitted light and spatial variations in the microhardness of conventional resin-based composites (RBCs) up to 1.2 mm in thickness has been demonstrated.[13,18] However, a recent study on certain bulk fill composites did not show an influence of beam homogeneity on the cure's efficiency throughout the entire restoration.[8,12] In addition, monowave and polywave LEDs have different beam profiles and they might influence the DC of bulk fill composites that contain different photoinitiators. This could produce regions within the restoration with varied DCs and properties and may affect the clinical performance of bulk fill composites.

Thus, the aim of this study was to evaluate the influence of the beam profile of monowave and polywave LEDs on the degree of conversion of bulk fill composites containing only CQ or CQ associated with alternative photoinitiators. The hypotheses to be tested were that 1) monowave and polywave LEDs emit nonhomogeneous light beams, and 2) the beam profile of the monowave and polywave LEDs affects the homogeneity of the DC of bulk fill composites.

METHODS AND MATERIALS

Light-curing Unit Characterization

The mean radiant emittance (mW/cm^2) of a monowave LED (Smartlite Focus, Dentsply, York, PA, USA) and a polywave LED (Valo Cordless, Ultradent, South Jordan, UT, USA) were measured using a portable spectrometer-based instrument (CheckMARC, BlueLight Analytics, Nova Scotia, Canada) in order to calculate the photoactivation time needed to produce a radiant exposure of 20 J/cm^2.

The radiant exposure in the violet range (380-420 nm), blue range (420-495 nm), and overall range (380-495 nm) for each LED was obtained by integrating the irradiance vs the wavelength obtained with a spectrometer (MARC Resin Calibrator,

Table 1: *Manufacturer, Photoinitiator System, and Composition of Each Bulk fill Composite Evaluated*

Code	Bulk Fill Composite (Shade/Lot No.)	Manufacturer	Photoinitiator System	Resin Composition	Filler Amount (wt%/vol%)	Depth of Cure, mm[a]
SF	Sonic Fill 2 (A2/ 4427398)	Kerr, Orange, CA, USA	CQ, EDMAB	EPO, TEGDMA	Glass, SiO_2, oxide (84/66)	5
TEB	Tetric EvoCeram Bulk Fill (IVA/ P84136)	Ivoclar Vivadent, Schaan, Liechtenstein	CQ, EDMAB, TPO, Ivocerin	Bis-GMA, Bis-EMA, UDMA	Barium glass, YbF_3, oxide, PPF (81/61)	4

Abbreviations: Bis-EMA, ethoxylated Bis-phenol A methacrylate; Bis-GMA, bisphenol A glycidyl methacrylate; CQ, camphorquinone; EPO, poly(oxy-1,2-ethanediyl); PPF, prepolymerized fillers; TEGDMA, triethylene glycol dimethacrylate; TPO, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide; UDMA, urethane dimethacrylate; YbF_3, ytterbium trifluoride
[a] *According to the manufacturer.*

BlueLight Analytics). The Resin Calibrator has a cosine-corrected input sensor with a 4-mm-diameter aperture that receives light from 180°, and the light tips of the Valo Cordless and Smartlite Focus are 14 and 10 mm in diameter, respectively.

To determine the beam profile of each LED, radiant exposure distribution across the light tip was measured at the emitting surface using a laser beam analyzer (Model SP503U, Ophir-Spiricon, Logan, UT, USA). The resulting light from the LED was projected onto a diffusive surface of a frosted quartz target (DG2X21500, Thor Laboratories, Newton, NJ, USA), and the resulting image was recorded with the optical analysis software. Subsequently, narrow-bandpass filters with the full width at half-maximum of 10 nm (FWHM=10) (Thor Laboratories) were used to differentiate the spectral output at violet and blue wavelength peak regions, 400-410 nm and 455-465 nm, respectively. These were calibrated on separate images, and these images were plotted in color-coded maps in two-dimensional (2D) and three-dimensional (3D) views according to the maximum radiant emittance detected. The areas with higher and lower radiant emittance were determined in standard areas of 0.126 cm^2 in the regions of maximum and minimum radiant emittance detected.

Radiant Emittance Transmitted

Table 1 lists the bulk fill composites evaluated. Light transmittance through each composite was recorded during curing using Smartlite Focus and Valo Cordless LEDs. Samples of each bulk fill composite (n=3) were placed in Delrin molds (Ø=6 mm × 4 mm thick), which were placed on the bottom sensor (Ø=4 mm) of the Resin Calibrator with Mylar strips covering the top and bottom surfaces of the samples. The spectral radiant power and the radiant exposure transmitted through the bulk fill composite were calculated by integrating the irradiance over the different wavelength ranges from the graph of radiant emittance vs the wavelength obtained with the Resin Calibrator.

Mapping of the Degree of Conversion

Class I restorations (6×6 mm, 4 mm deep) of each bulk fill composite (n=3) were produced in a custom-designed transparent polymethylmethacrylate (PMMA) mold (Figure 1A-C).[8,12] The photoactivation was performed using each LED with 20 J/cm^2. A jig was made to position the LED reproducibly in order to establish the regions of the restoration exposed to the light emitted from the blue and violet LEDs and also the overlapping region in between from the polywave LED (Figure 1D). After 24 hours of dark, dry storage at 37°C, cross-section specimens (6 mm × 4 mm × 0.5 mm thick) from the center of the restoration, perpendicular to the top surface and parallel to the long axis of the block (Figure 1E), were obtained using an automated water-cooled, low-speed diamond saw (Isomet 1000, Buehler Ltd, Lake Bluff, IL, USA). The specimens were fixed onto a glass slab and placed over an automated x-y axis microscope platform. The DC was mapped along the cross section (width: 6 mm; depth: 4 mm) using a FT-NIR Microscope (Nicolet Continuum, Thermo Scientific, Waltham, MA, USA) coupled to a FT-NIR spectrometer (Nicolet Nexus 6700, Thermo Scientific) (Figure 1F). Every 500 μm in width and depth, an infrared spectrum was collected, resulting in 117 measuring points for each cross section. The measurements started 300 μm below the top surface in order to avoid the area of oxygen inhibition. At each measurement position, the specimens' NIR spectrums were collected in transmission mode with 50 scans at 4 cm^{-1} of resolution and a detector aperture size of 50. Spectra of uncured specimens (n=3) collected with the same settings were used as a reference to measure the peak area ratio corresponding to the aromatic and vinyl stretching absorptions. The DC (in %) was calculated as follows:

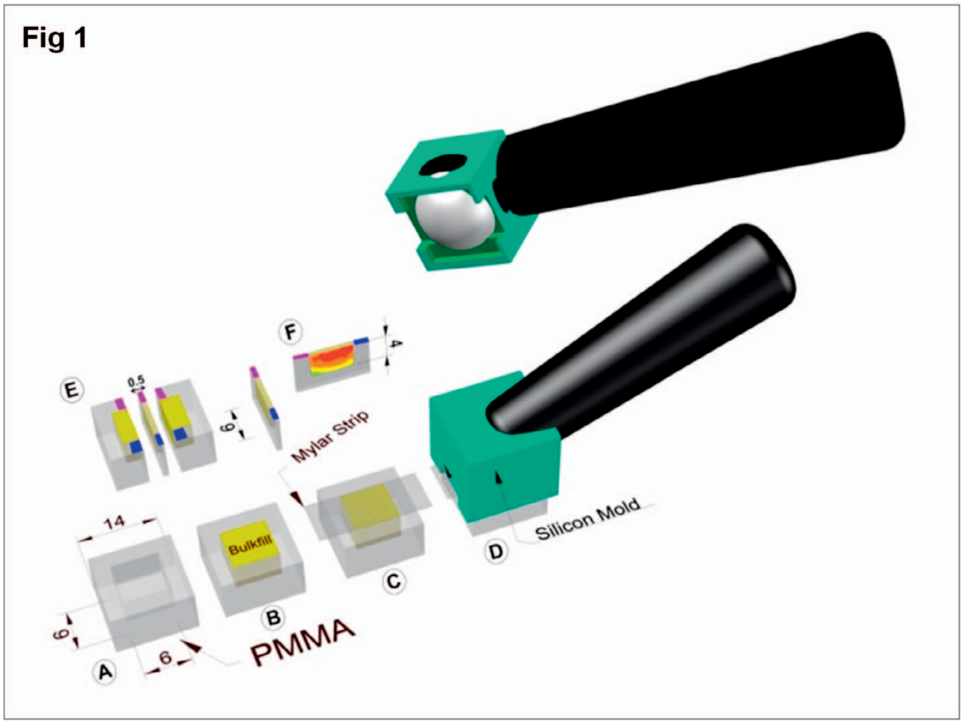

Figure 1. *Schematic design of the experimental setup. (A) PMMA mold with 6 × 6 × 4-mm cavity; (B) Bulk fill insertion into the PMMA mold; (C) Mylar strip covering the surface; (D) Light cured with 20 J/cm² using the LED positioned with a silicon jig mold; (E) Cross section of the center of the restoration with blue and violet LED emittance regions established; (F) Mapping of the DC using a FT-NIR microscope.*

$$DC = \{1 - [(\text{vinyl peak area pol}/\text{aromatic peak area pol})/(\text{vinyl peak area non pol}/\text{aromatic peak area non pol})]\} \times 100$$

where *pol* and *non pol* correspond to the area of the methacrylate peak for the polymeric and monomeric states, respectively.

The results were exported into mapping software (OriginPro 2015, OriginLab Co, Northampton, MA, USA). Color-coded maps were created to describe the DC as a function of position under the light beam in width (0-6 mm) and in depth (0-4 mm). For the polywave LED, the regions under the influence of the blue LED chips were set from 0 to 2 mm wide, the overlap in between the blue and violet LED chips were set from 2.5 to 4 mm wide, and the regions under the influence of the violet LED chips were set from 4.5 to 6 mm wide. Also, the map scales were set to indicate the maximum DC achieved with the bulk fill composites and a reduction of 10% of the maximum DC in each color-coded area.

Statistical Analysis

A split-plot analysis of variance was used for the statistical analysis of the DC values. The Tukey test was applied for multiple comparisons (α=0.05) for each of the different bulk fill composites (SF and TEB). The independent variables were set as between-subject groups for the LEDs (monowave or polywave) and as within-subject groups for the LED emittance regions in width (0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, and 6 mm) and depth (0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4 mm) below the tip of the LED. For the polywave LED, the regions under the influence of the blue LED chips were set as the mean of points from 0 to 2 mm wide, the overlap in between blue and violet LEDs chips were set as the mean of points from 2.5 to 4 mm wide, and the regions under the influence of the violet LED chips were set as the mean of points from 4.5 to 6 mm wide. Power analysis was conducted to determine the sample size for each experiment to provide a power of at least 0.8 at a significance level of 0.05 (β=0.2).

RESULTS

Table 2 shows the mean radiant emittance and the total radiant exposure within each wavelength range for each LED. Figure 2 illustrates the beam profile of both LED units in 2D and 3D of 400-410-nm and 455-465-nm wavelength ranges. Smartlite Focus had an active area of emission of 0.352 cm^2 and a maximum radiant emittance of 1850 mW/cm^2, but

Table 2: *Light-emitting Diode (LED) Units: Mean Radiant Emittance (mW/cm²) and Radiant Exposure (J/cm²) According to the Different Wavelength Ranges*

Light-curing Unit	Mean Radiant Emittance, mW/cm²	Time of Exposure, s	Wavelength Ranges, nm	Radiant Exposure, J/cm²
Smartlite Focus	1000	20	420-495	20 ± 0.5
VALO Cordless	954	21	380-420	4.5 ± 0.2
			420-495	15.5 ± 0.4

the radiant emittance was not homogeneously distributed across the tip. A high emission (1082 mW/cm^2) was localized in a small area (0.126 cm^2) at the center of the light tip (red dash circle). An area of lower radiant emittance (534 mW/cm^2) was localized at the periphery of the light tip (blue dash circle). Valo Cordless had an active area of emisson of 0.750 cm^2 and a maximum radiant emittance of 1449 mW/cm^2, but the radiant emittance and the wavelength emission were not homogeneously distributed across the tip. For the blue wavelength emisson, localized standard areas of a higher radiant emittance of 1085 mW/cm^2 and a lower radiant emittance of 397.5 mW/cm^2 were seen. For the violet wavelength emission, localized areas of a higher radiant emmitance of 431 mW/cm^2 and a lower radiant emittance of 50 mW/cm^2 were seen.

Figure 3 illustrates the radiant emittance vs wavelength of each LED on the top surface of the specimen and through each bulk fill composite. Smartlite Focus had a peak emission at 470 nm; Valo Cordless had three peaks of emission at 400, 440, and 460 nm. The radiant exposure at the bottom (4 mm) of TEB was 2.2 ± 0.2 J/cm^2 with the Smartlite Focus and 1.6 ± 0.3 J/cm^2 with the Valo Cordless. For SF, the radiant exposure was 0.4 ± 0.1 J/cm^2 for both LEDs.

Figure 4 shows the mean (± standard deviation [SD]) DC in depth of each bulk fill composite according to each LED. For SF, there was no statistical difference in the DC using the Smartlite Focus or Valo Cordless LED (df=1; F=1.2; p=0.28) at any depth. However, TEB showed a higher DC for Valo Cordless than for Smartlite Focus up to 2 mm in depth (df=1; F=4.9; p=0.04). Starting at 2.5 mm there was no statistical difference between Valo Cordless and Smartlite Focus.

Figure 5 illustrates the mapping of the DC of each bulk fill composite according to the different LEDs. Comparing the width point by point throughout the sample, Smartlite Focus showed no statistical difference in the DC for both SF (df=16; F=0.5; p=0.93) and TEB (df=16; F=0.1; p=0.9) at any depth. Also, Valo Cordless showed no statistical difference among the blue, violet, and overlapping regions for both SF (df=16; F=0.6; p=0.86) and TEB (df=16; F=0.12; p=0.9). In addition, there was no statistical difference between Smartlite Focus and Valo Cordless in the same region (width and depth) of the sample for

Fig 2

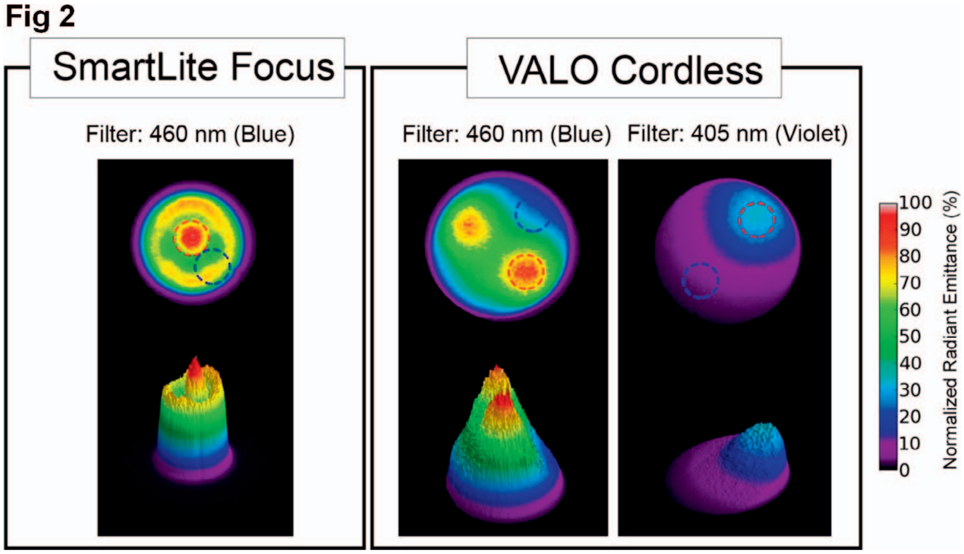

Figure 2. *Beam profile images of LED units (2D and 3D views) within 455-465-nm (blue) and 400-410-nm (violet) wavelength ranges. Red dash circles indicate area of higher radiant emittance, and blue dash circles indicate area of lower radiant emittance. One hundred percent normalized radiant emittance values were 1850 mW/cm² for Smartlite Focus and 1449 mW/cm² for Valo Cordless.*

Fig 3

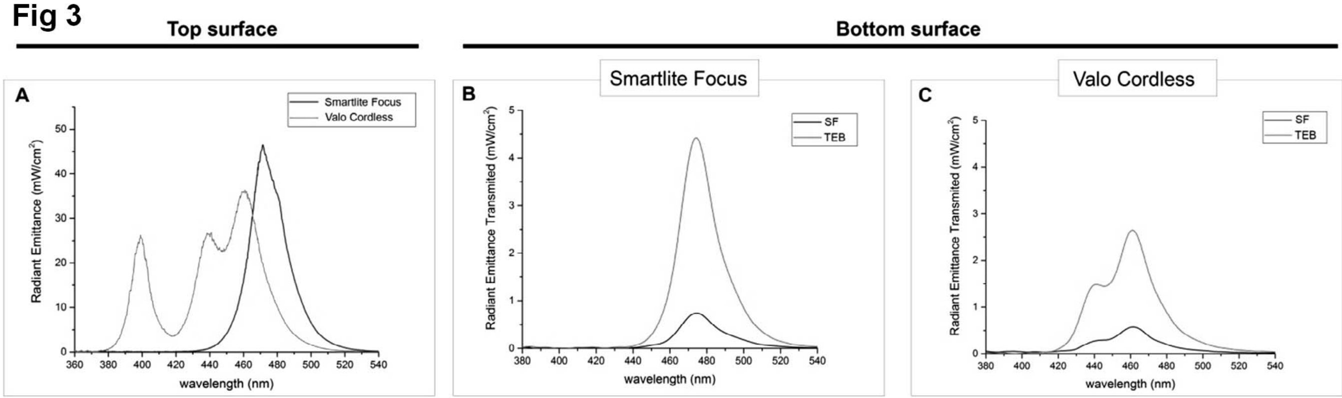

Fig 4

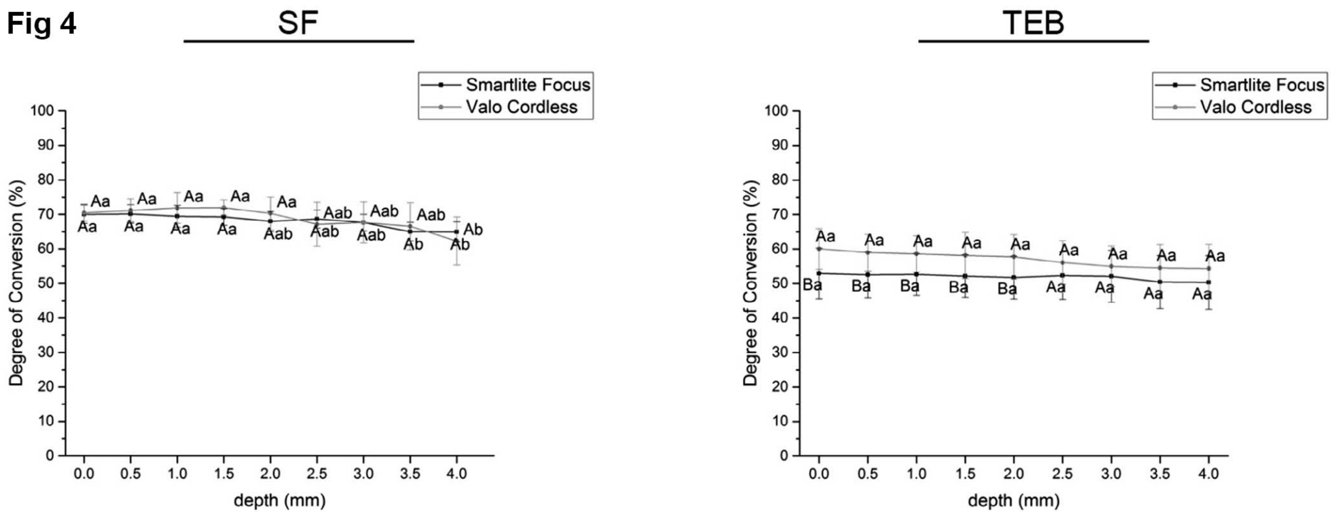

Figure 3. *Absolute irradiance (mW/cm^2/nm) × wavelength (nm) for bulk fill composite cured with each LED unit. (A) Smartlite Focus and Valo Cordless at 0 mm, (B) Smartlite Focus through 4-mm thickness of SF and TEB, and (C) Valo Cordless through 4-mm thickness of SF and TEB.*

Figure 4. *Mean DC (%) at 0 to 4 mm in depth of each bulk fill composite according to the different LED unit.*

SF (df=32; F=0.57; p=0.96) and TEB (df=32; F=0.1; p=0.99).

DISCUSSION

An important step before the photoactivation of RBCs is the assessment of the light-curing unit (LCU), because the energy delivered to the surface of the RBCs should be sufficient to provide an adequate cure of the material.[2,3] This is necessary because while the same radiant exposure may be emitted by two different LCUs, the spectral power distribution could be completely different.[3,10,14]

Table 2 shows the same total radiant exposure (±20 J/cm^2) for the Smartlite Focus and the Valo Cordless. Since Smartlite Focus is a monowave LED and emits only a single narrow Gaussian band with a wavelength peak at 470 nm, the radiant exposure emitted by this light is all within the blue range. In contrast, Valo Cordless is a polywave LED with three emission peaks at 400, 440, and 460 nm; thus, some of the spectral power is emitted in the violet region (4.5 J/cm^2), while the majority of it is emitted in the blue region (15.5 J/cm^2).

This study verified that monowave and polywave LEDs have differences in their radiant emittance and wavelength distribution across the light tip, as demonstrated in the beam profile images (Figure 2).[13,14] The monowave LED has one LED chip localized at the center of the tip; thus, an area of higher radiant emittance is clear near this region. The polywave LED has four LED chips, and the beam profile results corroborate that the different LED chips are widely spatially separated.[10,19] However, narrow band-pass filters (FWHM=10 nm) have to be used sequentially to determine the different wavelength outputs, and they might only detect part of the beam profile image for the polywave LED. Only the output emissions from two 460-nm chips

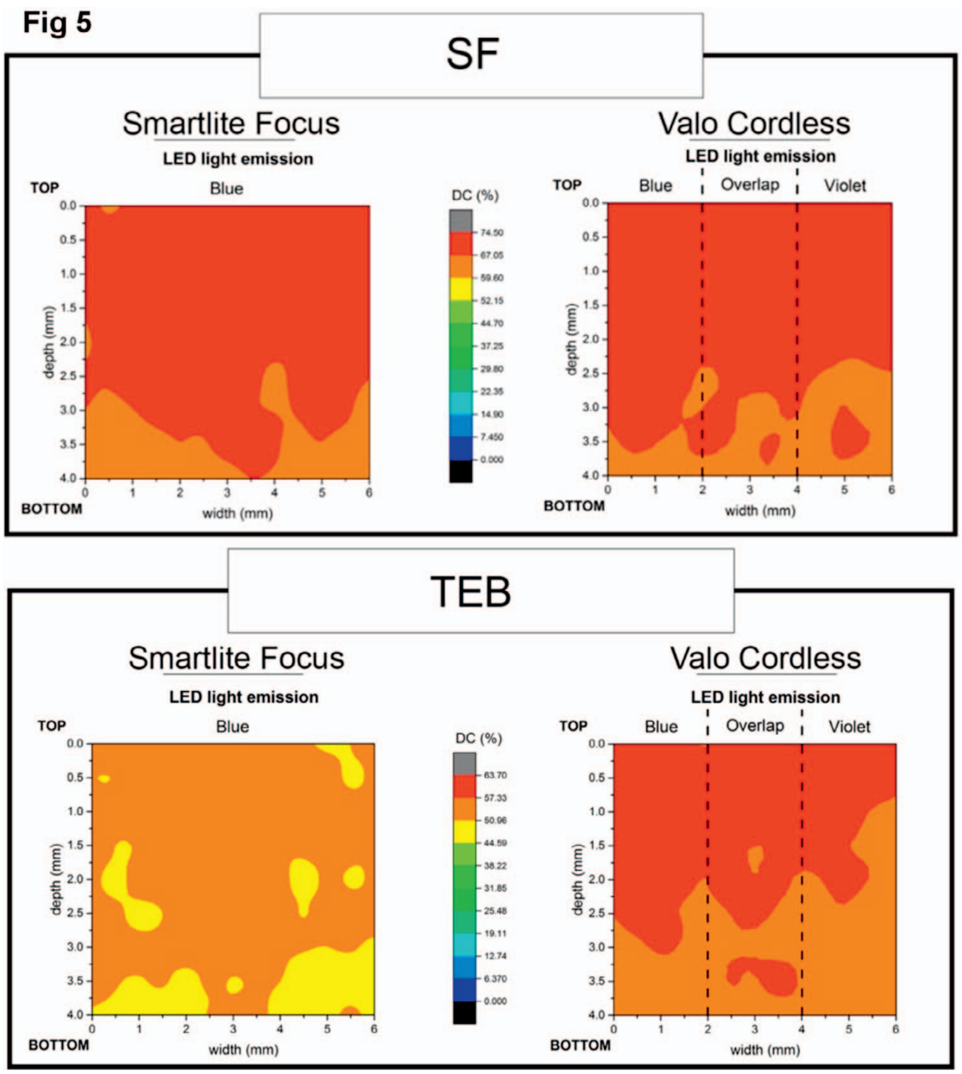

Figure 5. *Mapping of the DC (%) of bulk fill composites according to the different LED emittance regions (blue, violet, and the overlap in between blue and violet) of LED units.*

and the single 405-nm chip were detected; that of the 440-nm chip (which is located diagonally opposite to the 405-nm chip in the rectangular four-chip array) was not.[10] Thus, the first research hypothesis, that monowave and polywave LEDs emit a nonhomogeneous light beam, could be accepted. Polywave LEDs have previously been identified[14,18,19] as having a nonuniform spectral distribution across their light end tip at the violet and blue emission wavelengths. Local differences in irradiance distribution and spectral homogeneity could affect the extent or quality of the cure across the RBC specimen's surfaces and in its depth. The significance of these findings has yet to be widely appreciated, but the general impact of wide differences in the polywave LED's performance and the clinical factors related to the restoration's longevity are considered to be significant. Clinically, this means that the orientation and positioning of the LED might affect both the irradiance and wavelength received by different locations within the restoration.[13,14,18]

Despite the nonhomogeneous light beam emitted by both LEDs, the results showed that the curing profile of each bulk fill composite was similar for both LEDs. The distances in width and depth from the position of the LED chips of the monowave and polywave LEDs have no influence on the DC at any depth for SF or TEB. High-viscosity bulk fill composites such as SF and TEB are highly filled materials that contain 84/66 wt%/vol% and 81/61 wt%/vol%, respectively, of filler particles, as shown in Table 1. The mismatch between the refractive index of the filler particles and the organic matrix causes light scattering.[20] Thus, the light emitted by LEDs is scattered through the composite, and a diffuse reflection likely spreads light throughout the sample. Although the nonhomogeneous radiant emittance emitted by the LEDs is over the top of the sample, the light scattering promoted inside the bulk fill composites spreads light within the sample. This could have provided a more homogeneous DC.[6,7] Therefore, the second research hypothesis, that the beam profile of the monowave and polywave LEDs affects the homogeneity of the DC of bulk fill composites, was rejected.

Despite the beam profile of the monowave and polywave LEDs having had no influence on the DC, the spectral output of the LEDs had a significant impact on the DC in depth for bulk fill composites containing CQ associated with alternative photoinitiators, such as TEB. The mean DC for TEB using the monowave LED was lower than that achieved with the polywave LED. This can be explained by the radiant emittance of the monowave LED and photoinitiator systems used in TEB. TEB has a combination of three photoinitiator systems: a Norrish type II photoinitiator system, CQ associated with EDMAB (tertiary amine); and two Norrish type I photoinitiator systems, TPO and a benzoyl germanium (Ivocerin). CQ and the EDMAB photoinitiator system absorb light in the blue range from 420 to 495 nm, with a peak absorption at 470 nm.[8,21] Ivocerin absorbs light in the violet and blue ranges from 370 to 510 nm, with a peak absorption at 418 nm.[17] TPO absorbs light in the violet range from 350 to 420 nm, with a peak absorption at 370 nm.[8,21] Smartlite Focus only emitted light within the blue range from 440 to 495 nm, where CQ heavily absorbs, and light at these wavelengths was able to penetrate through a 4-mm thickness of the composite (Figure 3). Thus, only CQ and the EDMAB photoinitiator system were excited by the LED emission and generated free radicals to initiate the polymerization throughout the restoration. Therefore, once the spectral output of the LED did not correspond with spectral absorption of all photoinitiator systems in the composition, the monowave LED was not efficient in curing TEB. When the narrow spectrum emission of the monowave LED is used instead of the broad spectrum of the polywave LED, there might be a reduction in DC for TEB.

Despite the higher mean DC for TEB using the polywave LED rather than the monowave LED, this difference was not significant at all depths. As shown in Figure 4, from the top surface (0 mm) to 2 mm in depth, TEB had a higher DC when cured using the polywave LED, but beyond 2.5 mm no statistical difference was found between the two LEDs. Valo Cordless emits light that can be absorbed by CQ, TPO, and Ivocerin. A higher DC might be expected as a result of these photoinitiator systems in the TEB composition working in synergism, generating more free radicals than CQ alone.[8] However, only blue light was capable of penetrating through the 4-mm-thick composite, and then only CQ and Ivocerin would be excited by the polywave LED emission at deeper portions.[22,23] This means that TEB combines three photoinitiators with three absorption peaks that should work in synergism to ensure adequate cure of the composite. However, this photoinitiator combination was effective just at the top part of the restoration up to 2 mm. Therefore, photoinitiator systems with a lower wavelength absorption than that of blue did not improve the DC at greater depths because the light that activates these photoinitiators are attenuated through the RBC and could not reach deeper areas of the restoration.

When TEB was cured with Smartlite Focus, the color-coded map of the DC showed areas in yellow that correspond to less than 80% of the maximum DC achieved for this composite. Previous studies[5,24] have suggested that a hardness or DC of at least 80% of the maximum attainable is considered to be adequately cured, but the statistical analyses used in this study showed no significant difference for these areas. Despite no differences for the same point in the graph (width and depth) between Smartlite Focus and Valo Cordless, when the mean of the points of all areas of the map is considered, Smartlite Focus has a lower DC than Valo Cordless.

For SF, no differences were found in the DC values between the two LEDs at any depth. SF has only CQ and EDMAB as the photoinitiator system, which is heavily absorbed at the blue wavelength range. Although the monowave LED emitted higher radiant exposure within the blue range from 420 to 495 nm over the top of the samples, the same radiant exposure (0.4 J/cm^2) was transmitted through the samples during curing, and this might explain the similarity in the DCs of this composite.

Thus, for bulk fill composites containing only CQ as the photoinitiator system, the use of either a monowave or polywave LED did not affect the DC or homogeneity of the cure. However, for bulk fill composites containing CQ associated with other photoinitiators with lower wavelength absorption, the use of a monowave LED resulted in a reduced DC. Further studies are being conducted in order to evaluate if the same behavior will occur in Class II restorations as a result of the presence of a dentin barrier between the overlapping of blue and violet emittance from a polywave LED.

CONCLUSIONS

The monowave and polywave LEDs used in this study emitted nonhomogeneous light profiles, but the nonhomogeneity of the light beam did not affect the homogeneity of the DC of the bulk fill composites tested. For bulk fill composites containing only CQ as a photoinitiator, the monowave and polywave LEDs had the same efficiency. For composites containing CQ associated with alternative photoinitiators, the polywave LED had a higher DC, but only at the top part of the restoration and up to 2 mm in depth. Lower wavelength absorption photoinitiators were ineffective in deeper areas.

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Conflict of Interest

The authors of this manuscript 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.

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