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Evaluation of a New “Quad” Wavelength Curing Light Unit

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USU Operational Gap: IV, C

Objective: The purpose of this study was to compare the depth of cure, surface hardness, volumetric shrinkage, and temperature increase of the PinkWave LCU to a tri-spectrum LCU (Valo Grand, Ultradent) in standard curing mode. **Methods:** The irradiance of the LCUs was determined using a spectrophotometer (MARC Light Collector, BlueLight Analytics) with the 4mm-diameter sensor. A Valo Grand LCU was modified so its irradiance could be adjusted to match the PinkWave LCU irradiance. Also, a non-adjusted Valo Grand LCU was used as a comparison. Depth of cure was evaluated using the scraping technique (ISO 4049) with a 4mm-diameter by 8mm-long mold. Top and bottom surface hardness and bottom/maximum hardness ratios were determined using a hardness tester. Volumetric shrinkage was determined after 10 minutes using a video-imaging device (AcuVol, Bisco). Two resin-based composite materials (n=10) were utilized (Esthet-X HD, Dentsply; Tetric EvoCeram, Ivoclar Vivadent) with a curing time of 10 seconds. The increase in surface temperature of the lights was measured by placing the tip of a K-type thermocouple on the center of the light tip and activating it for 10 seconds. Data were analyzed with ANOVA/Tukeys/T-tests (alpha=0.05). **Results:** No significant difference in depth of cure was found with either composite between the PinkWave LCU and the modified Valo Grand LCU at similar irradiance. The unadjusted Valo Grand LCU had slightly less depth of cure. There was no difference in top or bottom surface hardness, bottom/maximum hardness ratios, or volumetric shrinkage between any of the LCU curing modes per composite type. The PinkWave LCU had a significantly greater increase in heat at the tip compared to the modified Valo Grand LCU at similar irradiance and the unadjusted Valo Grand LCU. **Conclusions:** The new quad-spectrum LCU, PinkWave, had a significant increase in surface temperature without any

improvement in the polymerization efficacy compared to the tri-spectrum LCU, Valo Grand, at similar irradiance.

Introduction

The clinical performance of dental composite restorative materials is dependent on many factors. One fundamental factor for contributing to a successful restoration is the proper selection and application of a light-curing unit (LCU). Often overlooked, LCUs can have an effect on depth of cure, degree of conversion, hardness, and polymerization kinetics of composites.(1) If a composite does not receive adequate energy from an LCU, or if the wavelength of the light does not activate the specific photoinitiator in the composite, its polymerization will be reduced.(2) When a composite is not properly polymerized, its mechanical strength and marginal integrity are significantly decreased, and water sorption is significantly increased.(3-5) An arbitrary increase of the curing time to prevent the under-curing of a composite can increase the temperature of the tooth, potentially damaging the pulp and surrounding tissues.(6) The ultimate goal is to improve restoration mechanical properties while minimizing heat transfer to the tooth.

Another key component of successful polymerization is to ensure the spectrum of light delivered by the LCU coincides with the photonic absorption of the photoinitiator in the composite.(7) Light-emitting diode (LED) LCUs with a single-spectral emission in the blue wavelength were originally introduced as an alternative to quartz-tungsten-halogen (QTH) LCUs with the benefits that they can be more physically compact, energy efficient, cordless, and do not require bandpass filters to isolate blue light.(8) Single-spectrum LED LCU emission is relatively more narrow and often centered near 470 nm to match the absorbance range of camphorquinone (CQ) which lies between 400-500 nm with a peak sensitivity at 468 nm.(CITE) Having a narrow spectrum tailored to the target photoinitiator is ideal because most of the energy delivered is able to be quantized to generate free radical formation and less is converted into molecular kinetic energy (heat). Some manufacturers use other photoinitiators, such as trimethylbenzoyl-

diphenylphosphine oxide (TPO), which is less yellow in color to create whiter restorative shades. These alternative initiators are usually sensitive to ultraviolet or violet light or a wavelength between 380 and 410 nm.(9) Products containing these alternative photoinitiators may not be effectively polymerized by single-spectrum LCUs that emit light at 400-500 nm wavelengths.(10) In response, some manufacturers market LCUs with additional LED diodes to deliver multiple different spectral emission peaks (multi-spectra) that correspond to the various absorption spectra of the different photoinitiators. A multi-spectra LED LCU with emission peaks near 380-410 and 470 is generally ideal to effectively polymerize the wide range of dental adhesives and composites available today.(11)

Vista-Apex Dental (Racine, WI) recently introduced a novel LCU called the PinkWave that reportedly provides “pink light” instead of the traditional “blue light”. Vista-Apex Dental claims the PinkWave has a patented “Quad Wave” technology with spectral emission peaks at 410nm (violet), 470nm (blue), 625nm (red), and 840nm (near-infrared). Due to these additional wavelengths, the manufacturer states the PinkWave LCU reduces composite polymerization shrinkage of composites by up to 37%, increases polymerization by up to 19%, and reduces energy absorption from the pulp. The PinkWave has reported irradiances of 1750 or 2300 mW/cm² depending on mode.(12) No evaluative research has been published evaluating the PinkWave LCU.

The purpose of this study was to compare depth of cure, top/bottom surface hardness, bottom/maximum hardness ratios, volumetric polymerization shrinkage, and the surface temperature at the LCU tip using two composite restorative materials (Esthet-X, Dentsply Caulk, Milford, DE; Tetric EvoCeram, Ivoclar Vivadent, Amherst, NY) polymerized with the PinkWave and the Valo Grand (Valo Grand, Ultradent Products, South Jordan, UT) LCUs. These observations will allow us to examine the polymerization efficacy of each LCU. The Valo Grand LCU has a similar tip surface area to the PinkWave LCU but a different emission spectrum. The PinkWave LCU has a tip area of 115 mm², and the Valo Grand LCU has a tip area of 107 mm². The Valo Grand is a tri-spectrum LED LCU with emission peaks near 405, 445, and 465 nms and irradiances of 1000, 1600, or 3200 mW/cm² depending on the mode. (12) The PinkWave LCU was compared to an

adjusted Valo Grand LCU with similar irradiance and to another Valo Grand LCU with no adjustments to the irradiance. Esthet-X HD and Tetric EvoCeram were chosen as composites because Esthet-X HD has just one photoinitiator (CQ), while Tetric EvoCeram has two photoinitiators (TPO and CQ).

The null hypotheses were that there would be no differences in the depth of cure, top/bottom surface hardness, bottom/maximum hardness ratios, volumetric polymerization shrinkage, or the surface temperature of the LCU tip when two common dental composites were polymerized by the PinkWave LCU, an adjusted Valo Grand LCU at similar irradiance to the PinkWave LCU, or an unadjusted Valo Grand LCU.

Materials and Methods

The LCUs were used in standard mode with a 10-second exposure time. One Valo Grand was modified to emit a similar irradiance to the PinkWave LCU to reduce the variability associated with unequal irradiances. A second unmodified Valo Grand LCU was used as a control. See tables 1 and 2 below for more details on the composites and LCUs utilized in this study.

Composite	Type	Manufacturer and Claimed DOC (mm)	Filler wt% & vol. %		Matrix Chemistry	Photoinitiator	Filler	Filler Size	Shade	
Tetric EvoCeram	Nanohybrid	Ivoclar Vivadent, Amherst, NY	2.0	75	53	Bis-EMA, Bis-GMA, UDMA	TPO, CQ	BAFSG, silica dioxide, YbF3	0.04 to 3 um	A2
Esthet-X	Nanohybrid	Dentsply Caulk, York, PA	2.0	77	60	Bis-EMA, Bis-GMA, TEGDMA	CQ	BAFSG, silica dioxide	0.02-2.5 um	A2

Abbreviations: BAFSG, barium aluminofluorosilicate glass; YbF3, ytterbium trifluoride; Bis-EMA, bisphenol A ethoxy dimethacrylate; Bis-GMA, bisphenol A diglycidyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate. TPO, Trimethylbenzoyl-diphenyl phosphine oxide

Table 1: Components of Composite Materials

LCU	Type	Manufacturer	Battery Type	Power Option	Tip Surface Area	Irradiance (mW/cm ²)	Emission Peaks (nms)
PinkWave	Quad-spectrum LED	Vista-Apex Dental, Racine, WI	Li-Ion	Cordless	115 mm ²	1750 or 2300	410, 470, 625, and 840
Valo Grand	Tri-spectrum LED	Ultradent Products, South Jordan, UT	Li-Ion	Corded or Cordless	107 mm ²	1000, 1600, or 3200	405, 445 and 465

Table 2: Types of Light-Curing Units

Modification of the Power

The radiant power of the Valo Grand LCU was modified by adjusting the applied voltage to the LED assembly to be similar to the power of the PinkWave LCU. A regulated, adjustable, constant voltage DC power supply source (Eventek KPS305D, Shen Zhen Sheng Ya Hardware Products Co., Ltd, China) was supplied to the LED assembly by first passing through an electrically isolated interval timer circuit. Briefly, a separately powered, voltage regulated, monostable multivibrator circuit produced a timed, one-shot square wave output. This square wave duration was determined partially by using fixed resistors within the circuit but also a variable resistor for fine adjustment. This output turned on and off a power metal-oxide–semiconductor field-effect transistor (MOSFET) that in turn energized a mechanical relay that controlled the applied voltage from the Eventek DC power source to the LED assembly. Thus, the timing circuit was electrically isolated from the LED irradiance voltage in both its operation as a one-shot timer and as an activator of the LED assembly. A manual override was made to allow adjustment and measurement of the irradiance by the operator before utilizing the timed protocol. Through this method, an applied voltage to irradiance standard curve was established. The irradiance and emission spectrums of both LCUs were measured using the 4mm diameter sensor of a spectrophotometer (MARC Light Collector, Blue Light Analytics, Halifax, Canada). The irradiance of each LCU was measured ten times, and a mean and standard deviation was determined. See Figure 1 and Table 3.

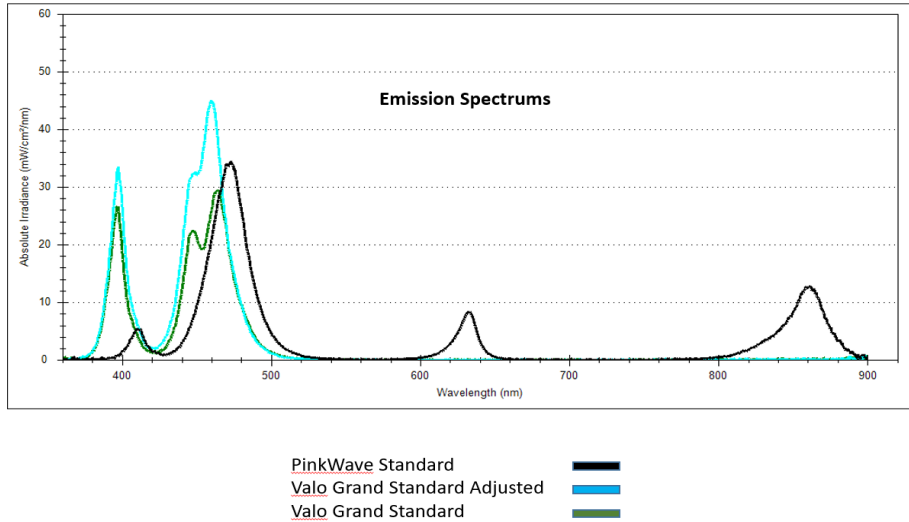


Figure 1: Emission spectrum of the PinkWave LCU, adjusted Valo Grand LCU and unadjusted Valo Grand LCU in Standard Mode

Depth of Cure

To determine the depth of cure, ten specimens of each composite were tested using the scraping technique (ISO Standard 4049). (13) A 4 mm diameter by 8 mm long stainless-steel split mold (Sabri Dental Enterprises, Downers Grove, IL) was placed on a plastic-strip-covered glass slide on a standard white background. The composite was injected into the mold, a plastic strip was placed, and the composite was condensed with a glass slide to displace excess resin. The glass slide was removed, and the composite was immediately polymerized for 10 seconds with the LCUs. The LCUs were positioned with a clamp so that they were flush with the top surface of the plastic-strip-covered composite. The uncured resin was then scraped with a plastic instrument starting from the deepest point on the underside of the mold until polymerized resin was reached. The specimens were visually inspected and discarded if any voids were noted. The length of the remaining polymerized material was measured with an electronic digital caliper (GA182, Grobet Vigor, Carlstadt, NJ) and divided by two according to the ISO standard. (13) A mean depth of cure (mm) and standard deviation were determined for each material and LCU curing mode.

Surface Hardness

Sixty composite specimens (30 Tetric EvoCeram, 30 Esthet-X HD) were created to evaluate surface hardness. Cylindrical plastic split molds, 2.0 mm in height and 8.0 mm in diameter (Sabri Dental Enterprises), were placed on a plastic-strip-covered glass slide on a standard white background. The composite was inserted into the mold. Another plastic strip was then placed on top, while a microscope glass slide was used to flatten the top surface. Afterwards, the glass slide was removed. The LCUs were positioned with a clamp as before. The composites were light-cured for 10 seconds. Following light curing, specimens were stored in the dark at 37°C in 100% humidity for 24 hours in an incubator (Model 20 GC, Quincy Lab Corp, Chicago, IL). Three hardness indentations were made on the top and the bottom of each specimen in the central 4mm area of the specimen surface using a load of 100 grams for ten seconds in a Knoop hardness testing device (LECO, LM-300AT, St. Joseph, MI). The mean top and bottom Knoop hardness value and standard deviation were determined for each material and LCU curing mode. In addition, the percent bottom/maximum Knoop hardness ratio was calculated by dividing the bottom surface hardness by the maximum recorded hardness per material and multiplying by 100.

Percent Volumetric Polymerization Shrinkage

To determine volumetric polymerization shrinkage, 4mm-diameter composite specimens were placed on a pedestal in a video-imaging device (AcuVol, Bisco, Schaumburg, IL). Ten specimens of each composite per LCU were imaged from the side at a distance of 10cm. The video camera digitized and analyzed the images with the provided image-processing software. The specimens were cured separately with each LCU mode for 10 seconds of curing time. Percent polymerization shrinkage was recorded continuously for 10 minutes after the light initiation. A mean percent volumetric polymerization shrinkage and standard deviation were determined for each material and LCU curing mode.

Surface Temperature of LCU Tip

To measure the surface temperature of the LCU tip, a K-type thermocouple wire probe (Digi-Sense Type-K Wire Probes, 30 Gauge; Cole-Parmer, Vernon Hills, IL) was connected to a data-logging thermometer (SDL200 4-Channel Datalogging Thermometer, Extech, Nashua, NH) and positioned in contact with the center of the LCU tip. A baseline temperature was recorded. The maximum increase in temperature was recorded after a 10-second exposure time. Ten temperature readings were recorded. (8) A mean increase in surface temperature and standard deviation were determined for each LCU curing mode.

The data were analyzed with two-way and one-way ANOVAs with Tukey's post hoc tests and unpaired t-tests ($\alpha = 0.05$). See tables 3 and 4.

Results

The mean irradiance of the PinkWave LCU was found to be $1871.7 \pm 11.6 \text{ mW/cm}^2$ in standard mode, which was not significantly different ($p=0.93$) from the modified Valo Grand LCU at $1868.0 \pm 12.6 \text{ mW/cm}^2$ in standard mode. The irradiance of the PinkWave LCU and adjusted Valo Grand LCU were significantly greater ($p<0.001$) than the unadjusted Valo Grand LCU in standard mode ($1411.8 \pm 13.6 \text{ mW/cm}^2$).

The depth of cure of the composite materials using the PinkWave LCU was not significantly different from the adjusted Valo Grand LCU ($p=0.77$), but both were greater than the unadjusted Valo Grand LCU ($p<0.001$). There was no significant difference in depth of cure between the two composite types ($p>0.10$). Additionally, there was no significant difference in surface hardness based on the type of composite ($p>0.08$) or LCU curing mode ($p>0.07$) for both the top and bottom surfaces. When evaluating the bottom/maximum hardness ratios, no significant difference was found in percent hardness ratios based on composite type ($p>0.49$) or LCU curing mode ($p>0.31$). The percent volumetric shrinkage of the composites was not significantly different between

the various LCU curing modes ($p>0.61$), but Tetric Evo Ceram had significantly lower shrinkage ($p<0.001$) than Esthet-X HD. The PinkWave LCU had the greatest increase in temperature at the tip ($29.0 \pm 1.4^{\circ}\text{C}$), which was significantly greater ($p<0.001$) than the adjusted Valo Grand LCU ($23.6 \pm 1.3^{\circ}\text{C}$). The unadjusted Valo Grand LCU had the lowest increase in temperature at the tip ($19.8 \pm 1.2^{\circ}\text{C}$) and was significantly less ($p<0.01$) than the PinkWave LCU and adjusted Valo Grand LCU.

Curing Light	Mode	Irradiance 4mm dia Mean (st dev)	Depth of Cure (mm) Mean (st dev)		Shrinkage (%) Mean (st dev)		Heat Increase at Tip ($^{\circ}\text{C}$) Mean (st dev)
			Esthet-X HD	Tetric Evo Ceram	Esthet-X HD	Tetric Evo Ceram	
PinkWave	Standard	1871.7 (11.6) a	2.23 (0.04) Aa	2.21 (0.04) Aa	2.86 (0.07) Aa	1.87 (0.08) Ba	29.0 (1.4) a
Valo Grand	Standard Adjusted	1868.0 (12.6) a	2.22 (0.03) Aa	2.24 (0.03) Aa	2.85 (0.06) Aa	1.90 (0.08) Ba	23.6 (1.3) b
Valo Grand	Standard	1411.8 (13.6) b	2.16 (0.04) Ab	2.16 (0.04) Ab	2.85 (0.07) Aa	1.91 (0.08) Ba	19.8 (1.2) c

Groups with the same upper case letter per row and property or lower case letter by column are not significantly different ($P > 0.05$)

Table 3. Irradiance, depth of cure, shrinkage of the composites, and heat increase at the tip using the LCUs.

Curing Light	Mode	Knoop Hardness (kg/mm^2) Mean (st dev)					
		Top		Bottom		Bottom/Max % Ratio	
		Esthet-X HD	Tetric EvoCeram	Esthet-X HD	Tetric EvoCeram	Esthet-X HD	Tetric EvoCeram
PinkWave	Standard	38.5 (3.3) Aa	36.9 (3.4) Aa	28.4 (1.7) Aa	26.3 (2.1) Aa	74.3 (7.8) % Aa	71.8 (7.1) % Aa
Valo Grand	Standard Adjusted	37.9 (2.6) Aa	36.2 (3.7) Aa	28.9 (2.6) Aa	26.6 (2.5) Aa	75.1 (6.8) % Aa	72.2 (6.7) % Aa
Valo Grand	Standard	37.0 (3.3) Aa	35.2 (3.5) Aa	26.1 (2.1) Aa	24.7 (2.4) Aa	67.9 (5.4) % Aa	67.0 (6.5) % Aa

Groups with the same uppercase letter per row and property or lowercase letter per column are not significantly different ($p>0.05$)

Table 4. Knoop hardness values of the composites using the LCUs.

Discussion

This study evaluated the quad-spectrum PinkWave, a novel LCU that contains emission peaks in the red and near-infrared in addition to the more traditional peaks in the violet and blue wavelengths of light. With the additional emission at higher wavelengths, the manufacturer claims that the PinkWave LCU reduces shrinkage and

increases polymerization while reducing the energy absorption by the pulp. The tri-spectrum Valo Grand LCU, with emission peaks in the violet and blue wavelengths of light, was selected as a control to compare the efficacy of the additional red and infrared wavelengths of PinkWave LCU.

To reduce variability, the LCUs were stabilized with a clamp to align and center the light tip during testing. Also, all tests were conducted with 10 seconds of exposure time from the LCUs. The irradiance was measured in the center 4mm of the light tip of the LCUs using a spectrophotometer with a 4mm-diameter sensor to match the 4mm diameter of the mold used for the depth of cure test (ISO Standard 4049). Surface hardness measurements were made in the center 4mm of the composite specimens, and 4mm-diameter composite specimens were created and light-cured when evaluating polymerization shrinkage. Additionally, the surface temperature was measured in the center of the light guide with the thermocouple. Two nanohybrid composites containing different combinations of photoinitiators were selected to evaluate the potential effect of the various emission wavelengths of the LCUs on the properties of the composites.

Depth of cure and surface hardness were selected to examine the polymerization of the composite specimens. Significant differences were found in the depth of cure based on the type of LCU curing mode, so the null hypothesis was rejected. Depth of cure was not significantly different between the PinkWave LCU and the adjusted Valo Grand LCU with both composite types. The depth of cure of the composites was significantly lower with the unadjusted Valo Grand LCU with lower irradiance, but it was only a difference of 0.06mm for the Esthet-X HD and 0.08 mm for Tetric EvoCeram, both of which were not clinically significant. The low variability of the scrape test for determining the depth of cure could have contributed to the statistical differences between the groups. The null hypothesis was not rejected for surface hardness. The top and bottom surface hardness values and hardness ratios were not significantly different between the PinkWave LCU and the adjusted or unadjusted Valo Grand LCU with both composite types. Although there was a trend with the unadjusted Valo Grand LCU with lower irradiance to demonstrate lower surface hardness and hardness ratios, the differences were not statistically significant. Figure 1 displays the emission spectrum of the PinkWave LCU and the adjusted and unadjusted Valo Grand LCUs. Although the overall irradiance of

the adjusted Valo Grand LCU was similar to the PinkWave LCU, the absolute irradiance ($\text{mW}/\text{cm}^2/\text{nm}$) was greater for the adjusted Valo Grand LCU in the violet and blue wavelengths than the PinkWave LCU and the unadjusted Valo Grand LCU. In spite of the differences in absolute irradiances between the PinkWave LCU and the adjusted Valo Grand LCU at these wavelengths, no difference in depth of cure and surface hardness was demonstrated between the two LCUs per composite. Additionally, there was no difference in depth of cure or surface hardness between the two composite types. Esthet-X HD only contains CQ, and Tetric EvoCeram contains both CQ and TPO. Although the Valo Grand LCUs had relatively higher levels of absolute irradiance in the violet spectrum compared to the PinkWave LCU, both LCUs emit wavelengths in both the violet and blue spectrums to polymerize both CQ and TPO. However, wavelengths in the red and infrared regions were detectable for the PinkWave LCU and not the Valo Grand LCUs. The authors are not aware of any commercially available dental restorative composites with photoinitiators sensitive to light in the red or near-infrared range.(14)

Esthet-X HD had significantly greater volumetric polymerization shrinkage compared to Tetric EvoCeram, regardless of LCU curing mode. However, there was no significant difference in polymerization shrinkage per composite type based on LCU curing mode, and therefore, the null hypothesis was not rejected. The PinkWave LCU did not provide a decrease in polymerization shrinkage compared to the Valo Grand LCUs. The PinkWave LCU, however, had a significant increase in heat at the light tip compared to the adjusted or non-adjusted Valo Grand LCUs. The manufacturer, however, claims that the PinkWave LCU reduces the energy absorption from the pulp. Although this study did not measure pulpal temperatures, *in vivo* studies have demonstrated a relationship between the irradiance of LCUs and pulpal temperature.(15,16) Other than the undesirable production of greater surface heat at the light tip, it is questionable that the emission spectrum of the light from the PinkWave LCU in the red or near-infrared wavelengths contributed to an increase in polymerization or to a reduction in shrinkage of the composite specimens tested in this study.

Conclusions

The new quad-spectrum LCU, PinkWave, had a significant increase in surface temperature without any improvement in polymerization efficacy compared to the tri-spectrum LCU, Valo Grand, at similar irradiance.

Disclaimer: The views expressed are those of the authors and do not reflect the official views or policy of the Uniformed Services University, Department of Defense, or its Components. The authors do not have any financial interest in the companies whose materials are discussed in this abstract.

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