

# Effect of 457 nm Diode-Pumped Solid State Laser on the Polymerization Composite Resins: Microhardness, Cross-Link Density, and Polymerization Shrinkage

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## Abstract

**Objective:** The purpose of the present study was to test the usefulness of 457 nm diode-pumped solid state (DPSS) laser as a light source to cure composite resins. **Materials and methods:** Five different composite resins were light cured using three different light-curing units (LCUs): a DPSS 457 nm laser (LAS), a light-emitting diode (LED), and quartz-tungsten-halogen (QTH) units. The light intensity of LAS was 560 mW/cm<sup>2</sup>, whereas LED and QTH LCUs was ~900 mW/cm<sup>2</sup>. The degree of polymerization was tested by evaluating microhardness, cross-link density, and polymerization shrinkage. **Results:** Before water immersion, the microhardness of laser-treated specimens ranged from 40.8 to 84.7 HV and from 31.7 to 79.0 HV on the top and bottom surfaces, respectively, and these values were 3.3–23.2% and 2.9–31.1% lower than the highest microhardness obtained using LED or QTH LCUs. Also, laser-treated specimens had lower top and bottom microhardnesses than the other LCUs treated specimens by 2.4–19.4% and 1.4–27.8%, respectively. After ethanol immersion for 24 h, the microhardness of laser-treated specimens ranged from 20.3 to 63.2 HV on top and bottom surfaces, but from 24.9 to 71.5 HV when specimens were cured using the other LCUs. Polymerization shrinkage was 9.8–14.7 μm for laser-treated specimens, and these were significantly similar or lower (10.2–16.0 μm) than those obtained using the other LCUs. **Conclusions:** The results may suggest that the 457 nm DPSS laser can be used as a light source for light-curing dental resin composites.

## Introduction

THE APPLICATION OF AN APPROPRIATE LIGHT to cure composite resins is a basic process during dental restoration. Because the transformation of monomers to a polymer network is initiated by the activation of the photoinitiator camphorquinone (CQ), the resultant degree of polymerization depends much upon the quality of external light. In conjunction with the activation of CQ, light with a suitable emission spectrum and intensity is required. The spectral range and peak emission spectrum can be related to the efficiency of CQ activation. Light intensity is related to the number of photons emitted by a light-curing unit (LCU), and these photons optically excite CQ.

Currently, the LCUs used in dentistry are the quartz-tungsten-halogen (QTH) unit, the light-emitting diode (LED)

unit, and the argon laser. QTH LCUs have a wide spectral distribution from ~380 to 520 nm, which fully overlaps the absorption band of CQ.<sup>1–3</sup> Because QTH LCUs emit light at the same range of the absorption band of CQ, the light can evenly activate CQ. Among the issues related to QTH LCUs, heat generation by LCUs is a problem that affects tooth vitality. Because light emanates from a QTH filament, heat conduction from the QTH lamp through the fiber tip and a subsequent temperature rise is inevitable.<sup>4–7</sup> Light from LED LCUs fits the absorption peak of CQ, produces less heat, and has longer lifetimes than QTH LCUs.<sup>8–10</sup> The recently introduced dual-peak LED LCUs emit light with peaks at 405 and 465 nm; the former peak was introduced to activate co-initiator-containing composite resins.<sup>11–13</sup>

The argon laser was introduced to conservative dentistry to assist the restoration process. Because the argon laser

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emits blue light at 488 nm, it can also activate CQ. The advantages of an argon laser are that it produces highly monochromatic light of a coherent nature. Furthermore, this laser has been reported to be suitable for curing composite resins.<sup>14–16</sup> However, it is costly, and has limited usages to untrained users. Initially, a diode-pumped solid state (DPSS) laser was introduced as a light source for flow cytometers.<sup>17,18</sup> DPSS lasers are solid state lasers that are based on the pumping of a solid medium with a laser diode. The advantages of DPSS lasers over other lasers are low cost and a convenient size. Furthermore, because the wavelength of DPSS lasers can be controlled by frequency doubling of the original wavelength, a variety of DPSS lasers with multiple power options are available. In particular, the 473 nm DPSS laser has been examined for the curing of composite resins,<sup>19–21</sup> and these studies have shown that it is capable of matching the performances of other LCUs with respect to the cure of composite resins. Recently, a 457 nm DPSS laser was introduced, and spectroscopically, this light also matches well with the absorption peak of CQ.

The purpose of the present study was to test the usefulness of the 457 nm laser as a light source. Through the study, microhardness, cross-link density, and polymerization shrinkage of the cured specimens with 457 nm were assessed to estimate the degree of polymerization.

## Materials and Methods

### Composite resins and LCUs

For this study, five composite resins [Charisma Diamond (CD), Synergy D6 (SD), Tetric N Ceram (TN), Filtek Z250 (Z2), and Filtek Z350 (Z3)] were used. Table 1 lists their compositions and filler contents. All were of shade A3. For light curing, three different LCUs [DPSS 457 nm laser (Laser, LVI Technology, Seoul, Korea); L.E. Demetron (LED, Kerr, Danbury, CT); Optilux 501 (QTH, Kerr, Danbury, CT)] were used. The output light intensity of LED and QTH was  $\sim 900$  mW/cm<sup>2</sup>, as measured using built-in radiometers. The output power and spot size of Laser were 160 mW (PM3/FIELDMAX, Coherent, Portland, OR) and 6 mm, respectively, giving a resultant intensity of  $\sim 560$  mW/cm<sup>2</sup>.

The emission spectra of the LCUs and the absorption spectrum of CQ (Fig. 1) were measured using a photodiode array detector (M1420, EG&G PARC, Princeton, NJ) connected to a spectrometer (SpectroPro-500, Acton Research, Acton, MA).

### Microhardness test

To measure the surface microhardness (HV) of the specimens, resin was filled into a metal mold (4 × 2 × 3 mm) and light cured for 40 sec using an LCU. The cured specimen was then removed from the mold and aged for 24 h at 37°C in a dry, dark chamber. Microhardnesses of the top ( $z=0$ ) and bottom ( $z=3$  mm) surfaces were measured using a Vickers hardness tester (MVK-H1, Akashi, Tokyo, Japan) by evaluating the size of microindentations ( $n=12$  for each test condition). To make the microindentation, a 200 gf load and 10 sec dwell time were applied.

### Cross-link density evaluation

To examine cross-link density, specimens were prepared the same manner as for the microhardness test. After aging for 24 h at 37°C in a dry, dark chamber, the first microhardness measurements were performed, and specimens were then immersed in absolute ethanol for 24 h, rinsed, and dried with tissues. Second microhardness measurements were performed by following the steps described.

### Polymerization shrinkage measurement

The polymerization shrinkage ( $\mu\text{m}$ ) of specimens during and after light-curing was measured ( $n=7$  for each product) using a linometer (RB 404, R&B Inc., Daejeon, Korea). A resin of cylindrical shape (diameter, 4 mm; thickness, 2 mm) was placed over an aluminum disc (the specimen stage of the measurement system) and its top surface was secured using a glass slide. The end of the light guide was placed in contact with the glass slide. Before light curing, the initial position of the aluminum disc was set to zero (in the case of laser, specimens were irradiated with light at 90° to the specimen surface). Light was irradiated for 40 sec. As polymerization progressed, specimens shrank away to the light

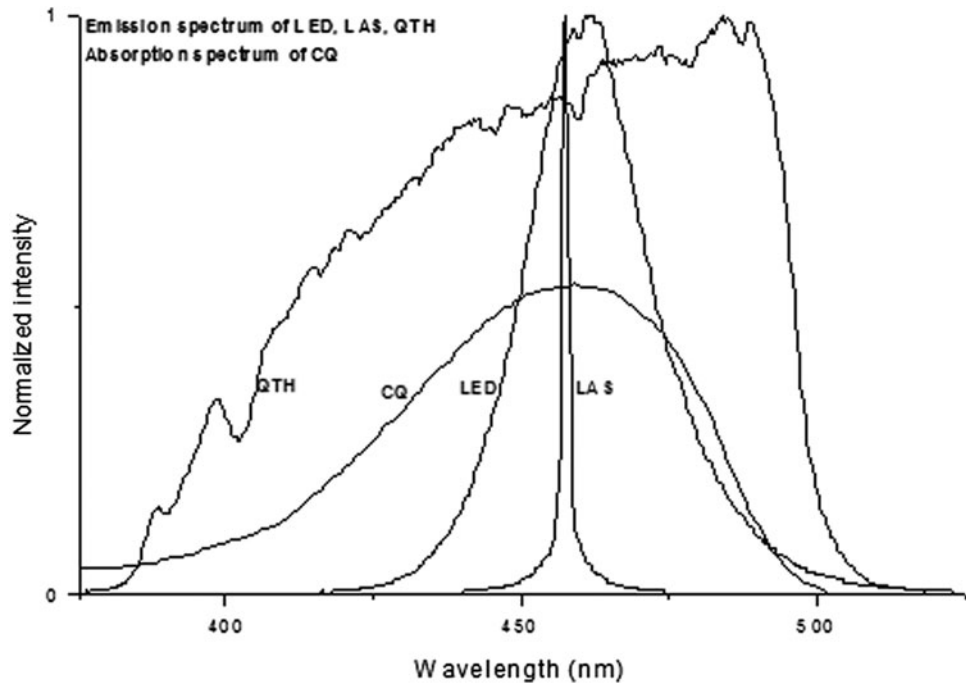
TABLE 1. MATERIALS TESTED IN THE PRESENT STUDY

Code	Composition	Filler content vol%/wt% <sup>1</sup> /wt% <sup>2</sup>	Manufacturer
CD	TCD-DI-HEA, UDMA, Ba-Al-F-silicate glass, SiO <sub>2</sub>	64/81/57.7	Heraeus Kulzer, GmbH, Hanau, Germany
SD	Bis-EMA, TEGDMA, UDMA, Barium glass, SiO <sub>2</sub>	65/80/75.2	Coltene/Whaledent Cuyaho Falls, OH
TN	Bis-EMA, TEGDMA, UDMA, Barium glass, YbF <sub>3</sub> , SiO <sub>2</sub>	57/80.5/61.9	Ivoclar Vivadent, Schann, Liechtenstein
Z2	Bis-GMA, Bis-EMA, UDMA, TEGDMA, Zirconia, silica	60/84.5/80.4	3M ESPE, St. Paul, MN
Z3	Bis-GMA, UDMA, TEGDMA, Bis-EMA, Non-aggregated silica, zirconia/ silica, nanosilica, nanocluster	59.5/82/74.7	3M ESPE, St. Paul, MN

wt%<sup>1</sup>, weight percent provided by the manufacturers.

wt%<sup>2</sup>, weight percent determined by ash method.

CD, Charisma Diamond; SD, Synergy D6; TN, Tetric N Ceram; Z2, Filtek Z250; Z3, Filtek Z350; UDMA, urethane dimethacrylate; Bis-EMA, bisphenol A glycol dimethacrylate; TEGMA, triethyleneglycol-dimethacrylate; Bis-GMA, bisphenol A glycidyl methacrylate.



**FIG. 1.** Emission spectra of the used light-curing units (LCUs) and absorption spectrum of camphorquinone (CQ).

source and the aluminum disc under the resin moved to the light source. The amount of disc displacement that occurred from polymerization shrinkage was measured automatically for 130 sec using a noncontacting inductive sensor placed below the aluminum disc. The resolution and measurement range of shrinkage sensor were 0.1 and 100  $\mu$ m, respectively.

*Statistical analysis*

Microhardness, cross-link density, and polymerization shrinkage results were analyzed by two way ANOVA fol-

lowed by post-hoc Tukey test for a multiple comparison. Statistical significance was accepted for  $p < 0.05$ .

**Results**

Figure 1 shows the emission spectra of the LCUs used, and the absorption spectrum of CQ. The QTH LCU showed the widest emission spectrum (380–520 nm), and Laser had the narrowest band, with emission peak at 457 nm.

Table 2 shows the microhardness (HV) of the specimens light cured using different LCUs. Before water immersion,

TABLE 2. MICROHARDNESS (HV) OF THE SPECIMENS LIGHT CURED USING DIFFERENT LCUs BEFORE AND AFTER IMMERSION IN DISTILLED WATER FOR 2 WEEKS

	Top			Bottom			
	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>C</sup>	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>B</sup>	
Before							
CD <sup>1</sup>	65.3 ± 0.4	69.6 ± 0.7	75.2 ± 0.4	CD <sup>1</sup>	43.4 ± 0.9	42.8 ± 0.8	50.7 ± 0.7
SD <sup>2</sup>	47.5 ± 0.7	55.9 ± 0.4	54.5 ± 0.5	SD <sup>1</sup>	37.5 ± 0.5	49.6 ± 0.6	44.8 ± 0.5
TN <sup>3</sup>	40.8 ± 0.7	45.6 ± 0.6	53.1 ± 0.5	TN <sup>2</sup>	31.7 ± 0.5	40.0 ± 0.4	37.6 ± 0.4
Z2 <sup>4</sup>	84.7 ± 0.6	86.0 ± 0.4	87.6 ± 0.9	Z2 <sup>3</sup>	79.0 ± 0.5	79.2 ± 0.6	81.4 ± 0.5
Z3 <sup>5</sup>	79.9 ± 0.6	84.0 ± 0.8	85.9 ± 0.7	Z3 <sup>4</sup>	66.2 ± 0.7	74.7 ± 0.5	74.9 ± 0.7
<i>p</i> Value	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$	
	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>B</sup>	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>B</sup>	
After							
CD <sup>1</sup>	50.6 ± 0.5	49.3 ± 0.3	56.5 ± 0.2	CD <sup>1</sup>	31.5 ± 0.3	36.5 ± 0.5	38.3 ± 0.3
SD <sup>2</sup>	40.5 ± 0.3	44.0 ± 0.4	43.6 ± 0.3	SD <sup>1</sup>	31.1 ± 0.4	39.7 ± 0.4	37.8 ± 0.4
TN <sup>3</sup>	30.4 ± 0.3	32.1 ± 0.3	37.7 ± 0.3	TN <sup>2</sup>	26.1 ± 0.4	28.4 ± 0.4	29.4 ± 0.4
Z2 <sup>4</sup>	69.3 ± 0.2	71.0 ± 0.4	69.3 ± 0.5	Z2 <sup>3</sup>	62.8 ± 0.4	61.7 ± 0.5	63.7 ± 0.3
Z3 <sup>5</sup>	62.4 ± 0.2	70.2 ± 0.5	63.4 ± 0.4	Z3 <sup>4</sup>	51.4 ± 0.5	60.0 ± 0.4	56.5 ± 0.4
<i>p</i> Value	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$	

Statistically significant difference on resin product is shown by superscript numbers, and on LCU by superscript letters. The same numbers or letters are not significantly different ( $p > 0.05$ ).

On *p* values, the letters  $\alpha$  and  $\beta$  denote resin product and LCU, respectively.

LCU, light-curing unit; LAS, laser; LED, light-emitting diode; QTH, quartz-tungsten-halogen; CD, Charisma Diamond; SD, Synergy D6; TN, Tetric N Ceram; Z2, Filtek Z250; Z3, Filtek Z350.

TABLE 3. MICROHARDNESS (HV) OF THE SPECIMENS LIGHT CURED USING DIFFERENT LCUS BEFORE AND AFTER IMMERSION IN ETHANOL FOR 24 H

	Top			Bottom			
	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>C</sup>	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>B</sup>	
Before							
CD <sup>1</sup>	65.1 ± 0.5	69.4 ± 0.6	75.1 ± 0.6	CD <sup>1</sup>	43.5 ± 0.8	42.4 ± 0.7	51.6 ± 0.5
SD <sup>2</sup>	48.0 ± 0.6	54.9 ± 0.7	54.8 ± 0.5	SD <sup>1</sup>	38.5 ± 0.7	49.4 ± 0.7	45.2 ± 0.7
TN <sup>3</sup>	40.2 ± 0.5	45.3 ± 0.4	52.8 ± 0.5	TN <sup>2</sup>	32.3 ± 0.5	40.2 ± 0.6	37.5 ± 0.6
Z2 <sup>4</sup>	84.9 ± 0.6	86.0 ± 0.4	87.9 ± 0.5	Z2 <sup>3</sup>	77.5 ± 0.5	79.3 ± 0.4	81.3 ± 0.3
Z3 <sup>5</sup>	80.0 ± 0.5	84.2 ± 0.8	85.6 ± 0.5	Z3 <sup>4</sup>	65.5 ± 0.6	74.2 ± 0.6	74.0 ± 0.6
<i>p</i> Value	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$		$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$
	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>C</sup>	LAS <sup>A</sup>	LED <sup>B</sup>	QTH <sup>B</sup>	
After							
CD <sup>1</sup>	36.0 ± 0.5	45.7 ± 0.6	51.1 ± 0.5	CD <sup>1</sup>	24.5 ± 0.5	37.5 ± 0.6	42.4 ± 0.7
SD <sup>2</sup>	27.0 ± 0.7	36.8 ± 0.5	41.3 ± 0.3	SD <sup>1</sup>	24.5 ± 0.6	34.8 ± 0.5	37.1 ± 0.4
TN <sup>3</sup>	22.6 ± 0.5	25.9 ± 0.3	33.9 ± 0.7	TN <sup>2</sup>	20.3 ± 0.6	24.9 ± 0.3	27.5 ± 0.5
Z2 <sup>4</sup>	63.2 ± 0.4	68.1 ± 0.5	71.5 ± 0.5	Z2 <sup>3</sup>	58.5 ± 0.4	65.5 ± 0.5	63.4 ± 0.6
Z3 <sup>5</sup>	59.5 ± 0.4	70.3 ± 0.6	71.4 ± 0.4	Z3 <sup>4</sup>	42.9 ± 0.7	60.6 ± 0.8	58.8 ± 0.6
<i>p</i> Value	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$		$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$

Statistically significant difference on resin product is shown by superscript numbers, and on LCU by superscript letters. The same numbers or letters are not significantly different ( $p > 0.05$ ).

On *p* values, the letters  $\alpha$  and  $\beta$  denote resin product and LCU, respectively.

LCU, light-curing unit; LAS, laser; LED, light-emitting diode; QTH, quartz-tungsten-halogen; CD, Charisma Diamond; SD, Synergy D6; TN, Tetric N Ceram; Z2, Filtek Z250; Z3, Filtek Z350.

specimens light cured with Laser showed significantly lower microhardness on the top and bottom surfaces than the other two LCUs (2.9–31.1%, depending upon LCU and resin). On the bottom surface, specimens showed 6.7–33.5%, 7.9–38.3%, and 7.1–32.6% lower microhardness than their top surface microhardness for Laser, LED, and QTH LCU, respectively. After immersion, specimens showed 14.7–29.6% and 14.7–29.0% reductions in the microhardness of top and bottom surfaces, respectively. Laser-treated specimens had significantly lower microhardness ( $p < 0.05$ ) than LED- and QTH-treated specimens.

The cross-link density of the specimens (Table 3) was also evaluated by measuring microhardness before and after immersion in ethanol for 24 h. After immersion, specimens

showed 25.6–44.7%, 16.5–42.8%, and 16.6–35.8% and 24.5–43.7%, 11.6–38.1%, and 17.8–26.7% microhardness decreases on the top and bottom surfaces for Laser, LED, and QTH, respectively. The specimens light cured with Laser had significantly lower ( $p < 0.05$ ) microhardness after immersion in ethanol.

Table 4 and Fig. 2 show the polymerization shrinkage and shrinkage profiles of specimens. Laser-produced shrinkage was similar to that of LED, and significantly lower than that of QTH. Furthermore, Laser induced less additional polymerization shrinkage after light curing for 40 sec. However, differences between the shrinkage values of the

TABLE 4. POLYMERIZATION SHRINKAGE ( $\mu\text{m}$ ) OF THE SPECIMENS LIGHT CURED USING DIFFERENT LCUS

	LCU		
	LAS <sup>A</sup>	LED <sup>A</sup>	QTH <sup>B</sup>
CD <sup>1</sup>	9.8 ± 0.4	10.2 ± 0.5	11.6 ± 0.8
SD <sup>2</sup>	14.7 ± 0.9	14.3 ± 0.2	16.0 ± 0.3
TN <sup>3</sup>	11.5 ± 0.9	12.2 ± 0.8	13.7 ± 0.2
Z2 <sup>3</sup>	12.3 ± 1.0	12.4 ± 0.6	12.7 ± 0.2
Z3 <sup>3</sup>	12.7 ± 0.6	11.5 ± 0.8	12.1 ± 1.2
<i>p</i> Value	$\alpha < 0.001$	$\beta < 0.001$	$\alpha \times \beta < 0.001$

Statistically significant difference on resin product is shown by superscript numbers, and on LCU by superscript letters. The same numbers or letters are not significantly different ( $p > 0.05$ ).

On *p* values, the letters  $\alpha$  and  $\beta$  denote resin product and LCU, respectively.

LCU, light-curing unit; LAS, laser; LED, light-emitting diode; QTH, quartz-tungsten-halogen; CD, Charisma Diamond; SD, Synergy D6; TN, Tetric N Ceram; Z2, Filtek Z250; Z3, Filtek Z350.

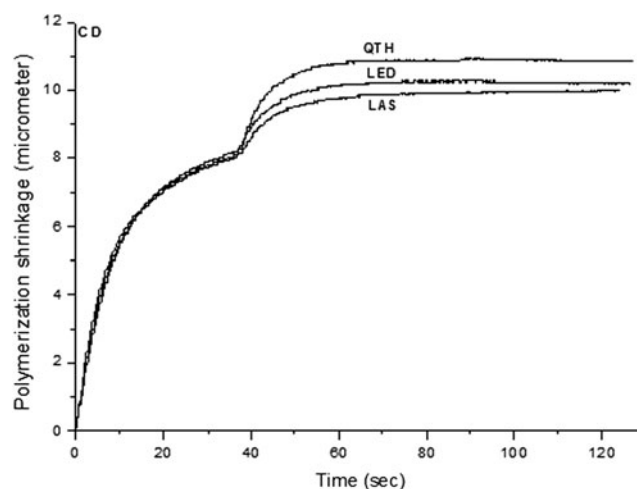


FIG. 2. Polymerization shrinkage of Charisma Diamond (CD) during and after light curing with different light-curing units (LCUs).

three LCUs were minor (9.8–14.7 vs. 10.2–16.0  $\mu\text{m}$  for Laser vs. the other two LCUs).

## Discussion

In the present study, the efficiency of photoinitiator activation by the light sources was addressed in terms of emission band width and light intensity. The advantages of LED and QTH LCUs over Laser are a broad emission of light that well matches the absorption band of CQ, and a high delivered light intensity, which indicates greater photon supply. However, because light from LED and QTH is not as coherent as that from Laser, their efficiencies may not be as high as indicated by considerations of light intensity alone, that is, 900 mW/cm<sup>2</sup> for LED and QTH versus 560 mW/cm<sup>2</sup> for Laser. On the other hand, despite the highly coherent and monochromatic nature of laser, its efficacy at activating CQ could be limited if the content of CQ in composite resin is not high enough to fully interact with Laser, which emits light only at 457 nm.

Microhardness is an indirect measure of degree of polymerization of composite resins.<sup>22–24</sup> Several intrinsic and extrinsic factors are known to affect microhardness. Among them, filler content is one such factor in this context, even though the correlation between filler content and microhardness can be easily changed depending upon the choice of test specimens.<sup>25,26</sup> In the present study, the resin products tested showed a positive linear relation between filler content and microhardness on top and bottom surfaces at  $R=0.82–0.94$  and  $0.38–0.82$  for nominal wt% and wt% as determined by the ash method, respectively, depending upon LCU. On the top and bottom surfaces, before water immersion, specimens cured using Laser had microhardnesses 2.9–31.1% lower than specimens cured with the other two LCUs. Because the light intensity of Laser (560 mW/cm<sup>2</sup>) was 38% lower than that of LED and QTH, this result might have been expected. However, on the top surface, except for TN, microhardness differences between Laser and the other two LCUs was only 15%, whereas on the bottom surface, differences varied from 14.4 to 31.1%, although excluding Z3 reduced this to <25%. Furthermore, Z2 showed a <4% difference between the top and bottom surfaces. In addition, before water immersion, microhardness differences between the top and bottom surfaces ranged from 6.7 to 33.5% and from 7.1 to 38.3% for Laser and the other two LCUs, respectively. After immersion, specimens light cured using Laser showed similar top-to-bottom microhardness differences as those before immersion. There was a 1.4–27.8% microhardness difference between those that were achieved using Laser and the other two LCUs on the top and bottom surfaces.

Cross-link density is an indirect measure of degree of polymerization.<sup>27,28</sup> When a polymer is densely cross-linked, the surface degradation by solvent can be reduced, and the resultant hardness also can be minimally affected. Intrinsic factors such as, monomer composition and combination and other resin ingredients, are controlled by manufacturers, but LCU type, light intensity, and curing time can be controlled by users. In the present study, cross-link density and microhardness trends were similar. After ethanol immersion, the top and bottom surfaces of specimens light cured with Laser and the other two LCUs ranged

from 22.6 to 63.2 HV and from 25.9 to 71.5 HV for the top surface and from 20.3 to 58.5 HV and from 24.9 to 65.5 HV for the bottom surface, respectively. As compared with before immersion, these values were from 25.6 to 43.8% and from 24.5 to 43.7% lower for the top surface and from 16.5 to 42.8% and from 11.6 to 38.1% lower for the bottom surface for Laser and the other two LCUs, respectively. As was observed for microhardness, Laser-treated specimens had a lower cross-link density, which would be attributable to the lower light intensity of Laser.

Polymerization shrinkage is one of the most unwanted side effects of methacrylate-based composite resins and is the source of many clinical problems, such as, bonding failure, recurrence of secondary caries, postoperative hypersensitivity, and marginal leakage.<sup>29–31</sup> Therefore, the minimization of polymerization shrinkage is essential. In the present study, 2 mm thick specimens showed shrinkage values of from 9.8 to 16.0  $\mu\text{m}$  depending upon the LCU used and the resin product. Laser and LED produced significantly different (usually lower) shrinkage values (from 9.8 to 14.7  $\mu\text{m}$ ) than QTH (from 11.6 to 16.0  $\mu\text{m}$ ;  $p < 0.05$ ). The slightly lower shrinkage shown by Laser-cured resins was attributed to the much lower light intensity.

## Conclusions

Of the LCUs tested in the present study, the 457 nm laser achieved 2.9–31.1% lower microhardness on the top and bottom specimen surfaces compared with the highest values obtained using LED and QTH LCUs, and 24.5–44.7% lower microhardness on the top and bottom surfaces after ethanol immersion compared with 11.6–42.8% for the other two LCUs. However, polymerization shrinkages for the three LCUs were similar. Importantly, Laser produced acceptable results even at a much lower light intensity (560 vs. 900 mW/cm<sup>2</sup>). Before reliable conclusions can be drawn, further studies are required on a wider range of composite resins.

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## Author Disclosure Statement

No competing financial interests exist.

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