

The Knoop Hardness of a Composite Resin Polymerized with Different Curing Lights and Different Modes

A. Rüya Yazıcı, DDS, PhD; Gerard Kugel, DMD, MS, PhD;
Gülsün Gül, DDS, MBA, MPH



Abstract

Aim: The purpose of this study was to compare the surface hardness of a hybrid composite resin polymerized with different curing lights.

Methods and Materials: Two 3.0 mm thick composite resin discs were polymerized in a prepared natural tooth mold using: (1) a conventional quartz-tungsten halogen light (QTH- Spectrum 800); (2) a high-intensity halogen light, Elipar Trilight (TL) - standard/exponential mode; (3) a high-intensity halogen light, Elipar Highlight (HL) - standard/soft-start mode; (4) a light-emitting diode, Elipar Freelight (LED); and (5) a plasma-arc curing light, Virtuoso (PAC). Exposure times were 40 seconds for the halogen and LED lights, and three and five seconds for the PAC light. Following polymerization, the Knoop hardness was measured at the bottom and the top surfaces of the discs.

Results: Significant differences were found between top and bottom Knoop Hardness number (KHN) values for all lights. The hardness of the top and bottom surfaces of both specimens cured by the PAC light was significantly lower than the other lights. No significant hardness differences were observed between the remaining curing units at the top of the 2.0 mm specimens. Significant differences were found between the LED and two modes of HL on the bottom surfaces. For the 3.0 mm thick samples, while significant differences were noted between LED and TL standard mode and between the two TL curing modes on the top, significant differences were only observed between QTH and the standard modes of TL and HL at the bottom.

Keywords: Light-curing units, hardness, composite resin

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Introduction

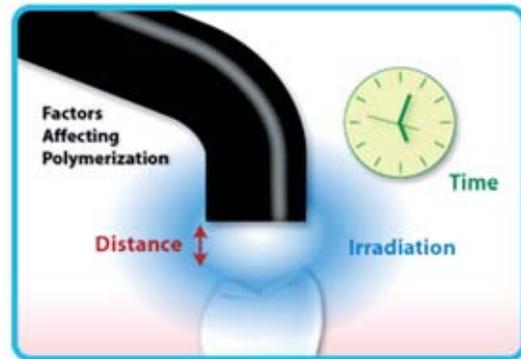
Light-cured composite resin is a restorative material commonly used in daily practice despite the inability to control polymerization shrinkage and the depth of cure.¹ Unfortunately, inadequate polymerization can contribute to a variety of clinical conditions such as discoloration, pulpal irritation, postoperative sensitivity, and the eventual failure of the restoration.² It is clear the success and longevity of composite-resin restorations depends on adequate polymerization, thus, elevating the importance of light-curing units. The depth of polymerization depends on the irradiance of the curing light, irradiation time³⁻⁴, as well as the distance of the light tip from the tooth-restorative material. The use of modified curing methods might also influence polymerization kinetics. By using the soft-start cure technique the composite resin is first polymerized at low intensity, then stepped up to high intensity. With the ramp-cure technique (exponential), light is initially applied at low intensity and gradually increased over time to high intensity. The reasons for these modifications of curing techniques are to reduce the polymerization stress or to cure the composite slowly by inducing the composite to flow in the gel state.⁵

Quartz-Tungsten-Halogen (QTH) Lights

For nearly two decades conventional quartz-tungsten-halogen (QTH) curing lights have been the standard equipment used for polymerizing composite resins. However, these lights have a number of inherent limitations such as degradation of the bulb, filter, reflector, and a limited effective lifetime. Moreover, composite resin is not likely to be completely polymerized with an aged light-curing unit. The reduction of light intensity due to long usage of the light-curing unit is well known. In recent years technologies such as the light-emitting diode (LED) and plasma arc curing lights (PAC) have been introduced to the dental profession as alternatives to conventional curing units.

Light-emitting Diode (LED) Lights

Light-emitting diode (LED) light-curing units are solid-state semiconductor devices that produce a more narrow spectral range that is closer to the absorption spectrum of camphorquinone photoinitiators used in composite resins to



facilitate polymerization.⁶ These units are cordless, portable, and lighter in weight compared to halogen light handpieces, and they generate minimal heat, so no fan is required.

Plasma Arc Curing (PAC) Lights

Manufacturers have focused on reducing the resin curing time by using units with high power density like plasma arc curing (PAC) light curing units. These units use a high frequency electrical field to generate plasma energy that is transformed into a mixture of ions, electrons, and molecules. It is this released plasma energy that initiates the polymerization of photosensitive composite resins.⁷ However, PAC units may not be able to produce comparable depths of cure as do conventional QTH lights.

Because surface hardness measurement is an effective way to evaluate the depth of cure, this study evaluated the effects of different light curing units and modes on the Knoop hardness of a hybrid composite resin.

Methods and Materials

A light-cured microhybrid composite resin (Vita shade A2) Herculite XRV™ (Kerr Corp., Orange, CA, USA) was used as the restorative material in this study. This particular product contains a blend of small and microfilled particles (80% by weight) with an average particle size of 0.6 microns. Human mandibular molar teeth molds were fabricated to stimulate the conditions of light reflection and absorption found in clinical cases. The teeth were embedded in acrylic resin and sectioned horizontally with a water-cooled saw to produce discs of enamel and dentin that were approximately 2.0 and 3.0 mm thick. A round hole (3.0 mm) was drilled at low speed through the center of each “tooth disc” and filled with the

microhybrid composite resin (Herculite XRV™). A mylar strip (Mylar Uni-Strip, Dentsply, Milford, DE, USA) was placed over the restorative material followed by a glass slide held under finger pressure to allow excess material to escape. The bottom of each specimen was covered with a block of 2.0 mm thick dentin. The specimens were light activated with one of the curing units (Figure 1).

The light curing units selected for this study included a conventional QTH light, two high

intensity halogen lights, a LED, and a PAC light. Exposure times were 40 seconds for the halogen and LED lights, and three and five seconds for the PAC light. Details of the light curing units and modes evaluated are shown in Table 1. The mean intensity of the curing units was measured with a radiometer.

The samples were then removed from the mold, and the top surface was marked with a permanent pen. Twelve specimens were made for each light-curing unit. After the samples were stored in

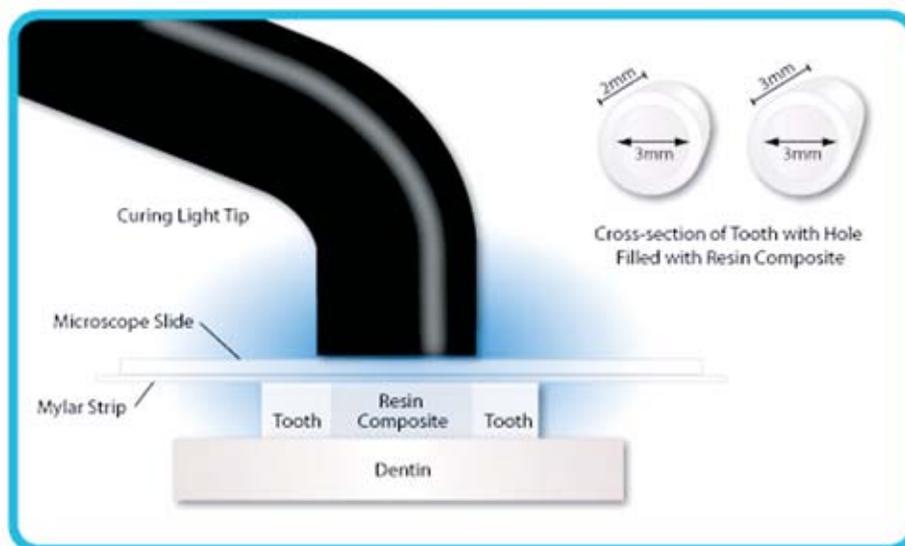


Figure 1. Schematic showing the design of sample preparation.

Table 1. Details of light curing units used in the study.

LCU	Manufacturer	Curing		
		Exposure time	Modes	Profile
Spectrum 800 (Halogen)	Dentsply, Milford, DE, USA	40 seconds	Standard	550 mW/cm ²
Elipar Highlight (High intensity halogen)	3M-ESPE, St. Paul, MN, USA	40 seconds 10 sec → 30 sec	Standard Two-step	700 mW/cm ² 150 mW/cm ² → 700mW/cm ²
Elipar Trilight (High intensity halogen)	3M-ESPE, St. Paul, MN, USA	40 seconds 15 sec → 25 sec	Standard Exponential	800mW/cm ² 100-800mW/cm ² → 800mW/cm ²
Elipar Freelight (LED)	3M-ESPE, St. Paul, MN, USA	40 seconds	Standard	400mW/cm ²
Virtuoso (PAC)	Den-Mat, Co, Santa Maria, CA, USA	3 seconds 5 seconds	Standard	1980 mW/cm ²

the dark in 100% humidity at 37°C for 24 hours, they were positioned beneath the indenter of a microhardness tester (Buehler Ltd, Lake Bluff, IL, USA) to determine the mean Knoop's Hardness number (KHN) of the top and bottom surfaces. A 500 g load was then applied through the indenter with a dwell time of 15 seconds. Three readings were taken on the top and bottom surface for each specimen and averaged to form a single value for that specimen. The mean KHN and hardness ratio of the specimens were then calculated using the formula:

$$\text{Hardness Ratio} = \frac{\text{KHN of bottom surface}}{\text{KHN of top surface}}$$

If that mean value exceeded 80%, the specimen was considered to be adequately polymerized.^{8,9}

The data were submitted to analysis of variance (ANOVA), and the means were compared by Tukey's test with a 5% of significance level ($P=0.05$). Values for the upper and lower surfaces in each group were analyzed using paired t-test.

Results

Means and standard deviations of the KHN and hardness ratios of the microhybrid composite after polymerization with different light curing units are shown in Table 2. ANOVA revealed significant

differences in mean top and bottom hardness values and hardness ratios for both the 2.0 and 3.0 mm thick samples among the tested curing lights ($P< 0.05$). The difference between the top and bottom surface hardness obtained within each curing unit was also statistically different ($P<0.05$).

For the 2.0 mm thick samples, KHN values at the top and bottom after polymerization with the PAC light for three and five seconds were significantly lower than after polymerization with other lights ($P<0.05$). While there was no difference in top surface hardness between the rest of the curing lights, significant differences were observed between the LED unit and the two modes of Elipar Highlight (HL) for bottom surface hardness.

The lowest hardness ratios were obtained in specimens cured with the PAC light (for three and five seconds), and these values were statistically different from the other curing lights. However the difference between two exposure times (three vs five seconds) with the PAC light was not statistically significant. There were also statistically significant differences in hardness ratio values between the LED and the two-step mode of the HL and between the LED and exponential mode of the Elipar Trilight (TL) unit ($P<0.05$).

Table 2. Mean KHN (standard deviation) and Hardness Ratio of 2 mm and 3 mm samples observed for the different light curing units.

Light-curing Units	2.0 mm samples			3.0 mm samples		
	Top Surface †	Bottom Surface †	Hardness Ratio	Top surface ‡	Bottom Surface ‡	Hardness Ratio
Spectrum 800	99.9 (7,1)	89.9 (6,0)	0.90 (0.08)	98.7 (6,6)	89.8 (4,3)	0.91(0.06)
HL standard mode	108.2 (9,3)	97.0 (10,4)	0.90 (0.06)	95.0 (7,1)	83.1(6,5)	0.85 (0.07)
HL two-step mode	104.0 (8,8)	97.4 (9,9)	0.94 (0.06)	97.8 (7,3)	88.2 (6,8)	0.81 (0.09)
TL standard mode	104.2 (10,6)	92.9 (7,4)	0.89 (0.09)	92.4 (6,0)	78.5 (4,9)	0.85 (0.05)
TL Exponential mode	97.8 (3,6)	88.9 (5,5)	0.91(0.05)	102.3 (6,0)	85.6 (7,6)	0.84 (0.07)
Freelight	105.9 (9,8)	84.8 (9,5)	0.80 (0.07)	102.1(3,7)	83.5 (6,8)	0.82 (0.06)
Virtuoso(3s)	75.6 (7,5)	48.0 (7,1)	0.63(0.11)	78.9 (6,4)	38.0 (4,7)	0.48 (0.07)
Virtuoso(5s)	82.7 (8,2)	50.8 (7,5)	0.60 (0.11)	79.5 (9,0)	23.0 (8,9)	0.29 (0.12)

For each column, brackets indicate statistical insignificance ($p>0.05$)

† indicates statistical significance between two columns ($p<0.05$)

‡ indicates statistical significance between two columns ($p<0.05$)

For the 3.0 mm thick samples, the PAC light had statistically lower top and bottom hardness values compared to the other units. The top surface KHN values of the specimens cured with the LED light were statistically different from the values obtained when the standard mode of TL was used. There was also a significant difference between standard and exponential modes of the TL for the top surface KHN. Statistically significant differences were observed between Halogen and the standard mode of TL and HL for bottom KHN values. The lowest hardness ratio values were again obtained in specimens that were cured with the PAC light (three and five seconds) and were statistically different from the other curing lights. The hardness differences between two exposure times were also significant ($P < 0.05$).

The difference between hardness ratio of 2.0 and 3.0 mm thick specimens were not statistically significant for all curing lights except for the PAC light.

Discussion

Hardness is an important parameter that has a bearing on the behavior of composite resin restorations in the oral environment. Adequate polymerization is required for clinically successful restorations. Therefore, the influence of different kinds of light curing units with varying intensities on the surface hardness of a composite resin was evaluated in the present study.

As the polymerization of composite is very susceptible to changes in light energy and density at depths greater than 2.0 mm¹⁰, it was decided also to include 3.0 mm thick composite resin samples. The 2.0 mm thick specimens were used in an attempt to ensure uniform and maximum polymerization.¹¹ To minimize the effects of colorants on light penetration, the Vita shade A2 shade of composite resin was selected.¹²

In most of the studies evaluating the hardness of resin based materials, aluminum or Teflon molds are used. However, tooth structure is more transparent and may transmit more light energy to the deeper regions of a preparation. Therefore, tooth molds were used in order to simulate clinical conditions.

For all light-curing units, microhardness was greater at the top surface which can be attributed to the relationship between irradiation distance and effectiveness of polymerization.¹³ Hansen and Asmussen¹⁴ found when the distance between the light tip and composite resin was decreased the depth of cure was increased. This finding is in agreement with several studies.¹⁵⁻¹⁶



On the other hand, surface hardness is not an adequate indicator for complete material polymerization.¹⁷ The hardness of the bottom surface should be close to the hardness of the top surface; the resulting hardness ratio should be greater than 0.8.⁸⁻⁹

For the 2.0 mm thick specimens polymerized with the exponential mode of TL, the mean hardness values at the top and bottom surfaces and the hardness ratio were close to those achieved with the standard mode of the same light. For the 3.0 mm thick samples, although the hardness ratio of the specimens that were cured with different modes of TL was equivalent, the top KNH values of exponential modes of TL were significantly greater than the values of standard mode. Moreover, there was a significant difference between the bottom KNH values of the specimens that were cured by TL standard mode and the QTH light.

When comparing different modes of HL, no significant differences in top and bottom KHN of the composite was observed using the two-step and standard modes of this light. Similar to the findings that were obtained with the standard mode of TL, for the 3 mm thick samples, the standard mode of HL promoted statistically lower bottom hardness values than QTH irradiated samples. On the other hand, the hardness ratio of different modes of TL or HL were almost the same as the standard modes of these lights and the QTH light.

In contrast to these findings, Yap, et al.¹⁸ evaluated the effects of different pulse activation and soft-start cycles on the Knoop hardness of

composite resin, and some pulse delay methods resulted in an inadequate hardness value compared to a control group that used continuous output.

Pilo and Cardash⁹ suggested the hardness ratio should be greater than 0.8. In this study, effective hardness ratios were achieved with all of the tested curing units except the PAC light. Interestingly, although the PAC light had the highest output, the composite resin specimens had the lowest hardness values and hardness ratios. This outcome could be related to the length of the exposure time used. A three second exposure time is recommended by the manufacturer and a five second exposure time was used in the present study. For the 3.0 mm thick samples, a statistically significant difference was observed between the hardness ratios of the three second and five second irradiation times of the PAC light. The hardness value was increased when irradiated for five seconds. Our results concur with those of Hofmann and others¹⁹ who observed irradiation of a composite resin by only one cycle of three seconds failed to produce adequate mechanical properties. Sharkey and others²⁰ compared the microhardness of different composite resins cured with the traditional halogen light source and plasma arc lamp. They reported the plasma arc lamp yielded lower hardness values for both top and bottom surfaces. A reduced irradiation time is claimed to be satisfactory by light manufacturers due to the high radiation intensity of the units. However, Dietschi et al.²¹ reported direct polymerization with a PAC light requires longer exposure times to reach hardness values obtained by conventional halogen lights. Based on the decreased hardness values that we and other investigators^{7,22-23} obtained with PAC units it would appear the higher intensities of this curing light cannot compensate for the reduced exposure time. While these new high energy light-curing units may require shorter polymerization times, the effects of such a

modification on composite resin hardness remains questionable. This finding may be due to the reality much of the light emitted from a PAC unit lies outside the effective polymerization region of 450–490 nm for composite resin materials.

Although the hardness ratios of LED cured specimens were lower than the hardness values obtained with the halogen curing units the difference was only significant between LED and PAC lights and between LED and the exponential and soft-start modes of halogen lights for the 2.0 mm thick samples. This outcome for the LED light may be explained by its low irradiation. Dunn and Bush²⁴ reported halogen lights produced significantly harder top and bottom composite surfaces than did LED lights. This finding is in agreement with the results of earlier investigations.²⁵⁻²⁶ On the other hand, in a recent study reported by Vandewalle and others²⁷ a second generation LED curing light had a similar curing efficiency as a QTH curing light at maximum output and similar energy densities. However, the LED and QTH halogen lights tested were not of equivalent energy densities in this study.

As a result, more *in vivo* and *in vitro* studies are needed to assess the effects of different light-curing units and modes on the hardness of different types of composite resin.

Conclusion

Based on the results of this study, the KNH values and hardness ratio of composite resin was significantly affected by different light-curing units. Except for the PAC light, all of the tested curing lights produced satisfactory levels of surface hardness ratio (above 0.8). PAC units may require longer irradiation times than those recommended by their respective manufacturers to adequately polymerize Herculite XRVTM microhybrid composite resin.

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About the Authors

A. Rüya Yazıcı, DDS, PhD



Dr. Yazıcı is an Associate Professor in the Department of Conservative Dentistry of the Faculty of Dentistry at Hacettepe University in Ankara, Turkey. Her research interests include: adhesive systems and composite resins.

e-mail: ruyay@hacettepe.edu.tr

Gerard Kugel, DMD, MS, PhD



Dr. Kugel serves as the Associate Dean for Research and is a Professor in the Department of Restorative Dentistry of the School of Dental Medicine at Tufts University in Boston, MA, USA. He is a Fellow in the American and International Colleges of Dentistry as well as the Academy of General Dentistry and the Academy of Dental Materials.

Gülsün Gül, DDS, MBA, MPH



Dr. Gül is an Assistant Professor and researcher at the pre-doctoral and post-doctoral levels in the Division of Public Health, Department of General Dentistry of the School of Dental Medicine at Tufts University in Boston, MA, USA.