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Curing Capability of Halogen and LED Light Curing Units in Deep Class II Cavities in Extracted Human Molars

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Clinical Relevance

Knoop hardness testing showed that the new generation of light-emitting diodes (LED) have enough power to cure composites in the same time as light curing units (LCU). The composite material and curing time have a significant association with the degree of polymerization.

SUMMARY

Class II cavities were prepared in extracted lower molars filled and cured in three 2-mm increments using a metal matrix. Three composites (Spectrum TPH A4, Ceram X mono M7 and Tetric Ceram A4) were cured with both the SmartLite PS LED LCU and the Spectrum 800 continuous cure halogen LCU using curing cycles of 10, 20 and 40 seconds. Each increment was cured before adding the next. After a seven-day incubation period, the composite specimens were removed from the teeth, embedded in self-curing resin and ground to half the orofacial width. Knoop microhardness was determined 100, 200, 500, 1000, 1500, 2500, 3500, 4500 and 5500 µm from the occlusal surface at a distance of 150 µm and 1000 µm from the metal matrix. The total degree of polymerization of a composite specimen for any given curing time and curing light was determined by calculating the area under the hardness curve.

Hardness values 150 µm from the metal matrix never reached maximum values and were generally lower than those 1000 µm from the matrix. The hardest composite was usually encountered between 200 µm and 1000 µm from the occlusal surface. For every composite-curing time combination, there was an increase in microhardness at the top of each increment (measurements at 500, 2500 and 4500 µm) and a decrease towards the bottom of each increment (measurements at 1500, 3500 and 5500 µm). Longer curing times were usually combined with harder composite samples. Spectrum TPH composite was the only composite showing a satisfactory degree of polymerization for all three curing times and both LCUs.

Multiple linear regression showed that only the curing time ($p<0.001$) and composite material ($p<0.001$) had a significant association with the

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degree of polymerization. The degree of polymerization achieved by the LED LCU was not significantly different from that achieved by the halogen LCU (p=0.54).

INTRODUCTION

Despite their popularity, halogen light curing units (LCUs) used to polymerize dental composite have several drawbacks. Halogen bulbs have a limited effective lifetime of about 40 to 100 hours. Their light intensity decreases with time (Rueggeberg & others, 1996), and their reflector and filter degrade over time due to the significant amount of heat produced during curing cycles (Jandt & others, 2000). Effectively, only 0.7% of the energy consumed by halogen LCUs is used to cure composites (Ernst, 2002). The aforementioned drawbacks will reduce the effectiveness of polymerization in composite restoratives (Barghi, Berry & Hatton, 1994). Inadequate composite polymerization has been associated with inferior physical properties, higher solubility, retention failures and adverse pulpal responses caused by residual unpolymerized monomers (Hofmann & others, 2002a; Blankenau & others, 1991; Ferracane & others, 1997). It has also been shown that practitioners are often unaware of lamp deterioration and continue to use poorly performing lights, further supporting inadequate polymerization (Martin, 1998; Barghi & others, 1994; Miyazaki & others, 1998).

In order to overcome the drawbacks of halogen LCUs, blue LED (light-emitting diodes) LCUs have been developed for the polymerization of light-activated dental materials. LEDs have a lifetime of more than 10,000 hours and undergo little degradation of light output over time. They use junctions of doped semiconductors (p-n junctions) to generate light and, therefore, require no filters to produce blue light. LEDs are resistant to shock and vibration. Their efficiency is 7% (10 x that of halogen LCUs). They produce less heat during the curing cycle (Ernst, 2002) and no ventilation is needed in the device, allowing for their silent operation. Their relatively low power consumption makes them suitable for portable use. The narrower spectral output of these blue LEDs, namely 440-490 nm, falls within the champherquinone absorption spectrum, a reason for their high efficacy (Mills, Jandt & Ashworth, 1999; Lee & others, 1993). Gordan and others (2002) showed that, with different LED lights, 78% to 95% of light output falls in the absorption spectrum of champherquinone, compared to 56% in a commonly used halogen light.

Previous studies (Mills & others, 1999; Jandt & others, 2000; Stahl & others, 2000) have shown that blue LED LCUs have the potential to polymerize dental composites without having the drawbacks of halogen LCUs. However, early LED-systems have been shown to need 2-3x longer curing times to create a depth of cure equal to that produced by the tungsten-halogen light (Nomoto, McCabe & Hirano, 2004). Rahiotis and others (2004) and Yap and others (2004) suggested that composites cured with the latest generation of LED lights have lower microhardness values and are less cross-linked but produce less linear polymerization shrinkage than composites cured with conventional halogen lights. In addition to lower polymerization shrinkage, Hofmann, Hugo and Klaiber (2002b) observed a considerably lower rise in temperature in the composite during polymerization when using LED LCUs. However, to date, none of the studies have compared the latest LED-lights with halogen lights in an experiment designed to mirror clinical situations.

Experiments with the SmartLite PS LED LCU (Dentsply-DeTrey, Konstanz, Germany) that have led to this study suggest that the depth of cure decreased significantly faster than with conventional halogen curing lamps when the tip-to-composite distance was increased. Since this LED LCU has its light source directly in the curing tip, the light is not concentrated on a defined area but is dispersed (radially) in all directions. Felix and Price (2003) showed that turbo light guides also demonstrated such dispersion, and this dispersion has resulted in a significantly higher reduction in power density at a distance 6 mm from the light tip compared to the conventional light guide.

This study determined whether light emitted from the SmartLite PS LED LCU sufficiently cures composite in 6 mm deep Class II cavities when compared to a conventional halogen LCU. The cavities were prepared in extracted human molars and filled and cured in three 2-mm composite increments using metal matrices.

METHODS AND MATERIALS

Choosing and Preparing the Teeth

Thirty-six extracted third molars of the lower jaw were chosen for this experiment. These molars were free of damage and caries upon clinical inspection. They had been stored at 5°C in a buffered thymol-saturated solution since being extracted. The roots of these teeth were then shortened using a grinding disk (Knuth-Rotor, Struers, Ballerup, Denmark). The teeth were then embedded in cylindrical molds with self-curing acrylic resin (Technovit 4071, Kulzer, Wehrheim, Germany) to a level 2-4 mm apical to the cemento-enamel-junction. When not used for the experiment, the embedded teeth were always stored at 5°C in a humidity chamber containing a thymol-saturated storage solution.

In these molars, 36 identical Class II (Figure 1) cavities were prepared by hand by the same operator with the aid of a binocular telescope (2.5 x magnification, Sandy Grendelmeyer, Switzerland). To control the exact

dimensions of the cavities during preparation, the ceramic plates were filed down to the exact width needed and used as gauges. The depth of the cavity was measured using a periodontal probe. The depth of the proximal box was 7 mm and was measured from the highest adjacent cusp. The oro-facial width was 3.4 mm and the mesio-distal length was 6 mm. From the cervical cavity edge towards the center of the tooth, the depth of the cavities decreased from 7 mm to 3 mm in two 2 x 2 mm steps. These steps allowed for filling in increments of 2 mm, leaving a 1 mm gap between the last increment and the tip of the light guide (Figure 2).

All the cavities were then photographed and measured under the microscope at 12.5x magnification (Leica M420) using multiple focus imaging (Leica IM500 version 4.0, Leica Microsystems Imaging Solutions Ltd, UK). The mean oro-facial width was 3432 ± 25 µm. The mean box depth was 7010 ± 112 µm, and the mean mesio-distal depth of the first step was 2040 ± 93 µm. The mean height of the first step was 2107 ± 103 µm and the second step was 1985 ± 140 µm. Then the teeth were randomly assigned to three groups of 12 and numbered from 1 to 36. They were sawed in half along the mesio-distal length of the cavity using a diamond-bladed rotating saw (Isomet low speed saw, Buehler LTD, USA). This decreased the cavity width by 0.4 mm. Holding the two halves of the teeth together, they were then placed in a block of putty (Optosil comfort, Heraeus Kulzer, Germany) to secure their position.

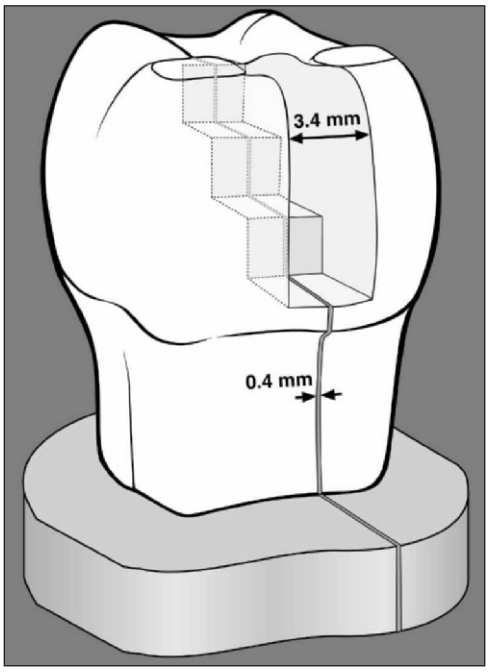

Figure 1: *The cavity design: After preparing the cavity, the tooth was sawed in half along the mesio-distal length of the cavity.*

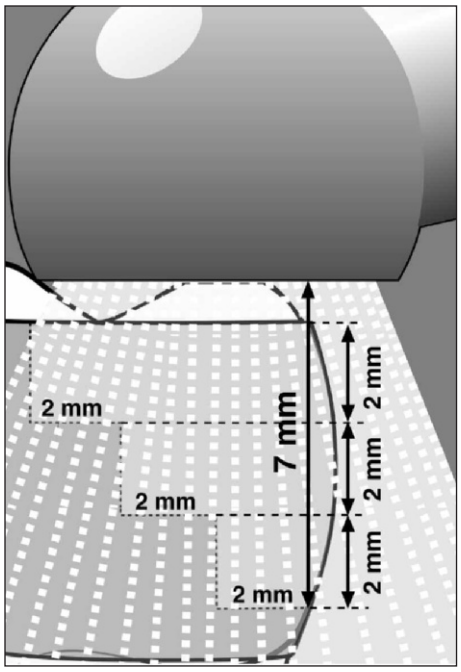

Figure 2: *Three 2-mm increments of composite were layed with the aid of the steps provided by the cavity design and the metal matrix. The LCU was placed directly on the tooth for curing cycles between the increments. SF-spatial filter, CCD-charge coupled device.*

Producing the Specimens

Three light curing materials of similar shades were used: Spectrum TPH composite A4 (Dentsply DeTrey GmbH, Konstanz, Germany), Ceram X mono composite M7 (Dentsply DeTrey GmbH) and Tetric Ceram composite A4 (Ivoclar Vivadent AG, Lichtenstein) (Table 1).

The Spectrum 800 (S800) continuous cure light (Dentsply DeTrey) with the standard 8-mm curing tip set at the highest output level was used as a conventional halogen LCU. The LED curing light used was the SmartLite PS (SL) (Dentsply DeTrey). The recommended Disposa-Shield (Dentsply) was always used to cover the light tip of the SL. The light intensity of each lamp was tested at the beginning and end of every curing session, using two conventional radiometers (Demetron, Danbury, CT, USA and Spring Light Meter 3K, Spring Health Products Inc, Norristown PA, USA) to ensure constant light emission. Although the radiometers showed different curing intensities for the curing lamps, light emission had remained constant throughout the examination (Demetron: 800 mW/cm^2

Table 1: *Fillers of Various Materials and Recommended Curing Lamps and Curing Times (Institut der Deutschen Zahnärzte, 2004)*

Material	Filler	Filler Particle Size	Filler Content/Volume
Spectrum TPH A4 Composite (Lot #0311001721)	Ba-glass Pyr SiO_2	mini	57%
Ceram X mono M7 Composite (Lot #0311000792)	Ba-glass	nano, mini	57%
Tetric Ceram A4 Composite (Lot #GM1051)	Ba-glass, pyr. SiO_2, YbF_3, mixoxide, Ba-Al-Fluorosilicate-glass	mini, midi, macro	60%

[SL], 700 mW/cm² [S800]; Spring Light Meter: 1200 mW/cm² [SL], 1300 mW/cm² [S800]).

The three composites were cured using 10, 20 and 40 second curing cycles with both curing lights (Table 2). The combination of a curing light, a composite and a curing time was defined as a curing mode (for example, curing mode 1 = Spectrum TPH composite cured for 10 seconds with the SmartLite LCU). Twelve cavities were filled for each curing mode. The order in which the 18 curing modes were processed was based on a randomized block design. For the study, a total of 216 fillings were made.

Table 2: *The 18 curing modes. Both curing lights were used to cure all three composites in curing cycles of 10, 20 and 40 seconds.*

SmartLite PS Curing Light	Spectrum TPH composite	10, 20 & 40 second curing cycles
	Ceram X composite	10, 20 & 40 second curing cycles
	Tetric Ceram composite	10, 20 & 40 second curing cycles
Spectrum 800 Curing Light	Spectrum TPH composite	10, 20 & 40 second curing cycles
	Ceram X composite	10, 20 & 40 second curing cycles
	Tetric Ceram composite	10, 20 & 40 second curing cycles

In terms of filling the teeth, the cavities were first coated with a very thin layer of glycerine (99% glycerine solution) to allow for removal of the composite fillings for hardness testing. With this method, it was possible to use each tooth more than once as a specimen. Metal matrices (Hawe Contoured Steel Matrices, KerrHawe SA, Bioggio, Switzerland) were tightened around the tooth using a Nystrom matrix retainer. The cavities were then filled in three 2-mm increments, with the help of the "steps" provided by the design of the cavities. Each increment was cured before adding the next. For every curing cycle, the light source was placed directly on the tooth, allowing for a 1 mm gap to the third and final increment without allowing the metal matrix to cast a shadow on the composite increments (Figure 2).

The metal matrix was removed from the teeth and they were then stored in a dark humidity chamber at 37°C for 7 days.

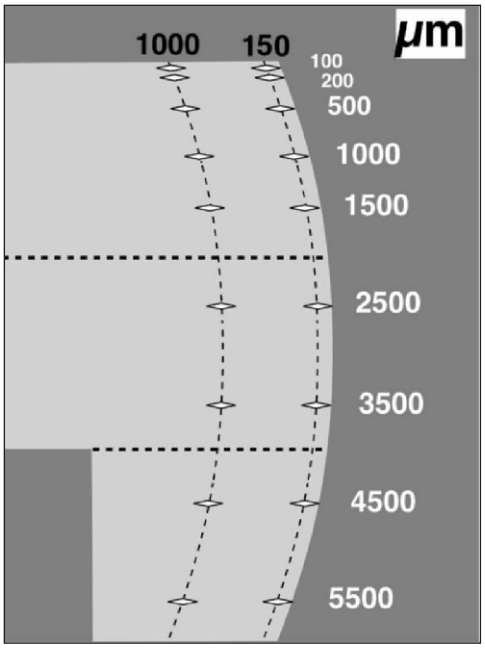

Figure 3: *The diamond indentations for Knoop hardness testing were made 100, 200, 500, 1000, 1500, 2500, 3500, 4500 and 5500 µm from the occlusal surface, 150 µm and 1000 µm from the metal matrix.*

Determining the Degree of Polymerization

After 7 days, the composite specimens were removed from the teeth, given a new, randomly allotted code number and embedded in self-curing acrylic resin (Paladur, Heraeus Kulzer, Hanau, Germany) inside parallel-sided steel molds 1.5 (= 1/2 cavity width) and 7 mm wide. These specimens were stored at 5°C until used in order to avoid a temperature rise during polymerization.

After the resin had set, the thinner mold (1.5 mm) was removed, and the specimen that was embedded in the thicker mold was serially polished on the Knuth Rotor polishing machine (Struers, Ballerup, Denmark) with silicon carbide paper disks of 65, 46, 30, 18, 10 and 6 µm grain. The polishing time at each stage was at least one minute per specimen. Before polishing with 3 µm diamond abrasive on a Buehler polishing cloth, the embedded specimens were removed from the molds. In-between the two polishing steps and after the final polishing, all specimens were rinsed and sonicated for 5 minutes in distilled water. These preparation steps wore away 1.5 mm, or half of the composite specimen.

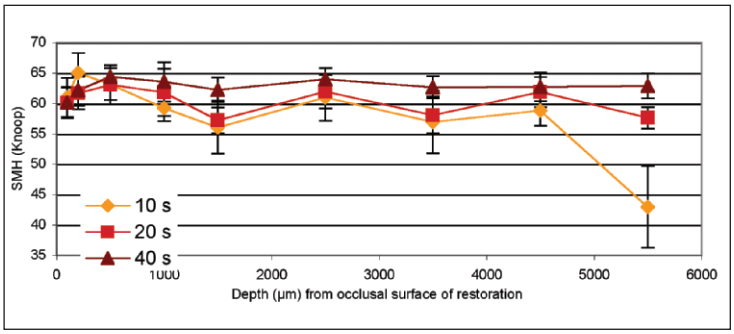

Figure 4: *Surface microhardness profile for Spectrum TPH composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

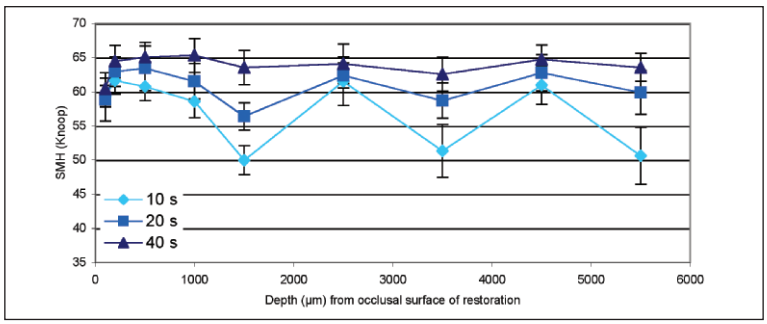

Figure 5: *Surface microhardness profile for Spectrum TPH composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

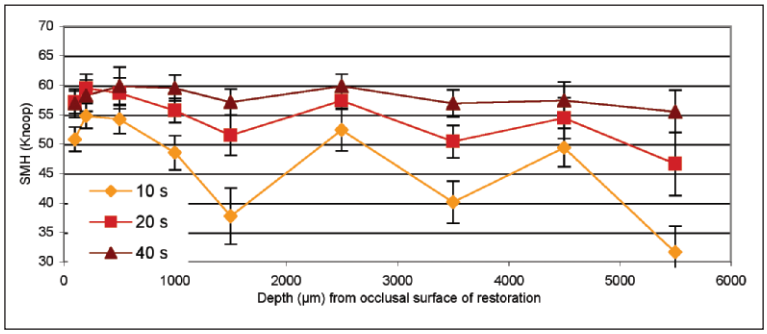

Figure 6: *Surface microhardness profile for Ceram X composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

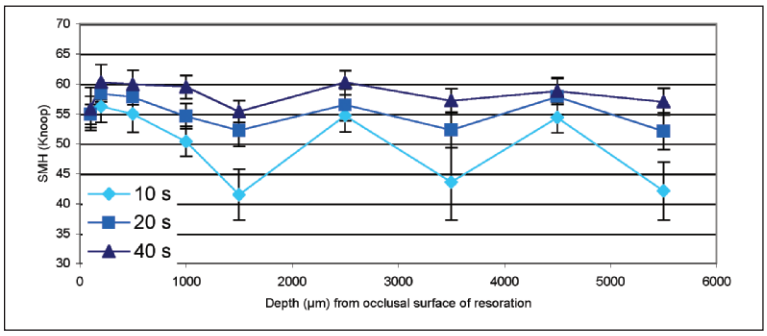

Figure 7: *Surface microhardness profile for Ceram X composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

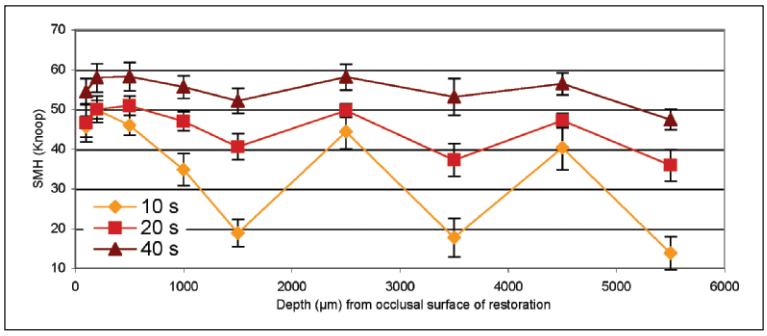

Figure 8: *Surface microhardness profile for Tetric Ceram composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

The degree of polymerization of the composite samples was then determined by hardness testing using a digital microhardness tester (Leitz-Miniload-2, Leitz, Heerbrugg, Switzerland). A force of 0.98 N was applied by the diamond indenter with a slope of 0.49 N/s and a dwell time of 15 seconds to obtain Knoop hardness. Knoop microhardness was measured 100, 200, 500, 1000, 1500, 2500, 3500, 4500 and 5500 µm from the occlusal surface at a distance of 150 and 1000 ± 20 µm from the proximal surface (metal matrix) (Figure 3).

Statistical Analysis

First, distribution of the data was analyzed using Q-Q-Plots (SPSS-Version 11, SPSS Inc, Chicago, IL, USA). As the data was normally distributed, parametric tests were employed.

The degree of composite polymerization was calculated by a computer program (Systat 5.2.1, Systat Inc, Evanston, IL, USA) that calculated the product of the Knoop hardness and depth from the occlusal surface of the filling (µm*KHN) as being the area under the hardness curve between 100 and 5500 µm. The larger the area under the curve, the higher the total degree of polymerization of the composite. Thus, it was possible to establish the degree of composite polymerization across the total depth of the cavity.

The statistical difference between the two groups was evaluated using the student *t*-test. Multiple linear regression was used to determine the factors that had a significant influence on the degree of polymerization. The dependent variable was the total polymerization expressed as the area under the hardness curve. The independent variables were the different curing times, the three composite materials and the two curing lamps. The significance level for all statistical tests was set at $p \leq 0.01$. When multiple comparisons were made, the Bonferroni correction was applied.

After every session of Knoop hardness testing, diamond imprints of one sample were remeasured to determine the standard error of individual measurements (Dahlberg, 1940) and, for this study, the measurement was 0.67 KHN or 1.2%.

RESULTS

The depth-hardness profiles for hardness measurements 150 µm from the metal matrix are shown in Figures 4-9, and Figures 10-15 show those with hardness measurements 1000 µm from the metal matrix. The hardness values at 150 µm never reached maximum values and were generally lower than those 1000 µm from the matrix. The hardest composite was usually encountered between 200-1000 µm from the occlusal surface. The figures also

clearly show that, for every curing mode combination, there was an increase in microhardness at the top of each increment (measurements at 500, 2500 and 4500 µm) and a decrease towards the bottom of each increment (measurements at 1500, 3500 and 5500 µm). The amplitude between the rise and fall in the hardness profile decreases as the curing time increases. Longer curing times were usually combined with harder composite samples.

Figures 16 and 17 show the total area under the hardness curve for both curing lights for measurements near the metal matrix and 1000 µm from the matrix, respectively. For both LCUs, the area under the curve generally increases as curing time increases. Spectrum TPH composite reached the highest overall degree of polymerization. The largest area under the curve was registered for S800 LCU, with a curing time of 40 seconds (345'346 µm*KHN).

For measurements 150 µm from the metal matrix (Figure 16), Ceram X composite cured for 10 seconds and Tetric Ceram composite cured for 10 and 20 seconds showed inferior polymerization. For Spectrum TPH 40 seconds and Ceram X 10 seconds, S800 showed significantly better results than SL ($p<0.01$). There was always a significant difference ($p<0.001$) between the values for 10, 20 and 40 seconds for each LCU, respectively.

For measurements 1000 µm from the matrix (Figure 17), Spectrum TPH cured for 40 seconds and Ceram X cured for 10 seconds, S800 showed a significantly higher degree of polymerization ($p<0.01$ and $p<0.001$, respectively) than SL. For Ceram X and Tetric Ceram, the values for 10, 20 and 40 seconds were always significantly different ($p<0.01$) for each lamp, respectively. There was, however, no significant difference between the 10 and 40 second values and between the 10 and 20 second values for Spectrum TPH cured with SL and between the 10 and 20 second values for Spectrum TPH cured with S800.

For each curing mode, when comparing the total areas achieved separately between measurements 150 µm and 1000 µm from the metal matrix, it becomes clear that the degree of polymerization of composite 150 µm from the matrix is below that of composite 1000 µm from the matrix. When comparing the means using the paired *t*-test, all but 7 curing modes (for SmartLite LCU: Spectrum TPH 20 and 40 seconds, Ceram X 40 seconds and Tetric Ceram 40 seconds; for Spectrum 800 LCU: Spectrum TPH 20 and 40 seconds and Ceram X 20 seconds) showed that measurements 1000 µm from the metal matrix showed significantly harder values than those 150 µm from the matrix at the same depth.

The comparison of the composites showed that Spectrum TPH reached a significantly higher degree

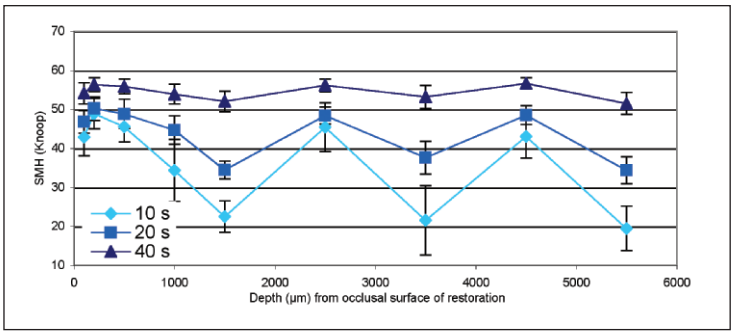

Figure 9: *Surface microhardness profile for Tetric Ceram composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 150 µm.*

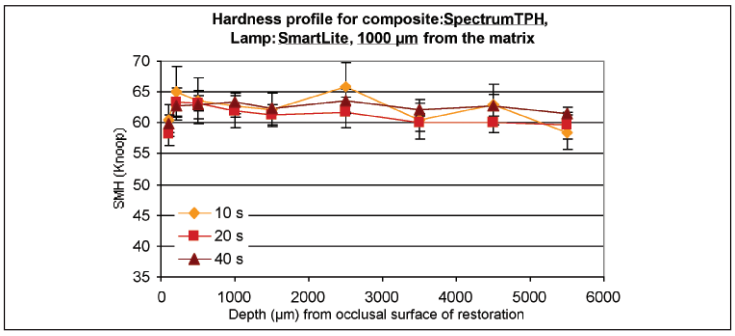

Figure 10: *Surface microhardness profile for Spectrum TPH composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

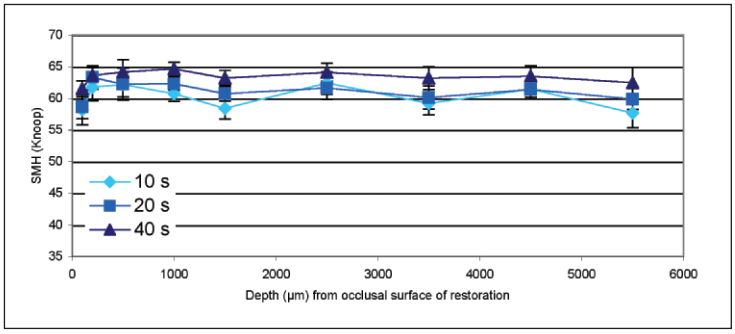

Figure 11: *Surface microhardness profile for Spectrum TPH composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

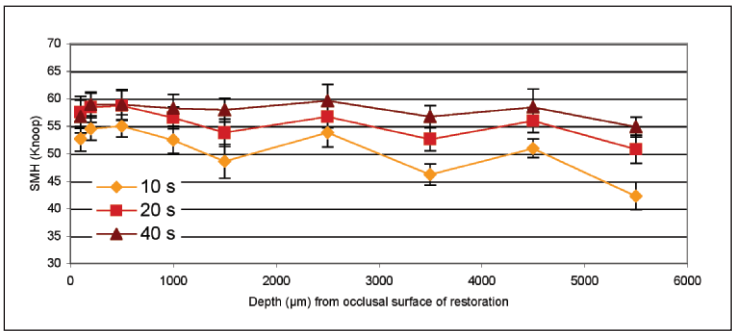

Figure 12: *Surface microhardness profile for Ceram X composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

Table 3: *Significant parameters for the curing of composites. Values are calculated from the measurements taken at 1000 µm from the metal matrix. The values in parentheses [eg. (485.67)] are those taken from the measurements at 150 µm from the metal matrix.*

Dependent Variable	Parameters	F-Value	*p*-Value	R2
Total polymerization expressed as the area under the hardness curve	composite material	485.67 (418.47)	$p<0.001$ ($p<0.001$)	.85 (.87)
	curing time	114.40 (252.70)	$p<0.001$ ($p<0.001$)	
	curing lamp	0.38 (2.44)	$p=0.54$ ($p=0.120$)	

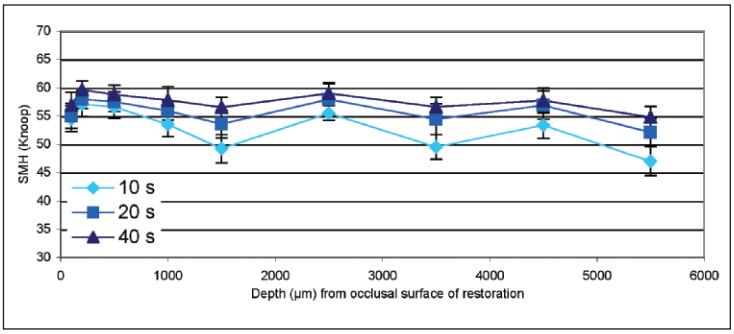

Figure 13: *Surface microhardness profile for Ceram X composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

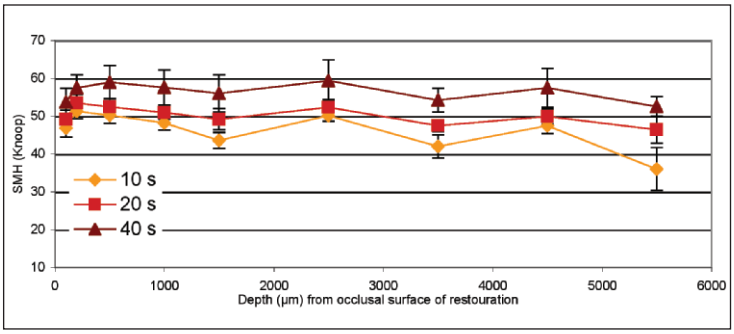

Figure 14: *Surface microhardness profile for Tetric Ceram composite using the SmartLite LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

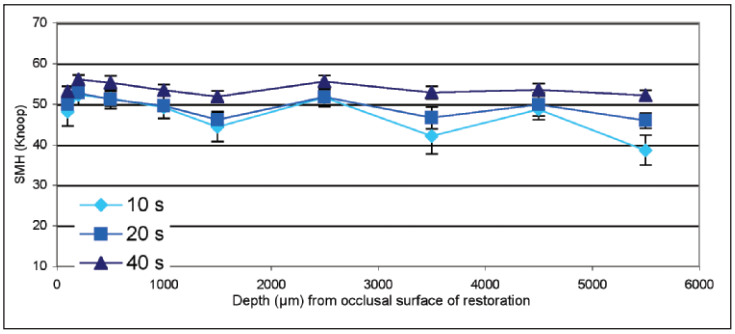

Figure 15: *Surface microhardness profile for Tetric Ceram composite using the Spectrum 800 LCU for 10, 20 and 40 seconds. Distance from the metal matrix: 1000 µm.*

of polymerization for 10, 20 and 40 seconds than the other two composites. Tetric Ceram had the lowest degree of polymerization.

Multiple linear regression revealed that only the curing time and composite material had a significant association with the degree of polymerization. For measurements 150 µm and 1000 µm from the metal matrix, 87% and 85% of the variability in the degree of polymerization could be explained using these two parameters. The composite material had the greatest influence (Table 3).

DISCUSSION

In this study, SmartLite PS LED LCU was compared to a conventional halogen LCU (Spectrum 800) with the aim of determining whether the LED LCU was capable of curing composites sufficiently in deep cavities when the composite is cured in 2 mm increments. Uhl, Mills and Jandt (2003) demonstrated that composites containing co-initiators with maximal absorption below a wavelength of 410 nm showed significantly lower hardness values if LED LCUs were used instead of halogen LCUs. For this reason, three composites were chosen, using only the photo initiator camphoroquinone.

The direct evaluation of the degree of polymerization of photoactivated composites by spectroscopic techniques is not easily accomplished. Therefore, the indirect evaluation using hardness as a parameter for indicating the degree of polymerization is widely accepted (Hofmann & others, 2002c).

In recent years, research into the possibility of curing composites using LED-technology has expanded widely. Generally, it can be said that composites using champherquinone as a photo initiator can be cured more efficiently using LED LCUs than conventional halogen LCUs. In 1998, Fujibayashi and others developed an LED LCU with an output of only 100 mW/cm^2 that produced equal curing depths as halogen LCUs in composite (Fujibayashi & others, 1998). Of the total light emitted by a blue LED, 78% to 95% falls within the range of 450-500 nm, compared to 56% for conventional halogen LCUs. Only light within this range can activate the champherquinone. However, more recent studies have shown that LED LCUs always needed longer curing times to reach similar depths of cure for composite materials (Nomoto & others, 2004).

The light intensity of the newest generation of LED LCUs has been improved greatly. The SmartLite PS

LED used in this study had virtually the same light intensity as the Spectrum 800 halogen LCU (using two conventional radiometers). Light is emitted radially from the SmartLite LCU. This means that the light intensity will decrease faster when the tip-to-composite distance is increased compared to it using a conventional light guide. Nevertheless, as shown by the results after multiple linear regression (Table 3), the design of the curing lights used for this study had no statistically significant influence on the degree of polymerization of the three composites tested. This result may have turned out differently if a stronger halogen LCU had been used. The ranking of the factors influencing the degree of polymerization (Knoop hardness) correlated strongly with the findings of Uhl and others (2003). The degree of polymerization was influenced most strongly by the composite, followed by the polymerization time. This showed that careful selection of the composite and curing time is important when striving to attain sufficient composite polymerization.

New questions were raised, since hardness generally decreased from the occlusal increment (with one curing cycle) to the one cervical increment (with three curing cycles), and the maximum area was found in the most occlusal increment that had only been cured once. How did curing of the second and third increments effect the degree of polymerization of the first and second increments, respectively? Additional (unpublished) experiments using the SmartLite LCU with 20-second curing cycles and Ceram X composite suggested that the underlying increments were not necessarily further polymerized when curing the more occlusal increments. Even the second increment was not further polymerized due to curing of the third and final increment. Apparently, it is necessary to cure the underlying increments of composite completely and thoroughly before laying the next increment, because it cannot be assumed that additional curing after finishing a filling will have any effect on the underlying increments. This may be due to a combination of the relatively significant distance to the light source (Price & others, 2003) and light absorption of the second and third increments (Prati & others, 1999). Rueggeberg and Jordan (1993) showed that, for exposure durations of 10, 20 and 40 seconds, a tip-to-composite distance greater than 4 mm demonstrated a significant decrease in resin polymerization 2 mm below the composite surface. This decrease may be less for the halogen LCU than for the LED LCU, because the halogen LCU has a much higher power output for longer wave lengths (within the champherquinone absorption spectrum), which penetrate composites deeper than do shorter wave lengths (Arikawa & others, 1998).

Andrzejewska (2004) has shown that radicals can be trapped during composite polymerization due to the formation of micro gel networks. The author suggested that this radical trapping may even occur at low degrees of polymerization and will contribute to the termination of a polymerization process. Thus, photo initiators may be trapped in the polymerization network after an initial curing cycle and are no longer available for further polymerization processes.

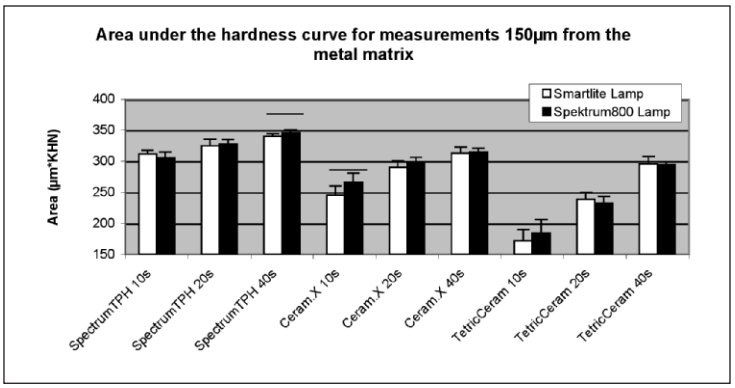

Figure 16: *The total area under the hardness curve for measurements 150 µm from the metal matrix and for each light-curing mode combination. The curing modes that showed a significant difference between SmartLite and Spectrum 800 LCUs are joined with a line. The results for 10, 20 and 40 seconds curing times were always significantly different for all three composites, respectively.*

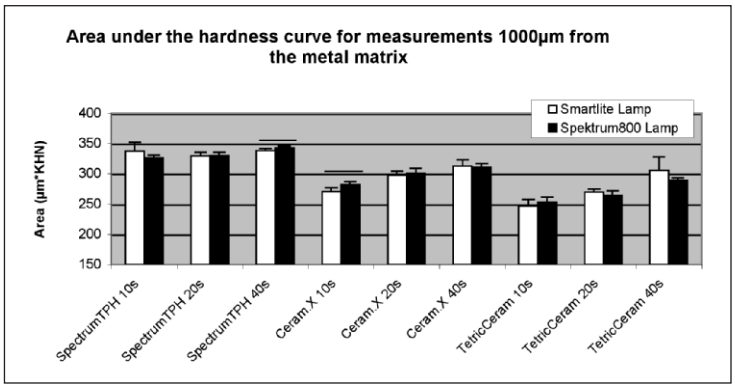

Figure 17: *The total area under the hardness curve for measurements 1000 µm from the metal matrix and for each light-curing mode combination. The curing modes that showed a significant difference between SmartLite and Spectrum 800 LCUs are joined with a line. For Ceram X and Tetric Ceram, the values for 10, 20 and 40 seconds were always significantly different (p<0.01). There was no significant difference between the 10 and 40 seconds and 10 and 20 second values for Spectrum TPH cured with the SL and between the 10 and 20 second values for Spectrum TPH cured with the S800.*

This study has also shown that composite along the surface of the metal matrix has a significantly lower degree of polymerization than composite within the bulk of the increments. The microhardness results 150 µm from the metal matrix strongly correlate with the results of oxygen inhibition in the first 200 µm along the occlusal surface of the specimens. It could be hypothesized that the metal matrix holds enough oxygen in the form of metal oxides to significantly inhibit composite polymerization along its surface or that reaction heat is taken up by the matrix. On the other hand, Kays, Sneed and Nuckles (1991)

showed that metal matrices show a higher degree of polymerization than clear matrices. Metal matrices seem to reflect more light than clear matrices, which leads to a higher degree of polymerization. Using a mirrored matrix, even better polymerization was found. It seems that procedures that use the reflection of light on the surface of the matrix may increase the degree of conversion.

Tetric Ceram composite showed the lowest hardness. This may be partially due to the fact that Tetric Ceram uses other fillers in addition to those used in the other two composites, has larger filler particle sizes and a slightly higher filler content and is on a different refractive index. Additionally, these fillers are in the form of splinters that reflect and disperse light far better than Ba-glass fillers in the other composites. Furthermore, the initiators and inhibitors used could be responsible for this behavior. These are factors that will effect the penetration of light through the composite and, consequently, composite polymerization.

CONCLUSIONS

The new SmartLite PS LED LCU was compared to the conventional Spectrum 800 halogen LCU regarding the degree of polymerization of three different composites cured in three 2-mm increments in deep Class II cavities.

The LED LCU has been shown to be equally capable of curing the three champherquinone-based composites to an acceptable degree of polymerization as a conventional halogen LCU. Both lamps achieved a significantly higher degree of polymerization with 40 second curing cycles than with 10 or 20 second cycles. This, once again, shows that careful consideration needs to be made when using 10 or 20 second curing cycles.

Careful consideration should also be given to the choice of composites for a given LCU. Though both lamps were equally apt in curing the composites in this study, the Spectrum TPH composite reached the highest degree of polymerization for 10, 20 and 40 second curing times. Ceram X and Tetric Ceram reached a significantly lower degree of polymerization for all three curing times.

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