Time Required for Adequate Curing of Sealants with High Intensity Light Emitting Diode

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<td>dental materials/biomaterials, preventive dentistry, dental technology</td>
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Title: Time required for adequate curing of sealants with high intensity light emitting diode.

Abstract

Purpose: Determine the shortest curing time for three light emitting diode (LED) units to adequately polymerize sealant materials. Methods: Three sealants (opaque-unfilled, opaque-filled and clear-filled) were light-cured in a stone covered-slot mold with three LEDs (VALO, SmartLite, Fusion) at various curing times (6-15 seconds), and with a quartz-tungsten halogen (QTH) light for 40 seconds as control (N=10). 24 hours after light-curing, microhardness was measured at the sealant surface and through the depth at 0.5 mm increments. Results were analyzed with ANOVA followed by Student-Newman-Keuls (α = 0.05). Results: The opaque-filled and clear-filled sealants cured with VALO for 6 or 9 seconds had hardness values that were statistically equivalent to or better than the QTH to a depth of 1.5 mm. Fusion at 10 seconds (exposure limit) did not adequately cure the three sealants beyond 1 mm. SmartLite at 15 seconds (maximum exposure period without overheating) did not adequately cure the three sealants beyond 0.5 mm. Conclusions: Among the tested high-intensity LEDs, only VALO at double or triple manufacturers’ shortest curing times (6 or 9 seconds) provided adequate curing of opaque-filled and clear-filled sealants at 1.5 mm depth compared to the 40-second QTH.
Introduction

Light emitting diode (LED) technology has dramatically increased the power of curing lights for polymerizing resin-based dental materials.\(^1\) With these new powerful lights, manufacturers suggest curing times of only a few seconds when used in high intensity modes.\(^2\) Compared to the standard 40 seconds when using a quartz-tungsten-halogen (QTH) light-curing unit,\(^3\) the short exposure times are appealing. For pediatric patients, reduced treatment time is especially advantageous because fast curing enables sealants or resin-based restorative materials to reach their required clinical properties before contamination may occur.

Long-term benefit of caries reduction from well-placed sealants has been documented.\(^4\) However, the desired results may not be achieved if the sealants are not properly cured. Since it is difficult to determine adequate polymerization of the sealant by visual inspection alone, clinicians often rely on manufacturers’ recommendations for curing times. Shorter curing times have a marketing benefit and seem feasible with the modern LED curing units. Unfortunately, a previous study showed that three high power LED curing lights did not adequately cure three common sealants when using the short curing times, ranging from 3 to 10 seconds, that were recommended by the manufacturers.\(^5\)

Light source, materials, and clinical procedures contribute to the extent of polymerization of light-cured sealants. QTH light-curing units have been an effective means of photo-curing in dentistry with a clinical track record of more than 30 years.\(^6\) Unlike the LEDs, the QTH spectrum includes a broad range of wavelengths compatible with a variety of photo-initiators.\(^7\) Adequate intensity of light at appropriate wavelengths to activate
Photoinitiators in the sealant materials is a prerequisite to the polymerization process.\textsuperscript{8,9} Fillers, shades, opacity, and thickness of the material affect light penetration.\textsuperscript{3,8,10} Distance of the curing light tip and exposure duration are also critical for the degree of cure,\textsuperscript{3,8,10,11} and can be controlled by clinicians to some extent.

Given the potential advantage of shorter curing times but the challenge of a thorough cure, the objective of this study was to determine the minimum light exposure time to achieve adequate curing in three different light-activated sealant materials using three high-power LED curing units. Adequate curing was defined as the cure achieved with a traditional QTH unit at 1.5 mm depth, which is the depth of cure specified by ISO 6874.\textsuperscript{12} Hardness measurement was used to assess the extent of cure.\textsuperscript{13}

**Methods**

**Sealant Materials** — Three sealant materials were tested (i) UltraSeal XT plus (Ultradent, South Jordan, UT, USA), a filled, fluoride releasing, opaque sealant; (ii) FluroShield VLC (Dentsply International, York, PA, USA), a filled, fluoride releasing, clear sealant; and (iii) Clinpro Sealant (3M ESPE, St. Paul, MN, USA), an unfilled, fluoride releasing, opaque sealant.

**Light-curing Units** — Three LED curing lights in their highest intensity setting were used to cure the sealant materials: (i) VALO (Ultradent) in a plasma emulation curing mode with an intensity of 3200 mW/cm\textsuperscript{2}; (ii) Fusion (DentLight Inc, Richardson, TX) in a high power mode with an intensity of 2700 mW/cm\textsuperscript{2}; (iii) SmartLite Max (Dentsply) in boost mode with an intensity of up to 2850 mW/cm\textsuperscript{2}. The shortest exposure times at the high intensity
settings per manufacturers were 3, 5, and 10 seconds for VALO, Fusion, and SmartLite, respectively. A QTH light-curing unit (XL3000, 3M ESPE) with an intensity of 450 mW/cm² served as control. The intensity of the QTH was measured with a radiometer (Model 100, Demetron Research Corp, Danbury, CT, USA), while the intensities for the LED units were obtained from the manufacturer information.

Depth-of-cure — The sealants were injected into a plaster mold with a rectangular slot (2 x 2 x 5 mm). The side of the slot was covered with an orange glass plate to ensure that the light entered only from the top (Figure 1A). The top of the slot was covered with a clear glass slip (0.15 mm thickness). The light tip was placed in contact with the clear glass slip, and the sealants were then cured with various exposure periods as explained in the following section. Uncured sealant at the end of the slot was removed. Cured sealant specimens were stored at room temperature in a light-safe container for 24 hours.

Microhardness (Vickers Hardness Number, VHN) was used to evaluate depth-of-cure of the sealant specimens. A Vickers Indenter with 25-g load and 10 seconds dwell time (QV-1000 Micro Hardness Tester, Qualitest USA LC, Fort Lauderdale, FL, USA) was applied at the end surface (0 mm) and successive 0.5-mm intervals down the depth (i.e., along the length of the slot) of the cured sealant specimens (Figure 1B). Depth-of-cure was measured for a total of 120 specimens (10 specimens/sealant/light), as summarized in Table 1.

Curing Time — Sealants cured with the QTH unit for 40 seconds were used as a control (N=10). To establish the minimum curing time necessary for each LED-sealant combination, a pilot study with 3 specimens per light was carried out. Curing times were determined from (i) comparing hardness values at 1.5 mm depth between specimens cured
with LEDs at successive increments of the shortest recommended time to the hardness of specimens cured with QTH for 40 seconds; and (ii) sealants were not cured longer than the manufacturers longest exposure limit (9 seconds for VALO and 10 seconds for Fusion in their high power mode, respectively).\textsuperscript{14,15}

The pilot study indicated that for the VALO LED unit, a 9-second cure for Clinpro and Ultraceal was needed to achieve comparable hardness to the QTH curing unit, and a 6-second cure was sufficient for FluroShield to be comparable to the QTH. For the Fusion LED unit, a maximum recommended time for constant cure was 10 seconds; therefore all sealants were cured for 10 seconds. For the SmartLite LED unit, a curing time of 15 seconds was used for all sealants since it was the maximum exposure period without overheating the LED unit.

Statistical Analysis — Vickers hardness numbers at each depth of the same sealant material were compared among the four curing lights using ANOVA statistics followed by Student-Newman-Keuls post-hoc test at a 0.05 significance level.

Results

Vickers hardness numbers with statistical results are shown in Tables 2-4 and plotted as a function of depth in Figure 2. The highest hardness was obtained at the sealant surface, after which it decreased with increasing depth for all sealant-light combinations.
FluroShield and UltraSeal sealants cured with VALO for 6 or 9 seconds were statistically equivalent to or better than the QTH (40 seconds) to a depth of 1.5 mm. The FluroShield surface exhibited the highest hardness when cured with VALO (6 seconds).

Fusion LED at 10 seconds curing time did not adequately cure Clinpro beyond the surface, Ultraseal beyond 0.5 mm, and FluroShield beyond 1.0 mm compared to the 40 seconds cure with the QTH unit. Similarly, SmartLite LED at 15 seconds did not adequately cure Clinpro and FluoroShied sealants beyond the surface.

All tested LEDs resulted in statistically lower hardness at 0.5 mm depth for Clinpro sealant compared to the QTH. The surface of Clinpro exhibited the highest hardness when cured with VALO.

Discussion
Hardness and depth of cure vary greatly among sealants and are affected by curing lights. Hardness at the sealant surface reached 30 VHN for Ultraseal, 18 VHN for FluroShield, and 12 VHN for Clinpro. The objective of this study was not to compare sealants to one another, as microhardness is a material specific property. Microhardness was used to evaluate the degree of conversion because they correlate well within each particular material. The higher hardness of Ultraseal and FluroShield are the consequence of their filler content. Ultraseal has 58% fillers, FluroShield has less than 30% fillers, whereas Clinpro is classified as an unfilled sealant despite the small amount of inorganic fillers.

Although this study did not compare depth-of-cure among the tested sealants, sealant type determined the effectiveness of curing lights. The clearest example can be seen
from FluroShield (Figure 2), which was not adequately cured by SmartLite, even at the
selant surface. Ultraseal sealant cured well with both the QTH (40 seconds) and VALO (9
seconds) while only the QTH could cure Clinpro beyond the sealant surface. Compatibility
between the wavelength spectrum and photoinitiators in the sealant can affect the
polymerization reaction. Polymerization of resin-based light-polymerized dental materials
including sealants requires activation of photoinitiators, often camphoroquinone, which
absorb light with wavelengths in the 470 nm region. Recent resin systems have
introduced proprietary photoinitiators that may absorb light at different wavelengths and
may not be adequately cured with some LED units. QTH light-curing units have a band-
pass filter between 400 and 550 nm whereas the LED units provide light with narrower
bandwidth (e.g., 450-470 nm) unless manufacturers incorporate light chips to
accommodate other photoinitiators, such as those found in the VALO LED unit. Although
we observed that Ultraseal exhibited the best curing behavior with VALO, both from the
same manufacturer, determination of the compatibility between sealant and light curing
unit was beyond the scope of this study.

Adequate polymerization of resin-based sealants is critical for their long-term
clinical success. QTH light-curing units have been used in dentistry for more than 30 years, and sealants placed with a QTH light-curing unit as a standard device have been effective. Therefore, the QTH was used as a control in this study, with a recommended curing time of 40 seconds. The depth of 1.5 mm was chosen as reference because the International Standard ISO 6874 requires a depth of cure that is not less than 1.5 mm for light-cured resin-based pit and fissure sealants, although sealants are often less than 1.5 mm thickness in a clinical setting.
A previous study found that the minimum manufacturer recommended curing time for each of the tested LED curing-lights did not provide sufficient depth-of-cure. By doubling or tripling VALO’s shortest curing time (3 seconds), FluroShield and UltraSeal sealants could be cured to the same level (or better) at 1.5 mm depth with the VALO LED as with the 40-second curing with a QTH. FluroShield is a clear sealant which would allow light penetration deeper into the material; hence, it required a shorter curing time. It should be noted that the plasma mode of VALO has a 2 seconds delay between each 3-second exposure. Therefore a 9 seconds exposure means a total of 13 seconds clinical time.

Clinicians should consider that different sealant types and different light sources may have different requirements to achieve sufficient polymerization. As shown in Table 5, VALO light did not cure Clinpro sealant beyond the surface even at 9 seconds, triple the recommended curing time. Fusion and SmartLite units may provide better curing with longer curing time, however, the exposure time is limited by the curing unit design of which the exposure time cannot be extended longer than 10 or 15 seconds, respectively. The manufacturers of the VALO and Fusion LED units recommend the lights to be used at maximum of 9 or 10 seconds in constant contact, respectively. The SmartLite overheated when used for more than 4 consecutive exposure periods of 5 seconds each. When the light overheats it must be plugged into the charger and takes up to 7 minutes to reset before it can be used again. These factors should be taken into account when selecting a sealant and curing-light combination.

Natural tooth enamel is more transparent than the opaque plaster mold used in this study. Therefore, it could be expected that the amount of light transmitted to the sealant
can be higher under clinical conditions. On the other hand, cusp tips limit the access of the
curing-light placement, increasing the distance and likely angulation of the curing-light, and
thus reduce the sealant cure. The experimental setting, despite its limitations, allowed
comparisons among the test groups under well-controlled conditions and demonstrated
the reliability and consistency of the QTH with 40 seconds curing time. Adequate curing of
sealants was not obtained from every high-intensity LED unit. If clinicians aim to reduce
the curing time to less than 10 seconds, only the VALO unit at its highest intensity (>3000
mW/cm²) achieved similar depth of cure as the QTH unit in two of the three sealants
tested. Reduced curing time can simplify the procedure and speed up placement, which is
beneficial for pediatric patients; however, adequate curing should be obtained to prevent
lost time spent repairing or replacing debonded sealant material.

Conclusions

Compared to a 40 seconds light-cure with a QTH unit:

1. The VALO LED curing light at its highest intensity and double or triple the
manufacturers’ shortest recommended curing times adequately cured FluroShield
(6 seconds) and Ultraseal (9 seconds) to a depth of 1.5 mm.
2. Clinpro sealant did not attain adequate curing with any of the LED lights.
3. The Fusion and SmartLite LED units at their maximum exposure durations (10 and
15 seconds, respectively) and highest intensity settings did not adequately cure the
tested sealants to a depth of 1.5 mm.
References


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   Date of Last Revision 05/16/13.
   http://www.dentsply.com/content/dam/dentsply/pim/manufacturer/Preventive/Seal
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   Downloaded 13 Oct 2014.

   18.
Table and Figure legends

**Table 1.** Light-curing units, sealants, and curing times used in the study.

**Table 2.** Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm$^2$) of Ultraseal at different depths.

**Table 3.** Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm$^2$) of Clinpro at different depths.

**Table 4.** Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm$^2$) of FluroShield at different depths.

**Figure 1.** A. Sealant material in a rectangular slot of a plaster mold covered with an orange glass plate. Light tip was placed in contact with a clear glass slip covering the top of the slot. B. Diagram showing Vickers indentations on the cured sealant specimens at the surface (0 mm) and successive 0.5 mm intervals along the length of the slot.

**Figure 2.** Depth-of-cure plots: Vickers hardness number (VHN; kg/mm$^2$) at a function of depth (mm).
Table 1. Light-curing units, sealants, and curing times used in the study.

<table>
<thead>
<tr>
<th>Light-curing unit &amp; intensity</th>
<th>Type</th>
<th>Shortest recommended curing time (seconds)</th>
<th>Tested curing times (seconds)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ultraseal</td>
</tr>
<tr>
<td>VALO 3200 mW/cm²</td>
<td>LED</td>
<td>3</td>
<td>9</td>
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<tr>
<td>Fusion 2700 mW/cm²</td>
<td>LED</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>SmartLite 2850 mW/cm²</td>
<td>LED</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>XL 3000 450 mW/cm²</td>
<td>QTH</td>
<td>n/a</td>
<td>40</td>
</tr>
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Table 2. Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm$^2$) of Ultraseal at different depths.

<table>
<thead>
<tr>
<th>Curing light; curing time</th>
<th>0 mm (surface)</th>
<th>0.5 mm</th>
<th>1.0 mm</th>
<th>1.5 mm</th>
<th>2.0 mm</th>
<th>2.5 mm</th>
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<tr>
<td>Fusion; 10 seconds</td>
<td>32.4 ± 1.7 b</td>
<td>23.8 ± 1.5 a</td>
<td>13.6 ± 1.2 a</td>
<td>5.7 ± 0.9 a</td>
<td>1.5 a</td>
<td>0.0 a</td>
</tr>
<tr>
<td>SmartLite; 15 seconds</td>
<td>28.6 ± 2.4 a</td>
<td>24.0 ± 1.7 a</td>
<td>15.3 ± 1.0 b</td>
<td>5.6 ± 0.8 a</td>
<td>0.7 ± 0.8 a</td>
<td>0.0 a</td>
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<tr>
<td>VALO; 9 seconds</td>
<td>30.5 ± 1.5 a,b</td>
<td>29.9 ± 2.5 b</td>
<td>21.6 ± 2.0 d</td>
<td>11.9 ± 1.8 b</td>
<td>4.4 ± 1.3 b</td>
<td>0.3 ± 0.5 a</td>
</tr>
<tr>
<td>QTH; 40 seconds</td>
<td>29.5 ± 3.1 a</td>
<td>25.1 ± 1.3 a</td>
<td>17.5 ± 2.7 c</td>
<td>11.2 ± 2.2 b</td>
<td>4.4 ± 1.2 b</td>
<td>0.4 ± 0.5 a</td>
</tr>
</tbody>
</table>

Different letters indicate statistically significant differences among the curing lights at the same depth (ANOVA followed by Student-Newman-Keuls posthoc test, $P<.05$).
Table 3. Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm\(^2\)) of Clinpro at different depths.

<table>
<thead>
<tr>
<th>Curing light; curing time</th>
<th>0 mm (surface)</th>
<th>0.5 mm</th>
<th>1.0 mm</th>
<th>1.5 mm</th>
<th>2.0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion; 10 seconds</td>
<td>11.6 ± 0.6 b</td>
<td>3.6 ± 0.4 a</td>
<td>2.8 ± 0.4 a,b</td>
<td>2.0 ± 0.5 a</td>
<td>0.0 a</td>
</tr>
<tr>
<td>SmartLite; 15 seconds</td>
<td>10.4 ± 0.5 a</td>
<td>3.2 ± 0.5 a</td>
<td>2.3 ± 0.5 a</td>
<td>1.4 ± 0.5 a</td>
<td>0.0 a</td>
</tr>
<tr>
<td>VALO; 9 seconds</td>
<td>12.3 ± 0.5 c</td>
<td>3.9 ± 0.7 a</td>
<td>3.4 ± 0.6 b</td>
<td>2.6 ± 0.3 b</td>
<td>1.2 ± 0.5 b</td>
</tr>
<tr>
<td>QTH; 40 seconds</td>
<td>11.3 ± 0.5 b</td>
<td>6.0 ± 1.1 b</td>
<td>4.8 ± 1.2 c</td>
<td>2.7 ± 1.1 b</td>
<td>1.0 ± 0.4 b</td>
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</table>

Different letters indicate statistically significant differences among the curing lights at the same depth (ANOVA followed by Student-Newman-Keuls posthoc test, \(P<.05\)).
**Table 4.** Mean ± standard deviation Vickers hardness numbers (VHN; kg/mm$^2$) of FluroShield at different depths.

<table>
<thead>
<tr>
<th>Curing light; curing time</th>
<th>0 mm (surface)</th>
<th>0.5 mm</th>
<th>1.0 mm</th>
<th>1.5 mm</th>
<th>2.0 mm</th>
<th>2.5 mm</th>
<th>3.0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fusion; 10 seconds</strong></td>
<td>14.5 ± 1.4 b</td>
<td>12.3 ± 1.3 b</td>
<td>10.4 ± 1.4 b</td>
<td>7.4 ± 1.2 b</td>
<td>4.9 ± 1.0 c</td>
<td>2.9 ± 0.6 b</td>
<td>1.4 ± 0.3 b</td>
</tr>
<tr>
<td><strong>SmartLite; 15 seconds</strong></td>
<td>8.3 ± 0.8 a</td>
<td>7.0 ± 0.9 a</td>
<td>4.9 ± 0.7 a</td>
<td>4.2 ± 0.5 a</td>
<td>2.9 ± 0.6 a</td>
<td>1.6 ± 0.5 a</td>
<td>0.8 ± 0.6 a</td>
</tr>
<tr>
<td><strong>VALO; 6 seconds</strong></td>
<td>17.7 ± 2.6 c</td>
<td>15.3 ± 2.2 c</td>
<td>11.4 ± 2.6 b</td>
<td>8.5 ± 1.3 c</td>
<td>4.0 ± 0.8 b</td>
<td>2.1 ± 0.6 a</td>
<td>0.9 ± 0.5 a</td>
</tr>
<tr>
<td><strong>QTH; 40 seconds</strong></td>
<td>14.8 ± 1.4 b</td>
<td>12.6 ± 1.8 b</td>
<td>10.7 ± 1.8 b</td>
<td>8.4 ± 0.9 c</td>
<td>7.0 ± 0.9 d</td>
<td>4.2 ± 0.9 c</td>
<td>2.4 ± 0.6 c</td>
</tr>
</tbody>
</table>

Different letters indicate statistically significant differences among the curing lights at the same depth (ANOVA followed by Student-Newman-Keuls posthoc test, $P<.05$).
A. Sealant material in a rectangular slot of a plaster mold covered with an orange glass plate. Light tip was placed in contact with a clear glass slip covering the top of the slot. B. Diagram showing Vickers indentations on the cured sealant specimens at the surface (0 mm) and successive 0.5 mm intervals along the length of the slot.

101x50mm (300 x 300 DPI)
Depth-of-cure plots: Vickers hardness number (VHN; kg/mm²) at a function of depth (mm).

54x14mm (300 x 300 DPI)