Efficacy of New LED Light-Curing Units in Hardening of Class II Composite Restorations

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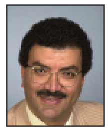


ABSTRACT

Purpose: The aim of this study was to determine the efficacy of new light-emitting diode (LED) curing units in the hardening of Class II composite restorations.

Methods and Materials: Disk specimens 2 mm in diameter and 2.5 mm thick were prepared from 2 composites (Vit-l-escence, shade A3, Ultradent; Herculite XRV, shade A2, Kerr) in the following manner. An extracted permanent molar tooth was prepared to receive a Class II restoration with proximal slot only. The tooth was sectioned horizontally on a plane above the gingival floor level such that the remaining depth of the proximal box was 4 mm. A Tofflemire matrix band and retainer were secured around the tooth. Composite specimens were placed below the tooth to coincide with the location of the slot opening at the bottom of the gingival floor. The specimens were subjected to light polymerization with various combinations of curing cycle and light unit: 1 of 3 continuous curing cycles (20 seconds, 40 seconds or 60 seconds) and 1 of 2 LED units (Utralume-5, Ultradent; IQ Smartlite, Dentsply) or a control quartz–tungsten–halogen (QTH) unit (Optilux 501, Kerr). Specimens were stored at 37°C for 24 hours. A hardness tester was used to obtain 4 measurements of Knoop hardness number (KHN) for each surface (upper and lower) of each specimen. Relative hardness (RH) was calculated as the KHN of the lower surface divided by the KHN of the upper surface. Data were analyzed with analysis of variance (ANOVA) and Tukey's test.

Results: ANOVA indicated significant differences in mean RH among the groups ($p < 0.001$). RH increased with increasing curing time. For the 60-second cycle with Vit-l-escence composite, mean RH was 0.47, 0.25 and 0.39 for the Ultralume-5, IQ Smartlite and Optilux 501 curing units, respectively. For the 60-second cycle with Herculite XRV composite, mean RH was 0.71, 0.81 and 0.56 for the Ultralume-5, IQ Smartlite and Optilux 501 curing units, respectively.

Conclusions: In general, the 2 LED units performed as well as the QTH unit; however, brand of composite and curing cycle had significant effects on RH values.

For citation purposes, the electronic version is the definitive version of this article: www.cda-adc.ca/jcda/vol-73/issue-3/253.html

Light-cured composite resins have become an integral part of modern dental practice. Dentists use these materials daily for various types of restorative work on both anterior and posterior teeth. The first generation of light-curing units are based on quartz–tungsten–halogen (QTH) lamps[1]; other currently available units are based on laser light, plasma arc or, more recently, light-emitting diodes (LEDs).[2] LED technology has various applications in everyday life, such as Christmas lights, automobile lights and traffic

Figure 1: Coronal tooth section 4 mm high with proximal portion of the simulated Class II cavity preparation and Tofflemire retainer with matrix band #1.

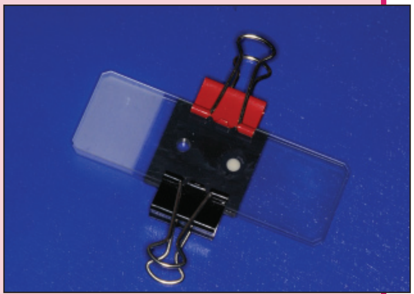


Figure 2: Composite specimen packed into plastic mould and ready for light curing.

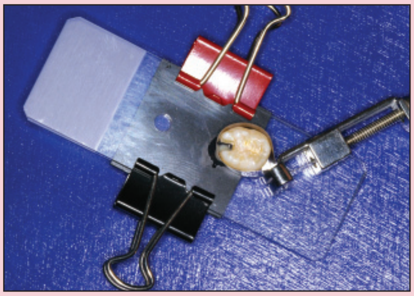


Figure 3: The composite specimen is positioned beneath the tooth–matrix assembly at a location coinciding with the location of the first increment of a Class II slot restoration that is 6 mm deep.

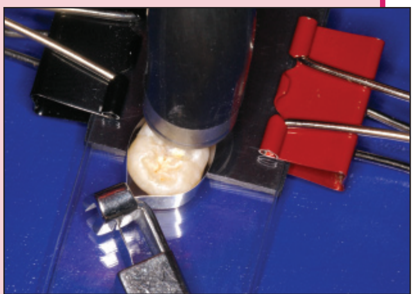


Figure 4: Application of light to the composite specimen. The surface of the light guide is in contact with the edge of the matrix band. The light travels a distance of 4 mm before it reaches the top surface of the composite specimen.

lights. Dental LED lights typically use indium–gallium–nitride semiconductors that produce a blue light when subjected to electrical current.[3] As a result, some of the components of QTH units, such as filters, may not be needed for LED-based units. This is an important consideration, given that the filters tend to deteriorate with time, which adversely affects light output.[4,5] LED lights have other merits over QTH lamps: they last significantly longer, their power density does not decrease with time, and some units are wireless.[3] The original generation of LED-based light units had a variety of arrangements for the location of the LEDs on the unit; in some, the LEDs were placed directly at the tip of the unit, whereas in others, the LEDs were located inside the unit and a fiberoptic light guide was used for light transmission. The number of LEDs per unit varied widely (from 2 to 19) from one manufacturer to another. In spite of this variability, the majority of these original versions had limited light intensity and consequently limited depth of cure.[6] Newer versions of LED-based light units have been significantly improved and have higher light intensity.

Most light-cured composites contain a light-sensitive absorber (camphoroquinone or its derivative), which initiates polymerization by breaking down into free radicals when subjected to light in the blue spectrum (wavelength 450–470 nm). In addition to the correct wavelength, sufficient light intensity and exposure time are important for optimal polymerization (adequate degree of monomer conversion).[7–10] In Class II resin composite restorations, the composite material is inserted into the prepared cavity in small increments of not more than 2 mm thickness to ensure adequate polymerization throughout the thickness of the restoration.[7] The first increment is typically placed at the full depth of the proximal box, and the light guide is applied to the occlusal surface, right on top of the edge of the matrix band. The light travels a short distance through the depth of the proximal box to reach the first increment of composite placed on the gingival floor. Light intensity may be significantly reduced during this process, which results in less-than-ideal polymerization of the first increment.

The aim of this study was to determine the efficacy of new LED-based curing units in the polymerization of resin composites used in Class II restorations. The results were compared with those obtained with a standard QTH-based light unit to ensure reliability.

Methods and Materials

An extracted permanent molar tooth was prepared to receive a Class II composite restoration with proximal slot only. The axial wall was at least 2 mm deep and the buccolingual width at least 3 mm. The cavity depth from occlusal surface to gingival floor was 5 mm. The prepared tooth was sectioned horizontally at a level just above the gingival floor. As a result, the gingival floor was eliminated, and the slot cavity had a depth of 4 mm; however, this created an opening at the gingival floor location. A Tofflemire matrix band and retainer were placed around the tooth section and secured with low-fusing compound, such that the edge of the matrix band was flush with the cusp tips (**Fig. 1**). A mould made from black plastic material with a cylindrical hole was filled with composite material (specified below) and covered from both sides with glass sections lined with clear celluloid film (**Fig. 2**). The mould was placed under the prepared tooth and centred so that the surface of the composite material was visible from the occlusal surface (**Fig. 3**). The composite specimen thus represented the first increment placed in the proximal box of a Class II cavity. This procedure yielded disk specimens 2 mm in diameter and 2.5 mm thick. Specimens were prepared from 2 composites (Vit-l-escence, shade A3, Ultradent, South Jordan, Utah; Herculite XRV, shade A2, Kerr, Orange, Calif.). The specimens were subjected to light polymerization through the occlusal opening with various combinations of curing cycle and light unit: 1 of 3 continuous curing cycles (20 seconds, 40 seconds or 60 seconds) and 1 of 2 LED units (Utralume-5, Ultradent; IQ Smartlite, Dentsply, Milford, Del.) or a control QTH unit (Optilux 501, Kerr). The curing light guide was maintained against the occlusal edge of the Tofflemire matrix throughout the curing cycle (**Fig. 4**). For each combination of curing cycle and light unit, 3 specimens were prepared from each composite material. Specimens were stored at 37°C for 24 hours. A hardness tester with a Knoop indenter (Tukon 300, Acco Industries Inc., Wilson Instrument Division, Bridgeport, Conn.) was used to obtain 4 measurements of Knoop hardness number (KHN) for the upper and lower surfaces of each specimen. A relative hardness (RH) value was calculated from each pair of measurements (upper and lower surfaces) as the KHN of the lower surface divided by the KHN of the upper surface. Thus, 4 RH values were obtained for each of the 3 specimens in each group, for a total of 12 RH values for each group. An overall mean RH value for the group was calculated by averaging these 12 values. Data were analyzed statistically with analysis of variance (ANOVA) and Tukey's test.

Results

Table 1 records the mean RH values (as percentages and standard deviations) for all test groups. **Table 2** records the mean KHNs (and standard deviations) for upper and lower surfaces of the specimens. RH values obtained with the Vit-l-escence composite were generally lower than the corresponding values obtained with Herculite XRV (**Table 1**). ANOVA revealed that the mean RH values obtained for Vit-l-escence were significantly lower than those obtained for Herculite XRV ($p < 0.001$). For all combinations of light unit and curing time with the Vit-l-escence composite, no single RH value exceeded 50%; however, 5 of the 9 mean RH values obtained with the Herculite XRV composite under different test conditions exceeded 50% (**Table 1**). ANOVA revealed significant differences in mean RH values obtained with the different curing lights and curing cycles ($p < 0.001$ for both). Further statistical analysis revealed that mean RH values obtained with 20 seconds of curing were significantly lower than those obtained with 40 seconds of curing (Tukey's test, $p < 0.001$). Similarly, the mean RH values obtained with 20 seconds or 40 seconds of curing were significantly lower than those obtained with 60 seconds of curing (Tukey's test, $p < 0.001$ for both comparisons).

Table 1 Relative hardness (as mean percent and standard deviation) for the 2 composites under different curing conditions

Curing time and light unit	Composite: Vit-l-escence	Composite: Herculite XRV
20-second curing time		
Optilux 501	10 (2)	21 (9)
Ultralume-5	20 (9)	42 (19)
IQ Smartlite	9 (1)	36 (13)
40-second curing time		
Optilux 501	17 (5)	49 (10)
Ultralume-5	24 (4)	64 (11)
IQ Smartlite	13 (2)	66 (10)
60-second curing time		
Optilux 501	39 (7)	56 (4)
Ultralume-5	47 (14)	71 (2)
IQ Smartlite	25 (4)	81 (7)

After curing for 20 seconds with any of the 3 light-curing units, specimens made with the Herculite XRV composite had considerably higher RH values than those made with the Vit-l-escence composite. The highest mean RH value (42%) was obtained with Herculite XRV composite cured with the Ultralume-5 light unit, and the lowest mean RH value (9%) was obtained with Vit-l-escence composite cured with the IQ Smartlite unit.

With 40 seconds of curing, the RH values for specimens made with XRV Herculite composite and cured with the 2 LED units were greater than those obtained with only 20 seconds of curing, and the mean RH exceeded 60%. However, the RH value obtained with the QTH unit for the same composite material at 40 seconds was below 60% (49%).

Specimens made with Herculite XRV composite and cured with either of the 2 LED units had mean RH values approaching the desirable level of 80%. However, specimens made with Vit-l-escence composite and cured with the IQ Smartlite had the lowest mean RH value (25%).

Discussion

The findings of this work are in general agreement with those reported recently by other researchers comparing new LED light-curing units to QTH units.[8,9] However, those studies used different curing cycles and

Table 2 Mean Knoop hardness numbers (and standard deviations) for upper and lower surfaces of specimens (n = 12)

	Curing time (seconds)		
Light and composite combination	**20 seconds**	**40 seconds**	**60 seconds**
IQ Smartlite light			
Herculite XRV composite			
Upper surface	77.23 (3.49)	75.03 (1.44)	83.07 (5.58)
Lower surface	27.37 (8.61)	49.70 (5.22)	64.63 (1.72)
Vit-l-escence composite			
Upper surface	59.53 (4.74)	65.93 (3.46)	69.40 (2.75)
Lower surface	5.25 (0.17)	8.42 (0.30)	17.60 (2.70)
Optilux 501 light			
Herculite XRV composite			
Upper surface	74.47 (1.91)	79.87 (1.81)	82.57 (2.80)
Lower surface	19.70 (2.88)	38.90 (9.43)	46.07 (3.65)
Vit-l-escence composite			
Upper surface	60.00 (13.47)	66.53 (17.85)	75.27 (5.51)
Lower surface	5.92 (1.09)	10.82 (2.92)	29.90 (7.86)
Ultralume-5 light			
Herculite XRV composite			
Upper surface	72.97 (3.29)	74.80 (3.14)	76.03 (0.32)
Lower surface	30.57 (13.62)	47.90 (9.53)	58.43 (1.59)
Vit-l-escence composite			
Upper surface	63.45 (2.55)	69.53 (3.67)	72.27 (3.45)
Lower surface	12.31 (5.87)	16.83 (2.15)	33.87 (10.32)

different composite materials, which makes direct comparisons with the present results almost impossible.

As mentioned above, the correct wavelength, sufficient light intensity and appropriate exposure time are important for optimal polymerization (adequate degree of monomer conversion).[9–12] The light intensities of the 3 light-curing units used in this study, measured by a digital light meter (Cure Rite, model 8000, Efos Inc, Williamsville, N.Y.), were 700, 550 and 950 mW/cm^2 for the Optilux 501, IQ Smartlite and Ultralume-5, respectively. However, these values should be interpreted with care, as this light meter was not specifically designed to measure the light intensity of LED units. Indeed, the diameter of the tip of the Ultralume-5 light, from which the light is emitted, is greater than the diameter of the sensor of the light meter. Therefore, these values should perhaps be considered only as broad indicators of intensity differences among the 3 units. Nevertheless, ranking the 3 light units by recorded light intensity does not correlate well with their performance (as determined by RH values). The Ultralume-5, which had the highest recorded intensity (950 mW/cm^2), and the IQ Smartlite, which had the lowest recorded intensity (550 mW/cm^2), performed equally well when used to cure Herculite XRV composite for 40 seconds and 60 seconds. Perhaps factors other than intensity at exit point led to this result. For example, the divergence of the light sources may well differ among the 3 units, and thus at 4 mm from the exit point there may be widely differing power densities.

The 2 composite materials tested had various hardening patterns, one material (Herculite XRV) achieving a much higher level of hardening and consequently higher RH ratios than the other (Vit-l-escence). A number of reasons can be suggested for this variability. The shape, size, opacity, distribution and content of inorganic fillers can significantly affect light transmission through the thickness of an increment of composite material.[13,14] The greater the distortion of the light as it passes through the composite, the shallower the depth it reaches in the increment, which will lead to a lower RH ratio. In addition, the Vit-l-escence specimens were made from a slightly darker shade (A3) than the Herculite XRV specimens (A2), which might have contributed to the difference in RH ratio. Darker shades of composites tend to result in greater attenuation of the light passing through during curing relative to lighter shades.[15] Finally, variability in the activator incorporated in the formulation (camphoroquinone or its derivative) might have played a role. A recent study reported similar findings in which RH of resin composites varied according to type and brand of material.[16] As in the present study, a number of LED light units were compared to a QTH unit, and their performance was satisfactory.[16]

Methods of evaluating the depth of cure of composites include scraping the specimen to determine depth of nonpolymerization, optical microscopy to detect changes in translucency of the polymerized section, infrared spectroscopy and calculation of RH of lower and upper surfaces of polymerized specimens.[17,18] The scraping and optical microscopy methods tend to overestimate the depth of polymerization, whereas the infrared spectroscopy and RH methods are more accurate and tend to correlate well.[17] Infrared spectroscopy appears to be the most sensitive method of determining the degree of conversion from monomer to polymer[17]; however, RH is more practical. In a recent study, lower-to-upper KHN ratios of 3 resin composite materials were highly correlated with lower-to-upper degree of conversion ratios.[19] The authors concluded that lower-to-upper KHN ratios provide an accurate and simple method of assessing the efficacy of photoinitiation strategies, which is preferable to the more complex Fourier Transform Infrared Spectroscopy (FTIR) methods of determining degree of conversion.[19] On the basis of this recent finding, the results of the present study are considered accurate indicators of degree of conversion of the 2 composites examined.

Up to now there has been no internationally recognized standard for adequate depth of polymerization or RH. However, Johnston and others,[20] using 2.5-mm-thick composite specimens, suggested that depth of polymerization should be based on the RH ratio and that, for practical purposes, a ratio of 90% should be promoted. Another author[21] used a lower ratio (80%) to assess adequate depth of polymerization, but in a study involving a number of private dental offices, none of fifty 3-mm-thick resin composite specimens cured for 50 seconds with QTH units achieved the equivalent of 80% RH or higher.[22] More recently, in a larger study involving 100 dental offices in Toronto and testing 214 QTH light-curing units, only 10% of the resin composite specimens cured with these lights for 40 seconds reached the desired RH of at least 80%.[23]

This study examined the efficacy of curing of the first increment of a Class II resin composite restoration in a simulated proximal box 6 mm deep. This represents the higher end of the range of depths for proximal boxes of Class II cavities. A typical Class II cavity would be expected to have a proximal box 4 mm deep. Subsequent composite increments would be expected to have a higher RH ratio because each subsequently placed increment is positioned closer (within 2 mm or less) to the tip of the light guide and as a result is likely to be polymerized more thoroughly.

On the basis of the present findings, dentists can be assured that some newer versions of LED light-curing units are as effective as QTH-based units in terms of degree of monomer conversion of resin composites. However, longer curing cycles are more likely to result in higher levels of conversion. Use of a longer curing cycle is particularly important for light-cured Class II composite restorations to ensure sufficient polymerization of the restoration in the gingival area, which has proved to be the area most prone to recurrent caries. Thorough polymerization of the composite increment in this area should help reduce the risk of recurrent caries.

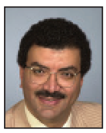
Conclusions

The new LED curing units tested in this study were more effective in photopolymerization of resin composites than a control QTH-based light unit in terms of RH. One of the 2 brands of composite materials tested had better RH, which indicates a better degree of conversion. For both composites tested, RH increased as the curing cycle increased from 20 to 60 seconds.

THE AUTHORS

Acknowledgement: *This work was supported in part by 3 dental product companies: Ultradent, Kerr and Dentsply, to whom the authors are grateful.*

A paper based on this study was presented at the annual meeting of the International Association for Dental Research in Baltimore in March 2005.



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The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

This article has been peer reviewed.

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