Efficacy of Halogen Photopolymerization Units in Private Dental Offices in Toronto

Omar El-Mowafy, *BDS, PhD, FADM,* **Wafa El-Badrawy,** *BDS, MSc,*
Donald W. Lewis, *DDS, DDPH, MScD, FRCD(C),* **Babak Shokati,** *DDS,*
Osama Soliman, *BSc,* **Jaffer Kermalli,** *BSc,* **Avedis Encioiu,** *BSc,*
Fatma Rajwani, *HBSc,* **Rema Zawi,** *BSc*

Contact Author

Dr. El-Mowafy
E-mail:
oel.mowafy@utoronto.ca

ABSTRACT

Purpose: Light units used for polymerization of resin composites are subject to deterioration with age, and frequent maintenance is required to maintain optimal efficacy. This study examined the efficacy of quartz–tungsten–halogen light units in private dental offices in Toronto for polymerization of resin composites.

Materials and Methods: One hundred dental offices met all selection criteria and agreed to participate in the study. The light intensity was determined for a total of 214 light units. Disk-shaped specimens, 2.5 mm thick, were made from 2 resin composites (Charisma, Heraeus Kulzer; Point 4, Kerr Corp) and were subjected to photopolymerization: Charisma for 20 seconds (99 units) and Point 4 for 20 and 40 seconds (all 214 units). Knoop hardness values for the upper and lower surfaces of each specimen were determined, and relative hardness values (hardness of lower surface/hardness of upper surface × 100) were calculated. Data were analyzed using descriptive statistics, t-tests, 1-way analysis of variance, and simple and multiple linear regression (a = 0.05).

Results: The light intensity of the individual units varied widely, from 120 to 1,000 mW/cm^2. Surface hardness and relative hardness were significantly ($p < 0.05$) and positively associated with light intensity, and wide ranges in surface hardness and relative hardness values were observed. Mean relative hardness ranged from 34.8% to 57.7%.

Conclusions: Light polymerization units in private dental offices displayed a wide range in light intensity, and many had below-recommended levels. Of the resin composite specimens polymerized for 40 seconds with each of the 214 light units, only 10% reached the desired relative hardness of at least 80%. A positive linear relationship was found between light intensity and relative hardness. Increased exposure time resulted in a significant increase in relative hardness. Also, relative hardness was found to be dependent on the brand of composite material used. Dentists should regularly monitor the condition of light units and replace deteriorating parts.

© *J Can Dent Assoc* 2005; 71(8):587
This article has been peer reviewed.

MeSH Key Words: composite resins/chemistry; dental equipment; evaluation studies; light

The use of resin composites for restoration of Class 1 and 2 preparations has increased significantly in recent years[1–3] because of environmental concerns about mercury in amalgam, increasing patient demand for more esthetically pleasing restorations, and the development and marketing of new resin composites.[1,2]

Although resin composites are available in both auto-polymerized and light-polymerized forms, dentists prefer the light-polymerized composites because of better handling characteristics.[4] Most light-polymerized composites contain a light-sensitive absorber such as camphoroquinone, which initiates polymerization by breaking down into free radicals when subjected to light in the blue spectrum (wavelength 450–470 nm).[5] In addition to the correct wavelength, sufficient light intensity and exposure time are also important for optimal polymerization.[6]

According to Rueggeberg and others,[6] light sources with intensity values less than 233 mW/cm^2 should not be used because of their "poor cure characteristics." Others have described light units with intensities of less than 200 mW/cm^2 or less than 300 mW/cm^2 as inadequate, unusable or unsuitable.[7–9]

Methods for evaluating the depth of polymerization of light-activated composites include optical microscopy to detect changes in the translucency of the polymerized section,[10] scraping the specimen to determine the depth of nonpolymerization,[11] infrared spectroscopy[12] and determining the relative hardness (RH) of the lower and upper surfaces of polymerized specimens.[13,14] The optical and scraping methods tend to overestimate the depth of polymerization, whereas the infrared spectroscopy and RH methods are more accurate and correlate relatively well.[12] Infrared spectroscopy appears to be the most sensitive test, from a biological standpoint, for measuring the degree of conversion of monomer to polymer;[12] however, RH determination is more practical. Factors that may contribute to the quality of polymerization of composite restorations include light intensity,[6,15–17] exposure time,[6,16,18–21] light wavelength,[22] thickness of the composite increment,[20] distance between the tip of the light guide and the surface of the composite,[23] shade of the composite[24] and composition of the composite material.[12,21,25,26]

Over the past decade, 4 studies of the intensity of light emitted by units used for polymerization of resin composites in private dental offices in various countries have been published.[7–9,17] The authors found a wide range in emitted intensity, from 11 to 1,368 mW/cm^2, and each study concluded that the light intensity used in many private offices was lower than needed for optimal polymerization of resin composite restorations. One of these studies further examined the effectiveness of the light units by determining the hardness of resin composite specimens (3 mm thick) prepared with these lights.[9] A strong correlation was found between the logarithmic transformation of hardness ratio and the light intensity.[9] The present study was conducted to investigate if the situation in private dental offices in a North American location had changed since publication of the original study by Barghi and others[7] in 1994.

It was also of interest to determine the efficacy of light units in the polymerization of different composite materials under varied durations of exposure.

The specific purposes of this study were to determine and compare the upper and lower surface hardness and RH achieved by 2 composite resins exposed, under standardized conditions, to polymerization light units used in private dental practices, and to examine the nature and extent of the relationship between light intensity and upper and lower composite surface hardness and RH.

Materials and Methods

The following selection criteria were used to identify private dental offices for participation in this study. The dentist operating the office had to be a general practitioner, not a specialist. The dental office had to be accessible by public transportation. The light polymerization unit(s) in the office had to use one or more quartz–tungsten–halogen (QTH) lamp. The dentist had to routinely use resin composites for restoration of posterior teeth.

The 2002 alphabetical listing of dentists published by the Royal College of Dental Surgeons of Ontario was used to identify dental offices located in the Greater Toronto Area. For each letter of the alphabet, the first 7 offices in the listing that met the first 2 selection criteria stated above were contacted by telephone to determine if they also met the other 2 criteria. For each office that met all 4 selection criteria, the dentist was contacted by telephone, at which time the study was explained, the dentist's interest was determined, and the methods were briefly explained. This process was repeated until 100 dental offices meeting the previously stated criteria had agreed to participate. Altogether, 416 offices were initially contacted.

Once agreement to participate was reached, an appointment was made for a visit to the office at a mutually convenient time. One of two trained teams, each consisting of 2 research assistants with identical equipment, visited each office. The teams had previously been instructed on how to conduct the light intensity measurements with a radiometer and how to prepare and polymerize specimens from composite materials for hardness testing. The teams had practised the procedures several times using light units in the restorative dentistry laboratory, faculty of dentistry, University of Toronto. When the team leader believed that the teams had been sufficiently trained, the office visits commenced. Upon arrival at each office, a detailed letter explaining the purpose and methods of the study and a message to the dentist thanking him or her for participating were presented to the office personnel. The number of QTH light units in the office and information about each unit, including approximate date of purchase and service history, as provided by office personnel or dentist, were recorded.

To measure light intensity, an analogue radiometer (Optilux, model 100; Kerr Corp, Orange, Calif.), with a range from 0 to 1,000 mW/cm^2, was used. According to the manufacturer this meter detects light in the wavelength range of 400 to 500 nm. Each day before visiting the dental office, the light radiometers were examined against another light radiometer at the university's restorative dentistry laboratory to ensure consistency of readings.

At each office, after a short warm-up period, 3 measurements of light intensity were recorded for each light unit.

Two composites from different manufacturers were used to explore the effect of brand of the materials on degree of light polymerization. At 50 of the dental offices, disk-shaped specimens, 2.5 mm thick and 3 mm in diameter, were prepared from Charisma resin composite (shade A2; Heraeus Kulzer, Dormagen, Germany) using black plastic moulds. For each specimen, the mould was first placed on a glass slide lined with a transparency film and then level-filled with the resin composite. A second glass slide lined with a transparent film (3M Dental Products, St. Paul, Minn.) was placed over the mould, and 2 spring clamps were used to hold the glass sections and mould together. Light polymerization was applied for 20 seconds on the upper surface only, with the tip of the light guide maintained in contact with the glass section. A total of 99 light units were tested with this material, and 2 specimens were prepared for testing each light unit. In addition, at each of the 100 participating dental offices, specimens were similarly prepared from another resin composite (Point 4, shade A2; Kerr Corp). For each of the 214 light units, 2 specimens were subjected to light polymerization for 20 seconds and 2 specimens for 40 seconds. Immediately after polymerization, specimens were stored in the dark in small boxes until hardness testing.

On the day after preparation of the specimens, 3 measurements of Knoop hardness number (KHN) were obtained from the upper and lower surfaces of each specimen using a hardness tester with a Knoop indenter (Tukon 300; Acco Industries Inc, Wilson Instrument Division, Bridgeport, Conn.). A 30-g load was applied to create 3 indentations for each surface.

The collected data were entered into a computer database (Excel 2000, version 9.0.4402SR-1; Microsoft Corp, Troy, N.Y.) and, after editing to correct data entry errors, the RH of each composite was calculated (RH = mean lower surface KHN/mean upper surface KHN × 100). These data were then analyzed with statistical software (SPSS for Windows, release 6.1.2; SPSS Inc., Chicago, Ill.).

Consistent with the overall purposes of this study, 4 specific research questions were addressed. The

Table 1. Knoop hardness number (KHN) for various resin composite surfaces

	KHN				Percentile					
Composite, exposure time and surface	**Overall mean**	**SD**	**Min.**	**Max.**	**10th**	**25th**	**50th**	**75th**	**90th**	***n***
Charisma										
20 s, upper	39.7	7.6	21.2	56.6	29.5	33.6	41.3	45.5	48.5	99
20 s, lower	17.9	9.0	3.6	43.1	6.9	11.0	17.1	22.2	30.4	99
Point 4										
20 s, upper	42.3	7.4	19.4	54.8	30.6	38.3	44.7	47.3	49.4	214
20 s, lower	14.6	9.0	0.0	48.7	4.4	8.1	13.2	20.0	27.0	214
40 s, upper	45.6	6.3	24.7	56.4	34.4	44.1	46.5	50.0	51.8	214
40 s, lower	26.2	9.3	1.1	50.3	13.5	19.7	26.3	33.4	37.4	214

SD = standard deviation

Table 2. Relative hardness (RH) for various resin composite surfaces

	RH (%)[a]				Percentile					
Composite and exposure time	**Mean**	**SD**	**Min.**	**Max.**	**10th**	**25th**	**50th**	**75th**	**90th**	***n***
Charisma (20 s)	44.8	19.8	9.5	98.9	18.1	30.7	43.9	56.5	72.2	99
Point 4										
20 s	34.8	20.3	0.0	98.3	11.2	19.4	30.9	47.7	65.5	214
40 s	57.7	19.1	2.4	91.9	30.8	44.6	60.0	72.9	80.6	214

SD = standard deviation

[a]Relative hardness = lower surface Knoop hardness number/upper surface Knoop hardness number × 100

following statistical analyses were undertaken to answer these questions. Means, standard deviations and percentiles were calculated to answer questions regarding the characteristics of the upper and lower surface KHN and RH of each resin composite. Paired *t*-tests were used to determine whether there was a statistically significant difference ($\alpha = 0.05$) between the upper and lower surface KHN values of each resin composite. A one-way analysis of variance involving the RH of the 3 resin composite specimens was performed. This included Scheffé multiple-comparison tests to determine whether there were statistically significant differences ($\alpha = 0.05$) between the RH values of the 2 resin composites prepared with 20-second polymerization time and between the RHs of the 20- and 40-second Point 4 resin composites. Scatterplots and curve-fitting procedures involving stepwise use of simple and multiple linear regression, including second-degree (quadratic) and third-degree (cubic) polynomials, were used to answer questions about the nature and significance ($\alpha = 0.05$) of the relationships between surface KHN or RH as a dependent variable and light intensity, age of the lights (in years) and time elapsed since last light servicing (in months) as independent variables.

Table 3. Regression between light intensity and composite hardness

Composite, polymerization time (s) and surface	Best-fitting model[b]	*p* value of regression model	R^2 (%)	*n*[c]
Charisma				
20 s, upper	Linear	0.015	6.3	93
20 s, lower	Cubic	< 0.001	48.1	93
Point 4				
20 s, upper	Cubic	0.037	4.2	203
20 s, lower	Cubic	< 0.001	62.7	203
Point 4				
40 s, upper	Cubic	< 0.001	11.9	203
40 s, lower	Cubic	< 0.001	60.2	203
Charisma				
20 s, lower/ upper [a]	Cubic	< 0.001	40.2	93
Point 4				
20 s, lower/ upper [a]	Cubic	< 0.001	53.0	203
40 s, lower/ upper [a]	Cubic	< 0.001	46.4	203

[a] *Relative hardness = lower surface Knoop hardness number/upper surface Knoop hardness number × 100*

[b] *Simple linear regression is polynomial of degree 1, whereas cubic regression represents a third-degree polynomial (a curve with 2 bends)*

[c] *The 11 lights with intensity of 1,000 mW/cm² or greater were dropped from the analysis because the analogue radiometer did not record specific values for readings greater than 1,000 mW/cm².*

Results

A total of 214 polymerization light units from 100 dental practices were studied. The mean age, recorded for 203 of the 214 units, was just under 6 years. The mean intensity of emission from the light units was 526 mW/cm² (range 120 mW/cm² [1 light unit] to 1,000 mW/cm² or higher [11 units]). For 26 (12.1%) of the light units, light intensity was less than 300 mW/cm².

The means and percentiles of KHN for the 2 composites, 2 polymerization cycles and 2 surfaces are recorded in **Table 1**. Several observations are noteworthy, including the significantly higher mean KHN for Point 4 composite exposed for 40 seconds relative to that exposed for 20 seconds (26.2 and 14.6, respectively, for the lower surface) and the significantly higher mean KHN of the upper composite surfaces, directly exposed to the light emissions (39.7 to 45.6), relative to the indirectly exposed lower composite surfaces (14.6 to 26.2). For each of the 3 composite groups, mean KHN values for the upper surface were significantly greater than those for the lower surface (**Table 1**; paired *t*-tests, $p < 0.001$). The lower surfaces displayed more variability than did the upper surfaces.

Differences in KHN values between the upper and lower surfaces were most pronounced for the 10th percentile data (**Table 1**), especially for the 20-second exposure (29.5 and 6.9 for upper and lower surfaces of Charisma composite, respectively; 30.6 and 4.4 for upper and lower surfaces of Point 4 composite, respectively). Of the 21 KHN values for Point 4 composite that were below the 10th percentile, 4 values were 0.0, 3 values were less than 1.0 (0.8, 0.9 and 0.5 respectively), and none was greater than 4.4 (data not shown). The 10th percentile values for the upper surfaces were almost equal to the respective 90th percentiles for the lower surfaces for Charisma and Point 4 (20-second exposure) composites and to the 75th percentile for the lower surfaces for Point 4 composite (40-second exposure) (**Table 1**).

The RH data for each composite material are displayed in **Table 2**. Differences among the 3 mean RH values were significant ($p < 0.001$), and the difference between the highest mean value for Point 4 composite with 40-second exposure (57.7%) and the lowest mean value for Point 4 composite with 20-second exposure (34.8%) was also significant ($p < 0.05$). For the 20-second polymerization time, the RH achieved with Charisma significantly exceeded that achieved with Point 4 (Scheffé multiple-comparison test, $p < 0.05$). Three-quarters of the RH values for the Point 4 composite with 40-second exposure were greater than 44.6%, whereas three-quarters of the RH values for the same composite but with 20-second exposure exceeded 19.4% (see 25th percentiles). With Charisma, three-quarters of the specimens had a RH greater than 30.7%. Approximately 10% of the 214 specimens of the Point 4 composite with 40-second exposure achieved an RH of at least 80% (**Table 2**), but only 3%–5% of specimens of either composite prepared with 20-second exposure achieved this level of hardness.

Eighty-five percent of the lowest RH values among all 3 specimen groups combined were associated with the 53 lower-surface KHN values at or below the 10th percentile listed for each group in **Table 1**. However, a detailed assessment across the 3 specimen groups revealed that these lowest RH values were associated with 33 (not 53) light units.

Differences between these 33 light units and the remaining 181 light units, in terms of unit age and intensity of light emission, were assessed to determine why these units tended to yield lower surface KHNs and very low RH. The mean age of the 31 light units for which age data were available was significantly higher than for the

Table 4. Regression analysis statistics

Dependent variable Composite and time	Measure	Independent variable	x	B_x	SE B_x	t	P
Charisma, 20 s	KHN, upper	Intensity	1	0.01	0.004	2.5	0.01
Charisma, 20 s	KHN, lower	Intensity	1	0.22	0.06	3.9	0.002
		Intensity squared	2	-4.0×10^{-4}	1.0×10^{-4}	–3.6	0.005
		Intensity cubed	3	2.9×10^{-7}	7.8×10^{-8}	3.7	0.003
Point 4, 20 s	KHN, upper	Intensity	1	0.08	0.04	1.8	0.08
		Intensity squared	2	1.0×10^{-4}	9.3×10^{-5}	–1.5	0.13
		Intensity cubed	3	8.3×10^{-8}	5.9×10^{-8}	1.4	0.16[a]
Point 4, 20 s	KHN, lower	Intensity	1	0.09	0.03	3.0	0.003
		Intensity squared	2	-1.0×10^{-4}	6.4×10^{-5}	–2.1	0.04
		Intensity cubed	3	8.5×10^{-8}	4.0×10^{-8}	2.1	0.04
Point 4, 40 s	KHN, upper	Intensity	1	0.11	0.04	2.8	0.005
		Intensity squared	2	-2.0×10^{-4}	7.7×10^{-5}	–2.3	0.03
		Intensity cubed	3	9.5×10^{-8}	4.9×10^{-8}	1.9	0.05
Point 4, 40 s	KHN, lower	Intensity	1	0.17	0.04	4.8	0.001
		Intensity squared	2	-2.0×10^{-4}	7.2×10^{-5}	–3.3	0.001
		Intensity cubed	3	1.3×10^{-7}	4.6×10^{-8}	2.9	0.005
Charisma, 20 s	RH	Intensity	1	0.52	0.14	3.7	0.004
		Intensity squared	2	–0.001	3.0×10^{-4}	–3.3	0.001
		Intensity cubed	3	6.2×10^{-7}	1.9×10^{-7}	3.3	0.001
Point 4, 20 s	RH	Intensity	1	0.19	0.08	2.3	0.02
		Intensity squared	2	-2.5×10^{-4}	1.7×10^{-4}	–1.5	0.15
		Intensity cubed	3	1.5×10^{-7}	1.1×10^{-7}	1.4	0.15[a]
Point 4, 40 s	RH	Intensity	1	0.31	0.09	3.6	0. 004
		Intensity squared	2	-4.0×10^{-4}	1.8×10^{-4}	–2.4	0.02
		Intensity cubed	3	2.3×10^{-7}	1.1×10^{-7}	2.0	0.04

SE = standard error, KHN = Knoop hardness number, RH = relative hardness

[a] *When testing parameters to determine which polynomial model to use for estimation, it has been recommended that the test for the highest-order term be made at a more liberal level such as 0.20, rather than the more traditional level of 0.05 or 0.01.*

172 other units with age data (9.2 and 5 years, respectively; t-test, $p < 0.001$). The mean light intensity for the 33 light units was significantly lower than for the remaining 181 lights (263 and 574 mW/cm^2, respectively; t-test, $p < 0.001$).

Scatterplots revealed that as light intensity increased, surface KHN and RH also increased, with the increase in "slope" for upper surfaces being much less than for lower surfaces and RH. **Table 3** summarizes the results of the regression analyses, and the statistics for the regression analyses are detailed in **Table 4**. Although all 9 relationships were statistically significant by simple linear regression, for 8 of the 9 relationships a slightly better fit was obtained with multiple linear regression with a third-degree (cubic) polynomial model. Throughout the range of light intensities, the variability or scatter of surface KHNs was much greater for upper than for lower surfaces. This is exemplified in **Table 3** by the small R^2 values for upper surfaces (4.2% to 11.9%) and the moderately high R^2 values for lower surfaces and RH (40.2% to 62.7%). Other independent variables (age of light unit and service frequency) were entered separately into multiple linear regressions along with light intensity, but were not statistically significant ($p > 0.05$).

Discussion

In spite of previously published reports about the intensity of light emitted from polymerization units used in private dental offices,[7–9,17] the present study indicated continued wide variation in light intensity in private dental offices in Toronto; including some offices with units emitting light below minimum operational levels. The number of offices that participated in this study (100) is just below the range for numbers of offices participating in 3 similar studies in other countries (105 to 122).[7,9,17]

However, the mean number of light units tested per office in this study (2.1) was higher than that for the other 3 studies (1.0 to 1.7). The increase in the use of resin composites in private dental offices over the past 5 to 10 years[1–3] is the most likely reason that 78% of participating dental offices in Toronto had more than 1 light unit.

A recent study investigating the correlation between RH and degree of conversion for a variety of resin composites reported a strong association between the 2 methods of evaluating extent of polymerization.[27] The study's authors concluded that the simpler method (RH) was an accurate indirect reflection of degree of conversion ratios.[27] Thus, the findings of the present study should be considered an accurate reflection of degree of conversion ratios for the composite materials tested.

Because light intensity is directly associated with the polymerization of resin composites, low-intensity values are of concern.[6] Inadequate light polymerization of resin composite restorations might cause a number of clinical problems. Postoperative sensitivity may occur because of partial dissolution of unpolymerized material at the tooth–restoration interface, and recurrent caries along the interface may follow.[28] Inferior mechanical properties of the restoration may result in excessive wear or possibly bulk fracture of the composite.[17] Cytotoxicity due to ingestion of leached monomer or other unbound chemicals may occur with relatively thicker increments that are not well polymerized.[29–31]

The proportion of light units tested that had an intensity below 200 mW/cm^2 (4.2%) or 300 mW/cm^2 (12.1%) was lower than in other studies (14% to 33% and 25% to 55%, respectively[7–9,17]). Pilo and others[9] reported that the hardness of the upper surfaces of the composite specimens tested tended to plateau at relatively low intensity levels, whereas the hardness of the lower surfaces continued to increase with increased light intensity; thus, upper surface hardness was less dependent on light intensity. Similarly, in the present study, the upper surfaces displayed a plateau pattern and lower "slope" and R^2 values in relation to increasing intensity. For all composite specimens, the upper surfaces were significantly harder than the lower surfaces. This observation is also in agreement with the findings of Johnston and others,[13] who examined 2 light-polymerized products. As the light passes through the specimen, it becomes scattered, and the layers below the outer surface receive light with reduced intensity.[20] There is no internationally recognized standard for adequate depth of polymerization. However, Johnston and others,[13] using 2.5-mm-thick composite specimens, suggested that depth of polymerization be based on the RH value and that, for practical purposes, a relative value of 90% be promoted. Yearn[31] used 80% RH as a means of comparison for adequate depth of polymerization. It is interesting that Pilo and others[9] found that none of fifty 3-mm-thick specimens exposed for 50 seconds achieved the equivalent of 80% or higher RH.

Limiting the thickness of a composite increment to no more than 1 mm aids in maximizing RH. Rueggeberg and others[6] indicated that the thickness of an incremental layer of composite should not exceed 2 mm, with 1 mm being ideal. The authors recommended an exposure time of 60 seconds with a light source having an intensity of at least 400 mW/cm^2; however, a 40-second exposure was deemed sufficient. In the present study, 65 units had intensity values lower than 400 mW/cm^2, and 14 units had intensity values less than 233 mW/cm^2 (suggested by another author group as the lower limit of usefulness[6]). In other words, 30.3% of all tested units emitted light with less than the recommended intensity, and 21.5% of those 65 units emitted light with an intensity that could result in less than ideal polymerization characteristics. In comparison, about 52% of the lights tested in an Australian study[8] had intensities below 400 mW/cm^2, with 27% at or below 200 mW/cm^2, and in Tel Aviv[9] these proportions were 75%

and 33%, respectively. Also, in the present study, increasing the exposure time for the Point 4 composite from 20 seconds to 40 seconds resulted in a significant increase in RH.

Although the 2 composite materials used in the present study were of the same type (a small-particle hybrid) and had a similar shade, the RH values differed significantly when the 2 brands were polymerized for the same period (20 seconds). This finding agrees with those of Johnston and others[13] and is likely due to differing degrees of distortion as the light passes through the thickness of the specimen.[12] Size, shape and distribution of the inorganic filler particles within each composite material play a role in this respect.[26] Shade or opacity of the composite material also has an influence, with lighter, more translucent shades resulting in higher RH values than darker, more opaque shades.[24] A number of factors can lead to deterioration of intensity of light emitted by QTH units, including age of the lamp, condition of the filter and condition of the light guide.[7] When Miyazaki and others[17] replaced the lamps in 2 light polymerization units that had light intensities less than 300 mW/cm^2 (Visilux 2), light intensity increased by 21% and 36%, whereas changing the filters resulted in increases of 89% and 158%. Changing the fibre optic light guide of the same light units resulted in increases in light intensity of 36% and 46%.

However, when all 3 parts (lamp, filters and fibre optic light guides) were replaced at the same time, light intensity increased by 208% and 323%.[16] It has been suggested that the lamps of light polymerization units be replaced every 6 months to maintain adequate intensity.[32] However, it may also be important to routinely replace other components, including filter and light guide.

Filters used in light polymerization units produce light in the blue region of the spectrum (400–500 nm), which is necessary for activation of the photo-initiators in the resin composites.[32] A cracked, blistered or defective filter may not function properly and as a result, the wavelength of the produced light may not coincide well with the required range. In addition, a defective filter will reduce light intensity.[7] Therefore, it is possible that even with adequate light intensity, an incorrect wavelength output due to a defective filter might cause the light unit to function ineffectively.

Dentists are encouraged to adopt policies to routinely monitor the effectiveness of all light polymerization units. An appropriate light meter can be used to test light units. Routine maintenance should include evaluating lamps, light guides and filters and replacing them when there is evidence of deterioration. Regulatory bodies should consider the need for obligatory periodic testing of light polymerization units used by dentists in private dental offices.

New light curing units based on light-emitting diode (LED) technology have been introduced and are now being marketed. While some of the earliest versions of these lights did not perform well in terms of depth of cure, newer versions are expected to improve in this respect.[16] These lights do not have filters and their illuminating parts (the LEDs) last longer than QTH lamps. Therefore, they may need less maintenance.

Future research should aim to duplicate this study in a less developed country. This would be helpful for comparison purposes and would alert dentists in that country to the local situation and the need for regular maintenance of light polymerization units.

Conclusions

The 214 light units tested in the present study displayed various intensities of light emission, many of them at below-recommended levels. The mean RH of composite specimens prepared in private dental offices ranged between 34.8% and 57.7%, which is below the desirable level of 80% to 90%. Only 10% of the composite specimens polymerized for 40 seconds reached RH of at least 80%. For the 20-second polymerization cycle only 3% to 5% of the specimens achieved this level of hardness. RH was dependent on light intensity, exposure time and brand of composite. Light intensity was significantly ($p < 0.01$) and positively associated with increased surface KHNs, although the explanatory strength (R^2) of the relationship was much lower for upper surfaces than for lower surfaces. Units with low-intensity emissions yielded very low KHNs for the lower surface of the specimens and very low RH values. ◆

THE AUTHORS

Acknowledgements: *This article is based on a presentation made at the annual meeting of the International Association for Dental Research, Gothenberg, Sweden, June 2003. The work was supported in part by the Kerr Corp, Orange, Calif., to whom the authors are thankful. The authors would also like to acknowledge the assistance of Dr. Herenia Lawrence of the faculty of dentistry, University of Toronto, in the statistical analysis.*

Dr. El-Mowafy *is professor in restorative dentistry, faculty of dentistry, University of Toronto, Toronto, Ontario.*

Dr. El-Badrawy *is assistant professor in restorative dentistry, faculty of dentistry, University of Toronto, Toronto, Ontario.*

Dr. Lewis *is professor emeritus, faculty of dentistry, University of Toronto, Toronto, Ontario.*

Dr. Shokati *is a graduate student, faculty of dentistry, University of Toronto, Toronto, Ontario.*

Mr. Soliman *is a graduate student, University of Toronto, Toronto, Ontario.*

Mr. Kermalli *is an undergraduate dental student, University of Toronto, Toronto, Ontario.*

Mr. Encioiu *is an undergraduate dental student, University of Toronto, Toronto, Ontario.*

Ms. Rajwani *is a graduate student, McMaster University, Hamilton, Ontario.*

Ms. Zawi *is a student at the Canadian Memorial Chiropractic College, Toronto, Ontario.*

Correspondence to: *Dr. Omar El-Mowafy, Faculty of Dentistry, University of Toronto, 124 Edward St. Toronto, ON M5G 1G6. E-mail: oel.mowafy@utoronto.ca.*

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

References

1. Mjor IA, Shen C, Eliasson ST, Richter S. Placement and replacement of restorations in general dental practice in Iceland. *Oper Dent* 2002; 27(2):117–23.

2. Sundberg H, Mejare I, Espelid I, Tveit AB. Swedish dentists' decisions on preparation techniques and restorative materials. *Acta Odontol Scand* 2000; 58(3):135–41.

3. Bogacki RE, Hunt RJ, del Aguila M, Smith WR. Survival of posterior restorations using an insurance claims database. *Oper Dent* 2002; 27(5):488–92.

4. Bassiouny MA, Grant AA. A visible light-cured composite restorative. Clinical open assessment. *Brit Dent J* 1978; 145(11):327–30.

5. Craig RG, Powers JM, editors. Restorative dental materials. 11th ed. Mosby; 2002. p. 251.

6. Rueggeberg FA, Caughman WF, Curtis JW Jr. Effect of light intensity and exposure duration on cure of resin composites. *Oper Dent* 1994; 19(1):26–32.

7. Barghi N, Berry T, Hatton C. Evaluating intensity output of curing lights in private dental offices. *J Am Dent Assoc* 1994; 125(7):992–6.

8. Martin FE. A survey of the efficiency of visible light curing units. *J Dent* 1998; 26(3):239–43.

9. Pilo R, Oelgiesser D, Cardash HS. A survey of output intensity and potential for depth of cure among light-curing units in clinical use. *J Dent* 1999; 27(3):235–41.

10. Newman SM, Murray GA, Yates JL. Visible-lights and visible activated composite resin. *J Prosthet Dent* 1983; 50(1):31–5.

11. Cook W. Factors affecting the depth of cure of UV-polymerized composites. *J Dent Res* 1980; 59(5):800–8.

12. DeWald JP, Ferracane JL. A comparison of four modes of evaluating depth of cure of light-activated composites. *J Dent Res* 1987; 66(3):727–30.

13. Johnston WM, Leung RL, Fan PL. A mathematical model for post-irradiation hardening of photoactivated composite resins. *Dent Mater* 1985; 1(5):191–4.

14. Tirtha R, Fan PL, Dennison JB, Powers JM. In vitro depth of cure of photo-activated composites. *J Dent Res* 1982; 61(10):1184–7.

15. Fan PL, Schumacher RM, Azzolin K, Geary R, Eichmiller FC. Curing-light intensity and depth of cure of resin-based composites tested according to international standards. *J Am Dent Assoc* 2002; 133(4):429–34.

16. Santos GC Jr, El-Mowafy O, Rubo JH, Santos MJ. Hardening of dual-cure resin cements and a resin composite restorative with QTH and LED light curing. *J Can Dent Assoc* 2004; 70(5):323–8.

17. Miyazaki M, Hattori T, Ichishi Y, Kondo M, Moore BK. Evaluation of curing units used in private dental offices. *Oper Dent* 1998; 23(2):50–4.

18. Dietschi D, Marret N, Krejci I. Comparative efficiency of plasma and halogen light sources on composite micro-hardness in different curing conditions. *Dent Mater* 2003; 19(6):493–500.

19. Baharav H, Abraham D, Cardash HS, Helft M. Effect of exposure time on the depth of polymerization of a visible light-cured composite resin. *J Oral Rehabil* 1988; 15(2):167–72.

20. Yap AUJ. Effectiveness of polymerization in composite restoratives claiming bulk placement: impact of cavity depth and exposure time. *Oper Dent* 2000; 25(2):113–20.

21. Ruyter IE, Oysaed H. Conversion in different depths of ultraviolet and visible light activated composite materials. *Acta Odontol Scand* 1982; 40(3):179–92.

22. Price RB, Derand T, Sedarous M, Andreou P, Loney RW. Effect of distance on the power density from two light guides. *J Esthet Dent* 2000; 12(6):320–7.

23. Ferracane JL, Aday P, Matsumoto H, Marker VA. Relationship between shade and depth of cure for light-activated dental composite resins. *Dent Mater* 1986; 2(2):80–4.

24. Taira M, Urabe H, Hirose T, Wakasa K, Yamaki M. Analysis of photo-initiators in visible-light-cured dental composite resins. *J Dent Res* 1988; 67(1):24–8.

25. Ferracane JL, Greener EH. The effect of resin formulation on the degree of conversion and mechanical properties of dental restorative resins. *J Biomed Mater Res* 1986; 20(1):121–31.

26. Pashley DH. Mechanisms of dentin sensitivity. *Dent Clin North Am* 1990; 34(3):449–73.

27. Bouschlicher MR, Rueggeberg FA, Wilson BM. Correlation of bottom-to-top surface microhardness and conversion ratios for a variety of resin composite compositions. *Oper Dent* 2004; 29(6):698–704.

28. Caughman WF, Caughman GB, Shiflett RA, Rueggeberg F, Schuster GS. Correlation of cytotoxicity, filler loading and curing time of dental composites. *Biomaterials* 1991; 12(8):737–40.

29. Franz A, Koing F, Anglmayer M,Rausch-Fan X, Gille G, Rausch WD, and others. Cytotoxic effects of packable and nonpackable dental composites. *Dent Mater* 2003; 19(5):382–92.

30. deSouza Costa CA, Hebling J, Hanks CT. Effects of light-curing time on the cytotoxicity of a restorative resin composite applied to an immortalized odontoblast-cell line. *Oper Dent* 2003; 28(4):365–70.

31. Yearn JA. Factors affecting cure of visible light activated composites. *Int Dent J* 1985; 35(3):218–25.

32. Friedman J. Variability of lamp characteristics in dental curing lights. *J Esthet Dent* 1989; 1(6):189–90.