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## Laboratory Research

# Curing Efficiency of Three Different Curing Modes at Different Distances for Four Composites

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### Clinical Relevance

Doubling the exposure time of a high-intensity light-emitting diode curing light with a turbo tip and autofocus capability does not predictably compensate for distance in deep cavities.


### SUMMARY

**This study investigated the influence of the different curing distances with three polymerization modes in terms of the surface microhardness of four resin composites as a function of energy density. A hybrid resin composite and flowable composite from each of two manufacturers were evaluated. The specimens were polymerized with one of two light-curing units: 1) Mini LED AutoFocus (1500 mW/cm$^2$) with a fast curing mode, for which two polymerization regimens were used: a) one AutoFocus function cycle and b) two AutoFocus function cycles, and 2) LEDemetron I (950 mW/cm$^2$) with a 20-second curing time. Polymerization was performed with the curing tip at a distance of 0 mm, 3.0 mm, 6.0 mm, and 9.0 mm from the top surface of the specimen, and the power density of each light source was measured with a spectrophotometer. All specimens were stored in distilled water in a light-proof container at 37°C for 24 hours, and their top and bottom surface Knoop hardness numbers were determined. Microhardness data were submitted to two-way analysis of variance and multiple comparisons with a Tukey test. All statistical analyses were performed at a significance level of 0.05. Though the curing lights tested exhibited a decrease in power density with distance, the rate and extent of power density loss were not the same. The polymerization mode and curing tip distance had a significant effect on the composite microhardness. There was also a significant interaction among polymerization mode, curing tip distance, and microhardness. The curing ability of the three polymerization modes was ranked in terms of the hardness percent values: the LEDemetron I > two cycles of the Mini LED AutoFocus > one cycle of the Mini LED AutoFocus.**



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## INTRODUCTION

Light-curing units are widely used in modern dentistry. However, a sufficient power density with suitable irradiation time must reach all areas of a photoactivated restoration to ensure adequate polymerization and optimal physical and clinical performance.[1] Various types of light-curing units available to dental professionals include: high-output quartz tungsten halogen (QTH), light-emitting diode (LED), plasma arc, and Argon ion laser light units. The most commonly used dental curing lights are QTH and LED lights. Compared to QTH lights, LED units have the advantage of an extended lifetime of several thousand hours, and they undergo little degradation of light output over time.[2,3] Junctions of semiconductors are used to emit blue light in LED curing lights, eliminating the need for the filters used with halogen light bulbs.[2] LED curing lights can operate on battery power and consume little energy.[4] They generate a range of wavelengths from 410 nm to 490 nm, which matches the central absorption peak of the common photoinitiator, camphorquinone.[5,6]

The power density reached at the resin surface influences the rate and the extent of the polymerization process at the surface and within the material. A minimum of 400 mW/cm$^2$ within the correct wavelength range (450–500 nm) is generally accepted for routine polymerization of light-activated dental resin composites.[7,8] The amount of light energy reaching the top and bottom regions of a resin composite specimen is strongly dependent on a number of factors, such as light output intensity, exposure duration, distance from the light source to the material, the material's composition, shade, translucency, and increment thickness.[9–12] All of the lights available are characterized by a loss of power density as the distance from the light tip to the target material increases.[13–18] The logarithm of the intensity of light diminishes linearly with the distance.[19,20] Thus, it is especially important to locate the light sources as close as possible to the surface of the composite to prevent intensity reduction when low-power density lights are used. For ordinary curing lights, the ideal distance is reported to be 1 mm, not to exceed 4–5 mm, with an exposure time of 40 seconds per 2-mm increment.[4,9]

From a clinical standpoint, it is not always possible to locate the tip of the light source adjacent to the resin composite during polymerization as a result of factors such as cavity size and the position of the tooth in the arch. The distance between the light tip and the gingival floor of a typical Class II preparation is about 7 mm.[17,21,22] This distance could have a significant influence on the polymerization of the first resin composite increment. In such situations, increasing light-curing time has been recommended.[1] Another approach to overcome the reduction in power density with distance is to use light-curing units with higher power densities.[16,20] It is possible for the attenuated higher power density to provide adequate energy density with which to polymerize the first composite increment in deeper cavities.[16] With a claimed output of about 2000 mW/cm$^2$, the Mini LED AutoFocus (ACETEON, Cedex, France) is currently among the most powerful LED lights. It has one special feature, the AutoFocus function, that automatically adjusts the light emission time according to the position of the light guide with respect to the material surface, thus optimizing the polymerization energy delivered to the material. The expectation is that the AutoFocus function maintains a constant polymerization quality in a 2-mm increment of composite, correcting for position variations that may exist between the light guide tip and the material surface up to 9 mm.

The sufficient polymerization of a resin composite can be analyzed by several methods, such as analysis of the degree of conversion (DC) and hardness measurements. Knoop hardness number (KHN) has been demonstrated[23] to be a good predictor of the efficacy of different light sources. There appears to be a good correlation between DC and microhardness.[24-27] Therefore, Knoop hardness measurements were used in this study to determine the efficacy of different lights on the polymerization of four resin composites. The objective of this study was to evaluate the influence of the different curing distances with three polymerization modes in terms of the surface microhardness of four resin composites as a function of energy density. Another objective was to investigate the effectiveness of polymerization by comparing the highly filler-loaded hybrid composites with their less filled complementary flowable composites because they are commonly used in the deepest portion of a cavity. A previous study[28] showed that a flowable resin composite yielded a statistically significant higher depth of cure than did a universal hybrid version. A reason for this may be that higher filler content in the hybrid composite led to increased scattering of the light when the specimens were cured from a distance of 6 mm.[28]

The following hypotheses were tested in this study:

(1) Automatically increasing the exposure time

Table 1: *Composition of the Restorative Materials*

| Composite Code | Matrix | Filler | Batch Number |
|---|---|---|---|
| Admira Flow (AF) | Ormocers, functional dimethacrylate groups | Silicon dioxide<br>Content: 50.5 vol%; 64 wt%<br>Size (μm): 0.7 (0.04–1.2) | 780888 |
| Grandio (GR) | Bis-GMA<br>TEDMA<br>UDMA | Silica and barium glass<br>Content: 71.4 vol%; 87 wt%<br>Size (μm): 0.04–0.7 | 0831307 |
| Filtek™ Supreme Plus Flowable Restorative (FF) | Bis-GMA<br>TEGDMA<br>Bis-EMA | Zirconia and silica particles<br>Content: 55 vol%; 65 wt%<br>Size (μm): 0.04–0.7 | 20081006 |
| Filtek™ Z250 (FZ) | Bis-GMA<br>UDMA<br>Bis-EMA | Zirconia and silica<br>Content: 60 vol%; 82wt%<br>Size (μm): 0.6 (0.01–3.5) | 20080730 |

*Abbreviations: Bis-GMA, bisphenol A diglycidyl methacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, ethoxylated bisphenol A glycol dimethacrylate*

using a high-output LED curing unit with a turbo tip and an autofocus capability will compensate for expected decreases in top or bottom KHN of two hybrid and two flowable composites as distance increases to 9 mm;

(2) Automatically increasing the exposure time using a high-output LED curing unit with a turbo tip and an autofocus capability will compensate for expected decreases in the hardness percent values of two hybrid and two flowable composites as distance increases to 9 mm.

## METHODS AND MATERIALS

Human mandibular molar teeth were completely embedded in acrylic resin and sectioned horizontally with a water-cooled, slow-speed saw to produce discs of enamel and dentin that were 2 mm thick. An oval hole (5×3 mm) was drilled at low speed through the center of each tooth disc. At least 1 mm of tooth structure surrounding the hole remained. Specimens were stored in distilled water until use. Some previous studies[29,30] have shown that mold materials such as stainless steel or Teflon may affect the physical properties of the resin composite because of their differences in reflecting, absorbing, and transmitting light. Human molar teeth specimens are more relevant to the clinical aspects of composite curing.

Four light-cured resin composites (shade A3) were evaluated: Admira Flow (VOCO, Cuxhaven, Germany); Grandio (VOCO); Filtek™ Supreme Plus Flowable Restorative (FF; 3M ESPE, St Paul, MN, USA); and Filtek™ Z250 (3M ESPE). Grandio and Filtek™ Z250 are two hybrid resin composites recommended for universal clinical use; Admira Flow and Filtek™ Supreme Plus Flowable Restorative are flowable composites. The composition of each material is detailed in Table 1.

Each specimen was placed between two glass slides separated by Mylar matrix strips to obtain a smooth surface on the resin composite and was pressed with a static load of 500*g* for 60 seconds. The mold was filled in one increment and polymerized.

The specimens were polymerized with one of two light-curing units: 1) Mini LED AutoFocus with a fast-curing mode. The entry diameter and exit diameter of the light guide were 13 mm and 7.5 mm, respectively. The AutoFocus function mode was active, as recommended by the manufacturer. Two polymerization regimens were used: a) one AutoFocus function cycle and b) two AutoFocus function cycles with an interval of approximately one second between cycles. Each cycle lasted five to seven seconds depending on the distance variation between the light guide tip and the composite surface. 2) LEDemetron I (SDS/Kerr, Orange, CA, USA), with a 20-second curing time consistent with all of the experimental composite manufacturers' recommended irradiation times. The entry diameter and exit diameter of the light guide were both 13 mm. The power density of each light source was measured with a spectrophotometer with a FOIS-1 integrating sphere (USB2000, Ocean Optics Inc, FL, USA). Calibration of the spectrophotometer in absolute spectral irradiance units was done with a LS-1-CAL-INT NIST-traceable light source using OOIIrrad-C software, also from Ocean Optics. The power spectrum was integrated from 380 nm to 520 nm to obtain intensity values in mW/cm$^2$. The glass slides were removed and the mold with Mylar strips was placed on a block of 3.0 mm–thick dentin prior to polymerization. The dentin block was used to simulate the dentin floor of a clinical cavity preparation in a human tooth. Polymerization was performed with the light tip in a positioning device that held the curing tip at a distance of 0 mm (the tip touching the Mylar matrix strip), 3.0 mm, 6.0 mm, and 9.0 mm from the top surface of the specimen. Two hundred and forty specimens were made and divided into 48 groups with five specimens apiece. The three variables were resin composite, polymerization mode, and distance between the light source and the resin composite surface. Shade A3 was selected to represent a common shade in clinical practice. Two millimeter–thick composite specimens were measured, as they provided uniform and routine curing thickness and were also recommended by the experimental composite manufacturers.

Each specimen was removed from the mold after photocuring and stored in distilled water in a light-proof container at 37°C for 24 hours. After this period, the specimens were washed and surface KHNs were determined for the top and bottom surfaces within six minutes. Three indentations at the approximate center of each surface, along with the long axis of the oval hole and a constant 0.5-mm distance between each indentation, were made with a 100 *g* load and a dwell time of 15 seconds in a calibrated Leco Microhardness Tester (model M-400, Leco Co, Tokyo, Japan). The long diagonal of the indentation was measured under 20× magnification. A Leco computer printer (model ACP-94, Leco Co) was used to record the lengths and to calculate the KHNs.

The mean KHN for each surface was determined. The hardness percent value for each composite specimen was then calculated using the following formula:

$$\text{Hardness Percent Value} = (\text{KHN of bottom surface}) \div (\text{mean maximum KHN of top surface}) \times 100\%.$$

If the value exceeded 80%, the specimen was defined as adequately polymerized.

Table 2: *Power Density (mW/cm$^2$) (s.d.) for Two Curing Lights from Different Distances (mm)*[a]

| Distance | Mini LED AutoFocus | | LEDemetron I | |
|---|---|---|---|---|
| | Power Density | Percentage | Power Density | Percentage |
| 0 | 1523.00 (21.39) | 100 | 955.00 (8.46) | 100 |
| 3 | 1046.00 (17.09) | 68.68 | 776.00 (4.23) | 81.26 |
| 6 | 734.00 (9.42) | 48.19 | 634.00 (10.40) | 66.39 |
| 9 | 521.00 (10.70) | 34.21 | 529.00 (5.09) | 55.39 |

[a] *Power density reported as a mean of five measurements using a spectrophotometer.*

Data were submitted to two-way analysis of variance (ANOVA; identified factors: polymerization mode and curing tip distance) and multiple comparisons with a Tukey test using SigmaStat software (version 3.5, Systat Software Inc, Chicago, IL USA). All statistical analyses were performed at a significance level of 0.05.

## RESULTS

The measured mean power densities are described in Table 2. Also included is the percentage of remaining power density compared against the value at 0-mm distance. Figure 1 shows the decline in power density values as the curing tip was moved away from the detector. Though both lights tested exhibited a decrease in power density with distance, the rate and extent of power density loss were not the same for the two lights. The power density of the LEDemetron I didn't decrease as markedly as that of the Mini LED AutoFocus as distance from the surface increased. The mean top and bottom KHN of specimens of all resin composites measured 24 hours after curing are presented in Tables 3 and 4.

The two-way ANOVA revealed that the polymerization mode and curing tip distance had a significant effect on the composite microhardness ($p<0.001$). There was also a significant interaction among polymerization mode, curing tip distance, and microhardness ($p<0.001$).

In general, specimens cured with two cycles of the Mini LED AutoFocus light and the LEDemetron I light provided higher KHNs than did those photoactivated with one cycle of the Mini LED AutoFocus light ($p<0.05$). The mean microhardness values

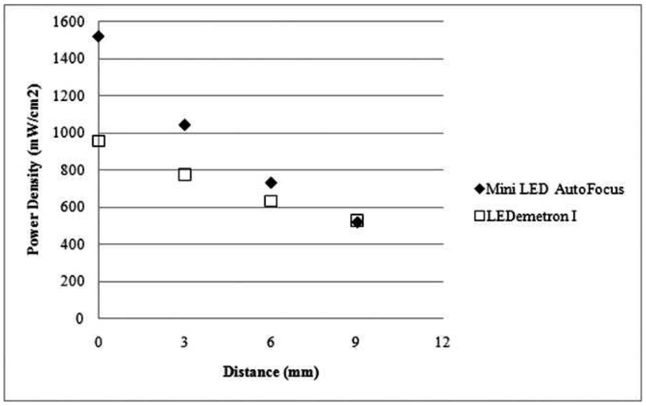


Figure 1. *Power density vs distance for Mini LED AutoFocus and LEDemetron I.*

using the LEDemetron I light were significantly greater than those values obtained using two cycles of the Mini LED AutoFocus light at the top of the 9-mm groups and the bottom of the 6-mm and 9-mm groups ($p<0.05$). It was also observed that when using the same light unit, the mean Knoop microhardness values decreased significantly as the curing tip distance increased, especially for one cycle of the Mini LED AutoFocus light and some bottom surfaces of the composites ($p<0.05$).

The maximum mean surface hardness was obtained on the top surface for each experimental resin composite. These values were selected as the overall reference to indicate the best obtainable value for each composite. Figures 2 and 3 show the hardness data for all the bottom surfaces divided by the reference value and multiplied by 100.

Twenty-four hours after light irradiation, although the hardness percent value of the LEDemetron I in the 0-mm distance group of FF composite was lower than 80%, it was not significantly different from groups that were cured with the same device that were above 80% ($p>0.05$).

## DISCUSSION

The first hypothesis was not supported in the present study. The composite microhardness was affected by the polymerization mode and curing tip distance. The LEDemetron I light provided higher KHNs than did the two modes of the Mini LED AutoFocus light, particularly for the bottom surface of relatively long-curing distance groups. The mean Knoop microhardness values decreased significantly as the curing tip distance increased, especially for bottom surfaces with one cycle of the Mini LED AutoFocus light.

The energy intensity is critical to the rate at and extent to which the polymerization process will proceed,[31] being calculated by multiplying the power density by exposure time. The higher energy density could have provided more photons for absorption by camphorquinone, accelerating the production of free radicals available for the polymerization reaction and forming a more cross-linked polymer network.[31] The greater the number of photons hitting the composite, the greater the number of camphorquinone molecules that will reach an excited state, react with the amine initiators, and generate free radicals. The high energy density could have also caused more exothermic heat in the composite polymeric matrix, making the polymer chains more mobile, consequently elevating the DC.[32,33]

Increased distance from the tip of the light guide would lead to changes in experienced power densities in current light sources. The relationship between power density and distance may be dependant on the entry diameter/exit diameter ratio (R) of individual lights.[34] The same curing light could result in a different relationship if different exit diameters were used.[35] When a certain amount of light is created, the exiting light beam from a small exit diameter (commercially defined "turbo") is in a cone shape. There is a relatively high power density in the proximal section of the guide tip. In contrast, with a tip having similar entry and exit diameters (commercially defined "standard"), the shape of the light beam is prone to be a cylinder.[36] The power density of a cone-shaped beam will decrease more rapidly with increasing distance in comparison with that of a cylinder-shaped beam. It has been shown[36] that tips with a higher R-value (cone-shaped beam) are more powerful if the tip and composite distance is less than 5 mm. But if the distance exceeds 5 mm, tips with a lower R-value (cylinder-shaped beam) generate better results.

In the current study, the exit diameters of the light guide were 7.5 mm for the Mini LED AutoFocus and 13 mm for the LEDemetron I, each sharing a common entry diameter of 13 mm. Although the Mini LED AutoFocus generated a higher initial power density than that of the LEDemetron I, it exhibited a more rapid decrease in power density as the distance increased. For the Mini LED AutoFocus, each cycle only lasted five to seven seconds, depending on the distance variation between the light guide tip and the composite surface up to 9 mm. The reduction in power densities was not matched by the increase in the irradiation times (one to two seconds). Therefore, one cycle of the Mini LED

Table 3: *Knoop Hardness Number, KHN (s.d.), of Admira Flow (AF) and Grandio (GR)[a]*

| Distance, mm | | | Mini LED AutoFocus One Cycle | Mini LED AutoFocus Two Cycles | LEDemetron I |
|---|---|---|---|---|---|
| AF | T | 0 | 14.51 (0.93) $A^a$ | 16.24 (1.36) $B^{ab}$ | 17.89 (0.86) $C^a$ |
| | | 3 | 15.19 (1.10) $A^a$ | 17.49 (0.23) $B^a$ | 18.41 (1.10) $B^a$ |
| | | 6 | 13.60 (0.87) $A^a$ | 16.98 (0.71) $B^{ab}$ | 18.07 (0.82) $B^a$ |
| | | 9 | 10.23 (0.47) $A^b$ | 15.67 (1.07) $B^b$ | 18.63 (1.56) $C^a$ |
| | B | 0 | 11.10 (1.30) $A_a$ | 17.07 (1.02) $B_a$ | 17.48 (0.46) $B_a$ |
| | | 3 | 8.17 (0.51) $A_b$ | 16.82 (0.88) $B_a$ | 15.88 (1.00) $B_b$ |
| | | 6 | 4.72 (0.75) $A_c$ | 12.70 (0.62) $B_b$ | 15.67 (0.99) $C_b$ |
| | | 9 | <4.00 $A_d$ | 8.09 (0.45) $B_c$ | 13.69 (0.78) $C_c$ |
| GR | T | 0 | 66.05 (1.69) $A^a$ | 66.35 (2.01) $A^{ab}$ | 70.89 (3.25) $B^a$ |
| | | 3 | 64.63 (1.66) $A^a$ | 68.19 (2.69) $B^a$ | 70.93 (1.50) $B^a$ |
| | | 6 | 63.03 (1.89) $A^a$ | 64.81 (1.17) $A^b$ | 69.70 (1.62) $B^a$ |
| | | 9 | 55.81 (1.84) $A^b$ | 61.11 (2.37) $B^c$ | 70.19 (0.73) $C^a$ |
| | B | 0 | 58.41 (0.94) $A_a$ | 63.50 (2.96) $B_a$ | 64.11 (3.32) $B_a$ |
| | | 3 | 52.24 (1.55) $A_b$ | 62.59 (3.37) $B_a$ | 62.80 (3.46) $B_a$ |
| | | 6 | 49.81 (0.99) $A_b$ | 53.95 (2.32) $B_b$ | 61.76 (3.17) $C_a$ |
| | | 9 | 36.59 (1.35) $A_c$ | 47.67 (2.16) $B_c$ | 61.13 (1.54) $C_a$ |

[a] *T, top surface; B, bottom surface. The same capital letter in a row indicates no statistical difference ($p>0.05$). The same superscripted letter in a column indicates no significant difference of KHN of the top surface for the same composite ($p>0.05$). The same subscripted letter in a column indicates no significant difference of KHN of the bottom surface for the same composite ($p>0.05$).*

AutoFocus provided lower energy densities and led to lower KHNs among the three modes. Based on the above results, resin composite polymerization is dependent on the initial light power density, the curing distance, the irradiation time, and the R-value of the guide tip, all critical variables for achievement of maximum curing.

The second hypothesis was not supported by the experimental data, and dissimilar hardness percent values were found. The curing abilities of the three polymerization modes were ranked in terms of the hardness percent values of the four resin composites: the LEDemetron I > two cycles of the Mini LED AutoFocus > one cycle of the Mini LED AutoFocus.

Table 4: *Knoop Hardness Number, KHN (s.d.), of Filtek™ Supreme Plus Flowable Restorative (FF) and Filtek™ Z250 (FZ)*

| Distance, mm | | | Mini LED AutoFocus One Cycle | Mini LED AutoFocus Two Cycles | LEDemetron I |
|---|---|---|---|---|---|
| FF | T | 0 | 23.92 (1.34) $A^a$ | 25.34 (0.62) $A^{ac}$ | 24.28 (1.28) $A^a$ |
| | | 3 | 26.96 (0.86) $A^b$ | 26.98 (0.62) $A^a$ | 26.43 (1.40) $A^b$ |
| | | 6 | 24.53 (1.52) $A^a$ | 23.69 (0.77) $A^{bc}$ | 26.97 (1.07) $B^b$ |
| | | 9 | 18.09 (0.76) $A^c$ | 22.67 (1.70) $B^b$ | 25.31 (1.30) $C^{ab}$ |
| | B | 0 | 19.62 (1.08) $A_a$ | 24.76 (1.02) $B_a$ | 21.52 (0.69) $C_{ab}$ |
| | | 3 | 19.16 (1.34) $A_a$ | 23.21 (0.52) $B_a$ | 23.09 (1.46) $B_a$ |
| | | 6 | 13.94 (1.28) $A_b$ | 16.95 (0.91) $B_b$ | 22.31 (0.70) $C_a$ |
| | | 9 | 7.43 (0.52) $A_c$ | 15.27 (0.65) $B_c$ | 20.59 (0.38) $C_b$ |
| FZ | T | 0 | 54.90 (1.47) $A^a$ | 52.90 (1.22) $A^{ab}$ | 52.46 (1.23) $A^a$ |
| | | 3 | 54.05 (1.89) $A^a$ | 55.28 (1.30) $A^a$ | 54.20 (1.70) $A^a$ |
| | | 6 | 50.81 (1.62) $A^b$ | 50.77 (3.19) $A^b$ | 54.87 (1.17) $B^a$ |
| | | 9 | 41.44 (1.55) $A^c$ | 41.17 (1.90) $B^c$ | 52.78 (1.01) $C^a$ |
| | B | 0 | 53.23 (1.33) $A_a$ | 50.65 (1.81) $AB_a$ | 48.75 (2.23) $B_a$ |
| | | 3 | 43.50 (1.20) $A_b$ | 49.19 (1.13) $B_a$ | 49.41 (1.49) $B_a$ |
| | | 6 | 34.35 (1.94) $A_c$ | 43.51 (1.24) $B_b$ | 48.15 (2.68) $C_a$ |
| | | 9 | 24.21 (1.77) $A_d$ | 32.58 (3.48) $B_c$ | 47.22 (1.11) $C_a$ |

[a] *T, top surface; B, bottom surface. The same capital letter in a row indicates no statistical difference ($p>0.05$). The same superscripted letter in a column indicates no significant difference of KHN of the top surface for the same composite ($p>0.05$). The same subscripted letter in a column indicates no significant difference of KHN of the bottom surface for the same composite ($p>0.05$).*

When the light transmits through the bulk of the composite, its intensity is reduced as a result of the reflecting, absorbing, and scattering of light by the

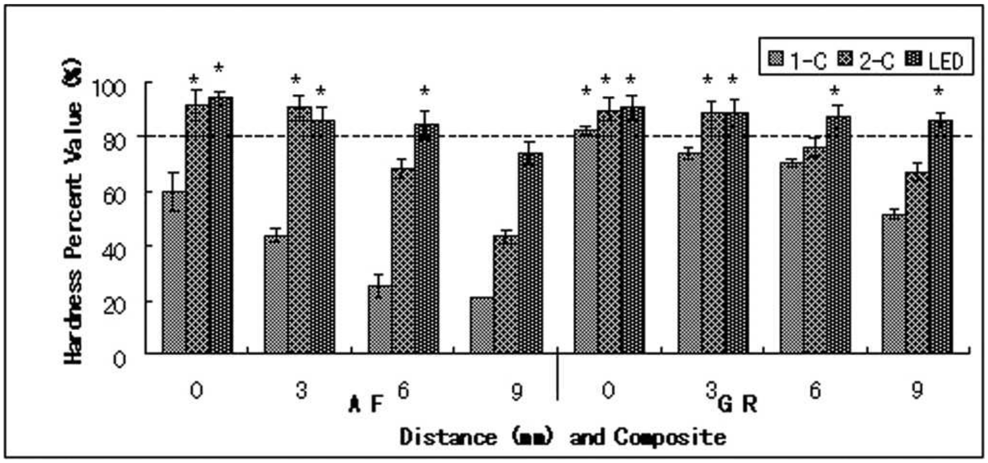


Figure 2. *Mean bottom to maximum mean top hardness percent value of Admira Flow (AF) and Grandio (GR) composites. Asterisks indicate values that are greater than 80% and statistically different from those of the other groups with the same mode (p<0.05). 1-C, one AutoFocus function cycle; 2-C, two AutoFocus function cycles; LED, LEDemetron I light.*

composite composition.[37] The resin composite on the top surface normally receives a sufficient amount of light energy for adequate polymerization. Deeper in the composite, light attenuation gives rise to fewer excited camphorquinone molecules, and the opportunity for collision with an amine decreases accordingly.[31] As a result, the polymerization reaction proceeds more slowly and to a more incomplete extent at the bottom surface of the specimens, resulting in a decreased DC and microhardness. It has been suggested[17,27] that a specimen of resin composite is adequately cured when there is no more than a 20% difference between the maximum hardness at the top of the composite and the hardness at the bottom. A bottom-to-top KHN percentage of 80% has been reported[38] to correspond to a bottom-to-top DC ratio of 90, indicating that sufficient light energy penetrated through 2 mm to polymerize the bottom of the resin composite. Although the absolute KHNs could not be used to predict DC when different composites were compared, a bottom-to-maximum top hardness percent value could reflect the relative extent of conversion of a bottom surface to that of the maximum cure obtainable at the composite's top surface, regardless of the composite composition.[38] The bottom surface KHNs require special attention because these values may be significantly inferior to those of the top surface and may greatly influence the ultimate result of a restoration. The lower KHNs and related lower DC are associated with inferior mechanical properties and water sorption as well as postopera-

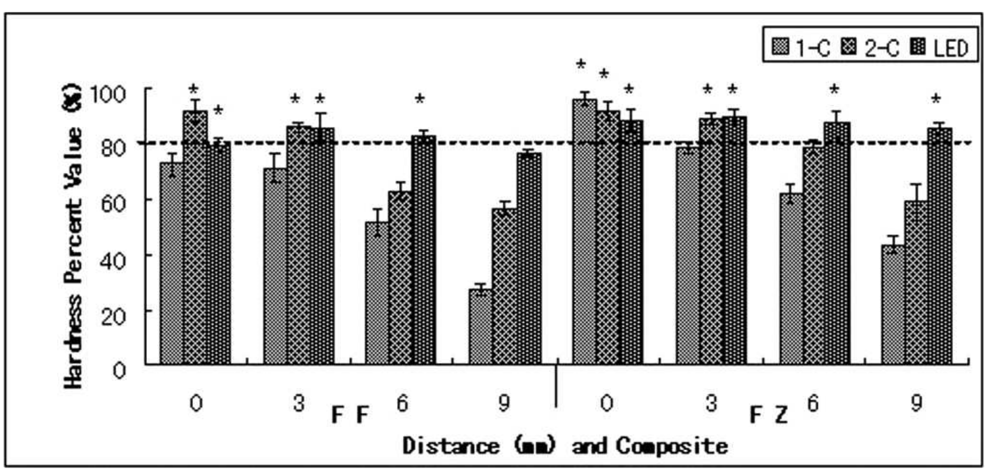


Figure 3. *Mean bottom to maximum mean top hardness percent value of Filtek™ Supreme Plus Flowable Restorative (FF) and Filtek™ Z250 (FZ) composites. Asterisks indicate values that are greater than 80% and statistically different from those of the other groups with the same mode (p<0.05). 1-C, one AutoFocus function cycle; 2-C, two AutoFocus function cycles; LED, LEDemetron I light.*

tive sensitivity, microleakage, secondary caries, and even pulp inflammation.[39-41]

Flowable composites are characterized by reduced filler loading and decreased viscosity. The lower viscosity is designed to facilitate their use as liners; fissure sealants; or, in areas of difficult access or flow, such as irregular internal surfaces, Class V and small Class III restorations.[42-48] Little information is available with regard to the R-values of curing light tips and the DC expected within flowable composites used as the bottom layer of a restoration. The reported power densities of the curing lights in these studies were only 400 mW/cm$^2$.[49,50] A study[14] has indicated that curing light sources with power densities of 400–500 mW/cm$^2$ were not able to adequately polymerize some resin composites with a thickness of 2 mm, even at a curing tip distance of 0 mm, after the specimens were stored for 24 hours. Thus, it is questionable to make conclusions about flowable composite liners and microleakage without ensuring that the liner is completely polymerized.[50]

According to the 24-hour results of the present study for flowable composites, the LEDemetron I light was able to polymerize a 2 mm–thick specimen with the light guide tip 6 mm from the top surface of the composites. Two cycles of the Mini LED AutoFocus were able to polymerize 2 mm when the tip was 3 mm from the surface. The distances between the light tips and the cavity floors can be 5 mm to 8 mm. In clinical applications, two cycles of the Mini LED AutoFocus could be recommended for the 5 mm–deep cavities since this mode would save several seconds of curing time (double five to seven seconds) when compared to using the LEDemetron I light for 20 seconds. The LEDemetron I light could provide adequate hardness percent values at a 9-mm distance when using hybrid resin composites and at a 6-mm distance with flowable resin composites. The possible explanations for this difference between materials include the following: the experimental flowable resin composites may be less photosensitive than the hybrid composites, which would result in compromised polymerization at the bottom surfaces of the specimens; and the degree of conversion of flowable resin composites may vary in relation to the material composition and cannot be generalized to all flowable resin composites. For the hybrid composites, a 2 mm–thick specimen was adequately cured with the light guide tip 9 mm from the top surface of the materials for the LEDemetron I light, 3 mm for the two cycles of the Mini LED AutoFocus, and 0 mm for one cycle of the Mini LED AutoFocus. This finding indicates that the LEDemetron I light could cure some hybrid resin composites at a relatively long curing distance.

## CONCLUSIONS

Under the conditions presented in this study, it has been demonstrated that 1) an automatic increase in the exposure time of a high-intensity LED with a turbo tip and an autofocus capability does not result in similar KHN for the top or bottom surface of a 2-mm increment of resin composite as distance increases to 9 mm; and 2) an automatic increase in the exposure time of a high-intensity LED with a turbo tip and an autofocus capability does not result in similar hardness percent values for the tested resin composites as distance increases to 9 mm.

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