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Composite Resin Microhardness: The Influence of Light Curing Method, Composite Shade, and Depth of Cure

Camila Silveira de Araújo, DDS, MS;
Marcelo Thomé Schein, DDS, MS;
Cesar Henrique Zanchi, DDS, MS;
Sinval Adalberto Rodrigues Jr., DDS, MS, PhD;
Flávio Fernando Demarco, DDS, PhD

Abstract

Aim: The aim of this study was to investigate the influence of light curing method, composite shade, and depth of cure on composite microhardness.

Methods and Materials: Forty-eight specimens with 4 mm of depth were prepared with a hybrid composite (Filtek Z-100, 3M ESPE); 24 with shade A1 and the remaining with shade C2. For each shade, two light curing units (LCUs) were used: a quartz-tungsten-halogen (QTH) LCU (Optilight Plus - Gnatus) and a light emitting diode (LED) LCU (LEC 470 II - MM Optics). The LED LCU was tested using two exposure times (LED 40 seconds and LED 60 seconds). After 24-hour storage, three indentations were made at mm depth intervals using a Knoop indenter. Data were submitted to three-way analysis of variance (ANOVA) and Tukey's test ($p<0.05$).

Results: The three factors tested (light curing method, shade, and depth) had a significant influence on the composite microhardness ($p<0.05$). All groups presented similar hardness values in the first mm, except for composite shade C2 cured with LED for 40 seconds. The hardness decreased with depth, especially for shade C2 for 40 seconds. Increasing light-curing time with LED produced hardness values similar to the QTH.

Conclusions: The light curing method including variations of time, the depth of cure, and the composite shade influence the composite microhardness.

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Clinical Significance: Clinicians should avoid thicker increments when working with composite restorations. Extended light-curing time might be indicated depending on the composite shade and on the light-curing device.

Keywords: Composite resin, hardness, shade, polymerization, light-curing unit, LCU, light emitting diode, LED

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Introduction

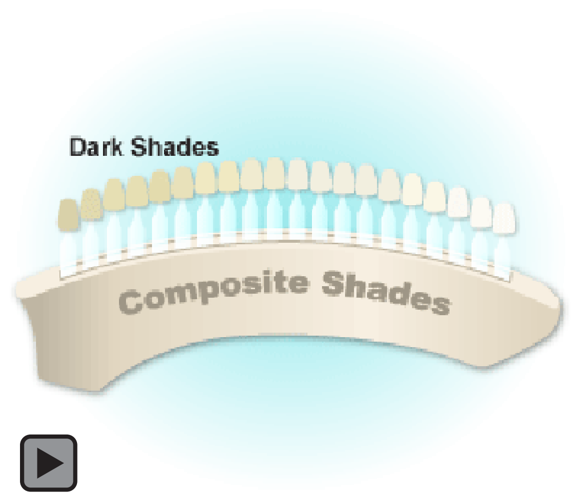
The development of new technologies have improved composite resin restoration survival to more than 17 years[1] and has decreased the annual failure rate to 2.2%, which is similar to dental amalgam.[2] The degree of conversion (DC) of the composite is an important aspect related to the durability of the restorations because it is directly related to the physical and mechanical properties of the material.[3] The DC depends upon factors such as monomer structure, amount and type of filler particles, composite shade,[4] light curing time, irradiance, and depth.[5]

The polymerization process generates a polymer network through the substitution of the carbon double links (C=C) by simple covalent links (C-C). The DC, which is represented by the reduction of the C=C rate, has been shown to maintain a direct relationship with the composite resin microhardness[3,5] so a hardness test can be used to indirectly evaluate it.[3] The polymerization starts with the excitation of the camphoroquinone molecules by the blue light corresponding to a spectrum range of 400-500 nm. The absorption peak of the camphoroquinone is around 470 nm. Thus, the narrower the light spectrum is around this peak, the more effective the polymerization will be.

The quartz-tungsten-halogen (QTH) light-curing units (LCUs) still are the most employed curing devices in clinical practice. Their light is produced through the incandescence of a light filament and it presents a wide range of wavelengths requiring a filter to select only the spectrum corresponding to the blue light. The use of these LCUs along time initiates a degradation process of the device due to the generation of heat and damage to the bulb, the reflector, and the filter reducing the life-span of these units considerably.

The light emitting diodes (LEDs) have been considered as an alternative technology to the QTH devices since they present some advantages over the conventional halogen lamps. LEDs produce blue light eliminating the need for a selective filter. In addition, the blue light is produced in a narrower spectrum very close to the 470 nm of the camphoroquinone absorption peak. Furthermore, as no filtering process is present, the heat generated by the first generation LEDs is very low and the life span of these LCUs is considerably higher (about 10,000 hours) than QTH devices.[6] On the other hand, these first generation LEDs only present a low light power density resulting in concern about the degree of conversion of the composites and the longevity of the restorations cured with them.[7] Increase in light-curing time could overcome the low light intensity, thus, improving the composite properties.[8,9]

Concerns remain about the effectiveness of this new technology when used with dark shade composites. The effect of the shade is negligible.[11]



The basic composite insertion and polymerization protocol usually recommends the use of increments not thicker than 2 mm to guarantee an effective polymerization. Further, the light guide should be as close as possible to the composite surface to guarantee the light will not be dissipated. However, some clinical situations present a real challenge to the utilization of these recommended polymerization techniques, such as accessing the floor of Class II proximal boxes where the distance between the light guide and the material surface is generally greater.[12] For such situations, the increase of the light-curing time has been strongly recommended.[9]

Thus, the aim of this study was to evaluate the influence of the light curing method, the composite shade, and the polymerization depth on composite microhardness.

Methods and Materials

Sample Preparation

Rectangular metallic split molds were used to produce the specimens. The inferior part of the molds contained eight grooves (2 mm of height X 2.2 mm of width X 4 mm of depth) transversely distributed in their upper surfaces where the specimens were inserted, allowing the evaluation of the hardness up to 4 mm of depth (Figures 1A and B). A polyester strip was positioned between the upper and lower parts of the mold to guarantee the superficial smoothness of the composite for the microhardness evaluation. The composite was inserted with a Teflon spatula to completely fill the grooves then light cured through the lateral face of the mold with the light guide placed as near as possible to the composite surface (Figure 1C).

Forty-eight specimens of the hybrid composite resin Filtek Z-100 (3M ESPE, St. Paul, MN, USA) were prepared either with shade A1 (batch #2LR) or shade C2 (batch #2KP). Light curing was performed using either a QTH LCU (Optilight Plus, batch #4139246043, Gnatus Ltda., Ribeirão Preto, SP, Brazil) or a first generation LED LCU (LEC 470 II, batch #FL0159, MM Optics Ltda., São Carlos, SP, Brazil) according to the exposure time regimens depicted in Table 1. The power

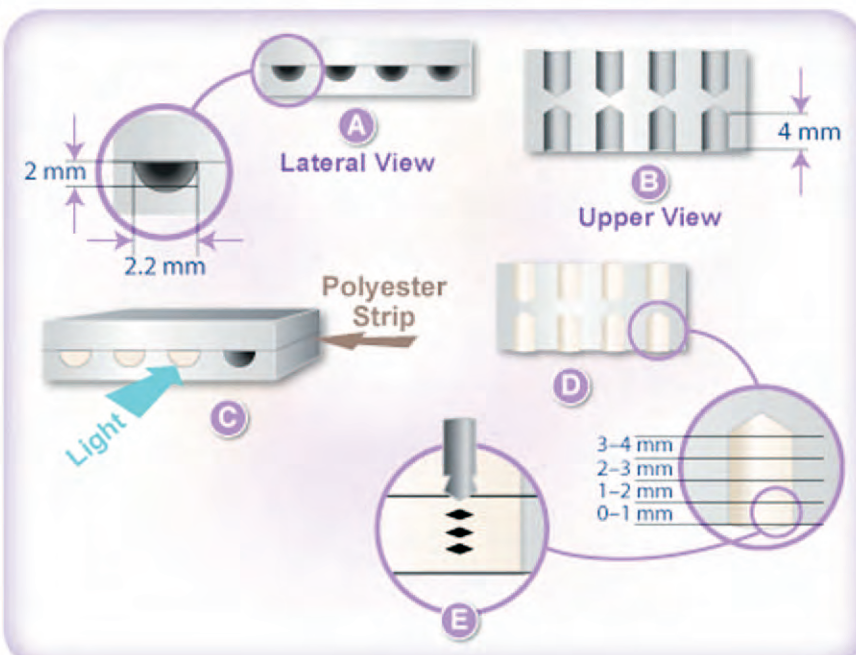


Figure 1. A. Lateral view of the bipartite mold employed in the study showing the ten grooves and their lateral extension. The grooves are 2 mm high and 2.2 mm wide. **B.** Upper view of the inferior part of the mold and the length of the grooves (4 mm) which simulates the depth. **C.** View of the insertion mode and polymerization of the composite. **D.** Division of the specimen in 4 mm for the hardness test. **E.** Indentation performed in the upper surface of the specimen, in each of the four millimeters, before and after the storage in ethanol.

Table 1. Groups division, light sources, manufacturers, light intensity, exposure times, and number of specimens.

Commercial brand	Light Source	Manufacturer	Light Intensity (mW/cm^2)	Shade	Exposure Time(s)	N
Optilight Plus	QTH	Gnatus Ltda®	500	A1	40	8
Optilight Plus	QTH	Gnatus Ltda®	500	C2	40	8
Lec 470 II	LED	MM Opitcs Ltda®	130	A1	40	8
Lec 470 II	LED	MM Opitcs Ltda®	130	C2	40	8
Lec 470 II	LED	MM Opitcs Ltda®	130	A1	60	8
Lec 470 II	LED	MM Opitcs Ltda ®	130	C2	60	8

density of both LCUs was constantly measured using a radiometer (Model 100 - Demetron Research Corp., Danbury, CT, USA - batch #118568).

Hardness Measurement

The specimens were stored for 24 hours in distilled water in a dark environment at room temperature. Following storage, their upper surfaces were divided in 4 mm depth intervals with a razor blade: 0-1, 1-2, 2-3, and 3-4 mm (Figure 1D). The Knoop hardness test was performed with a miniload hardness tester (Durimet, Ernst Leitz, Wetzlar, Germany). Three indentations were made in each millimeter interval with a 50 g load for 30 seconds.

Statistical Analysis

Statistical analysis was performed with a three-way analysis of variance (ANOVA) and Tukey's test. The tests were conducted at a significance level of 5%.

Results

ANOVA revealed the composite microhardness was influenced by the three factors tested: light-curing method, shade, and depth ($p<0.01$). The interaction between the three factors tested was also significant ($p<0.05$).

Table 2 shows the mean hardness values (KHN) at each depth in each tested group. All the groups presented similar hardness in the first millimeter, except the composite shade C2, when light cured with LED for 40 seconds. As expected, an inversely proportional relationship between hardness and depth was detected. The deepest regions (>2 mm) exhibited lower composite hardness values, regardless of the tested condition (Figure 2). In several situations the A1 shade presented higher hardness values when compared to the C2 shade. Generally, the increase in light curing time with a LED from 40 to 60 seconds enhanced the hardness values, producing similar results to those specimens polymerized with a QTH light.

Discussion

Different techniques can be used to evaluate the degree of conversion of composites, such as the Fourier's transformed infrared spectroscopy,[3,13-16] micro-raman,[4,5] and microhardness.[3,13-14] Rueggeberg and Craig[18] showed there is a direct correlation between the degree of conversion and the composite hardness.

The present study demonstrated the light curing method, the depth of cure, and composite shade significantly influenced the microhardness of composite. The increase of depth reduced the composite's hardness. However, in the superficial areas there was no significant difference between the groups (Table 2), excepting for the darker shade (C2) polymerized by a LED LCU for 40

Table 2. Mean (SD) Knoop hardness values (KHN) in each mm for the different conditions tested.

	QTH				LED 40				LED 60			
	A1		C2		A1		C2		A1		C2	
0-1 mm	110 (3)		106 (3)		102 (7)		84 (4)		107 (7)		103 (6)	
	a	A	a	A	a	A	a	B	a	A	a	A
1-2 mm	103 (9)		94 (5)		87 (9)		70 (5)		97 (8)		89 (5)	
	a	A	b	A	b	AB	b	C	a	A	b	A
2-3 mm	93 (4)		72 (6)		63 (9)		46 (7)		77 (10)		57 (12)	
	b	A	c	B	c	BC	c	C	b	B	c	C
3-4 mm	53 (8)		34 (4)		30 (1)		24 (2)		50 (8)		38 (7)	
	c	A	d	B	d	B	d	BC	c	A	d	B

*Small letters indicate statistical groupings within the columns; capital letters refer to statistical groupings in the lines. Different letters indicate statistical differences between groups ($p < 0.05$).

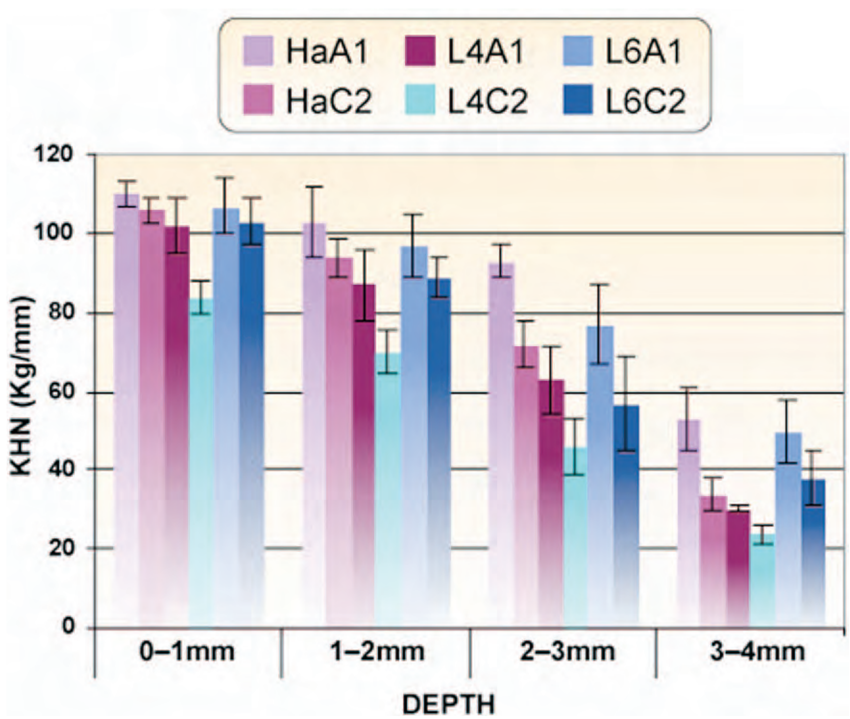


Figure 2. Knoop hardness values (KHN) for the different tested conditions in each mm.

seconds. The similar hardness results observed in the superficial areas of the composite might be explained by the fact the light easily excites the surface of light-cured composites. However, with the increase of composite depth part of this light is spread, absorbed, or its passage becomes more difficult because of the increase of density of the polymer formed which reduces the activation of camphorquinone molecules.[3,13] Our results corroborate previous studies that have shown the reduction of hardness with the increase of depth.[10] Tsai et al.[8] showed a lower degree of conversion was obtained in a depth up to 2 mm. In another study the depth of cure for almost all light-curing methods was not greater than 2 mm. These findings strongly suggest clinicians should avoid the application of thicker layers of composite during restoration placement.

The comparison of both light-curing units (QTH and LED), with the same light activation time (40 seconds), revealed the LED LCU generally produced lower hardness values, mainly for the darker composite shade. According to Hofmann et al.[19] LED LCUs produce a narrow light spectrum, closer to the camphoroquinone excitation peak which could lead to a higher degree of conversion, even at a low power density. Cefaly et al.[9] comparing LED and QTH LCUs found no significant differences in the Z100 top hardness values. In the same study the bottom hardness was lower when the composite was light-cured with LED and increased when the exposure time increased from 40 to 60 seconds. In the present study the increase of time could have compensated for the lower power density produced by the first generation LED LCU. In a previous study the same first generation LED (LEC 470 II) produced lower hardness values than the conventional QTH lamp (Optilux) on top and bottom surfaces of different composite disks, while this was not observed when second generation LEDs were used.[20] In fact, Park et al.[7] comparing different LCUs concluded second generation LEDs and the conventional QTH LCU polymerized composites more effectively than first generation LEDs. Therefore, clinicians should increase the light-curing time when using first generation LEDs to improve the composite's mechanical properties.

The composite shade was also an influential factor on microhardness. Apparently, the darker shade (C2) influenced the passage of the light through the composite, and the light power density produced by the LED LCU (130mw/cm^2) was not enough to reach a minimum degree of conversion. Davidson-Kaban et al.[21] pointed out that darker shades require a higher power density than the light or translucid shades during the light curing process. On the other hand, when the light-curing time with LED was increased to 60 seconds, the results obtained were very similar to the other groups. Furthermore, the shade effect could also be observed in depth. C2 specimens did not improve hardness in deeper regions compared to the other groups using either the LED LCU with increased light-curing time or the QTH LCU. The results confirm observations made by Aguiar et al.[10] who reported higher hardness values for the composite shade A1 in comparison with C2. On the other hand, Martins et al.[11] found no significant difference when testing different composite shades (A3, B3, C3, D3, and I). However, Dickinson et al.,[22] when analyzing the wear of composite with pigments and a translucid composite (Incisal), verified composite with no pigments was more resistant to wear. The authors of this study attributed this higher performance to the higher light penetration ensuring a more effective polymerization. Perhaps when using a darker shade clinicians should increase the light-curing time aiming to improve the degree of conversion and the mechanical properties of the composite.

Currently, several light-curing units are available in the market. Clinicians should exercise caution when choosing these devices because many of them present low power density, sometimes insufficient to reach an adequate polymerization level.[23]

Conclusions

Within the limitations of this study, it is possible to conclude:

1. The light curing method, the polymerization depth, and the shade influenced significantly the composite microhardness.
2. Using the LED LCU for 40 seconds generally produced significantly lower hardness values when compared to the QTH LCU for the same light-curing time. Increasing the LED light-curing time to 60 seconds improved the composite hardness similar to the QTH LCU.

Clinical Significance

Clinicians should avoid thick increments of material when placing composite restorations. Extended light-curing time should be considered depending on the composite shade and on the light-curing method.

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About the Authors

Camila Silveira de Araújo, DDS, MS

Dr. Araújo holds a Master of Science degree in Epidemiology and is a Research Fellow in the postgraduate program in Operative Dentistry at the Federal University of Pelotas, RS, Brazil.

Marcelo Thomé Schein, DDS, MS

Dr. Schein is an Assistant Professor in the School of Dentistry at the University of Joinville (UNIVILLE), SC, Brazil.

Cesar Henrique Zanchi, DDS, MS

Dr. Zanchi is a PhD student in Operative Dentistry in the School of Dentistry at the Federal University of Pelotas, RS, Brazil.

Sinval Adalberto Rodrigues Jr., DDS, MS, PhD

Dr. Rodrigues is a Substitute Professor in Operative Dentistry in the School of Dentistry at the Federal University of Pelotas, RS, Brazil.

Flávio Fernando Demarco, DDS, PhD

Dr. Demarco is an Associate Professor in the Department of Operative Dentistry of the School of Dentistry at the Federal University of Pelotas, RS, Brazil.

e-mail: fdemarco@ufpel.edu.br or flavio.demarco@pesquisador.cnpq.br