DENTAL-3156; No. of Pages 11
ARTICLE IN PRESS
DENTAL MATERIALS XXX (2018) XXX–XXX

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.intl.elsevierhealth.com/journals/dema

Effect of light curing units on the polymerization of bulk fill resin-based composites

Carlos Alberto Kenji Shimokawa [a], *Míriam Lacalle Turbino* [a], *Marcelo Giannini* [b], *Roberto Ruggiero Braga* [c], *Richard Bengt Price* [d,*]

[a] *University of São Paulo, School of Dentistry, Restorative Dentistry, São Paulo, São Paulo, Brazil*
[b] *University of Campinas, Piracicaba Dental School, Restorative Dentistry, Piracicaba, São Paulo, Brazil*
[c] *University of São Paulo, School of Dentistry, Biomaterials and Oral Biology, São Paulo, São Paulo, Brazil*
[d] *Dalhousie University, Faculty of Dentistry, Dental Clinical Sciences, 5981 University Ave., Halifax, Nova Scotia, B3H 4R2, Canada*

ARTICLE INFO

Article history:
Received 14 February 2018
Received in revised form
15 April 2018
Accepted 2 May 2018
Available online xxx

Keywords:
Dental curing lights
Composite resins
Hardness tests
Polymerization

ABSTRACT

Objective. To determine the potential effect of four different light curing units (LCUs) on the curing profile of two bulk fill resin-based composites (RBCs).
Methods. Four LCUs (Bluephase 20i, Celalux 3, Elipar DeepCure-S and Valo Grand) were used to light cure two RBCs (Filtek Bulk Fill Posterior Restorative and Tetric EvoCeram Bulk Fill). The effective tip diameter, radiant power, radiant emittance, emission spectrum and light beam profile of the LCUs were measured. Knoop microhardness was measured at the top and bottom surfaces of RBC specimens that were 12-mm in diameter and 4-mm deep ($n = 5$). The distribution of the spectral radiant power that was delivered to the surface of the specimen and the light transmission through the 4-mm thick specimens was measured using an integrating sphere. Two-way ANOVA and Tukey tests ($\alpha = 0.05$) were applied.
Results. The Valo Grand produced the most homogeneous microhardness across the surfaces of the RBCs ($p > 0.05$). When the Celalux 3, Bluephase 20i and Elipar DeepCure-S lights were used, the center of the specimens achieved greater hardness values compared to their outer regions ($p < 0.05$). Approximately 10% of the radiant power delivered to the top reached the bottom of the specimen, although almost no violet light passed through 4 mm of either RBC. A positive correlation was observed between the radiant exposure and microhardness.
Significance. The characteristics of the LCUs influenced the photoactivation of the RBCs. The use of a wide tip with a homogeneous light distribution is preferred when light curing RBCs using a bulk curing technique.

1. Introduction

The manufacturers of bulk fill resin-based composites (RBCs) claim that it possible to successfully photo-cure 4 or even

* *Corresponding author.*
E-mail addresses: carlos.shimokawa@usp.br (C.A.K. Shimokawa), miturbin@usp.br (M.L. Turbino), giannini@fop.unicamp.br (M. Giannini), rrbraga@usp.br (R.R. Braga), richard.price@dal.ca (R.B. Price).
https://doi.org/10.1016/j.dental.2018.05.002
0109-5641/© 2018 Published by Elsevier Inc. on behalf of The Academy of Dental Materials.

Table 1 – Information provided by the manufacturers about their light curing units.

Light curing unit	Manufacturer	Stated irradiance (mW/cm^2)	Emission spectrum (nm)	Stated tip diameter (mm)
Bluephase 20i (sn: P626170S548780)	Ivoclar Vivadent, Amherst, NY, USA	1200 (±10%)	385–515	8
Celalux 3 (sn: 1637091)	VOCO, Cuxhaven, Germany	approx. 1300	450–480	8
Elipar DeepCure-S (sn: 933112-001111)	3M Oral Care, St. Paul, MN, USA	1470 (−10%/+20%)	430–480	10
Valo Grand (sn: MFG3277-5)	Ultradent, South Jordan, UT, USA	1000 (±10%)	395–480	12

5-mm increments of RBC instead of the customary 2 mm increment. While this approach may introduce less voids between each increment and reduce overall treatment times, the ability to adequately photo-cure such a large volume of RBC in one exposure is a concern.

Many types of light curing units (LCUs) are available for dentists to purchase. The spectral radiant power, light tip diameter, and radiant emittance (tip irradiance) from these LCUs are often different and this may have a negative impact on the ability of these units to photo-cure RBCs [1–3]. Although camphorquinone is currently used in all RBCs, some RBCs also include alternative photoinitiators requiring activation by lower wavelengths of light. These RBCs benefit from the use of a broad spectrum light source that delivers violet light as well as blue light [4–6]. However, since the lower wavelengths of light (in the violet range) do not penetrate as far into the RBC as the longer wavelengths of blue light, the alternative photoinitiators in the deeper regions may receive an insufficient amount of the lower wavelengths of light and the RBC may remain undercured in the deeper parts of the RBC [7,8].

The homogeneity, or the lack of thereof, of the emitted light beam with respect to the radiant emittance and spectrum of light across the RBC surface, can affect the polymerization of the RBC. Additionally, the effective light tips of some LCUs are 7 mm or less in diameter, and multiple light exposures are required to fully cover the entire restoration with light [3,9]. This is not a concern if an incremental RBC filling technique is used, since even small tips are able to cover the entire increment. However, with the introduction of bulk fill RBCs manufacturers have promoted filling the entire cavity with a single portion of RBC and then curing the restorations with one light exposure. When LCUs with small diameter light tips are used to light cure large restorations in molar teeth, any RBC that is not covered by the light tip may be inadequately polymerized.

Several studies have evaluated the depth of cure of bulk fill RBCs at the center of the specimens [10,11], but none has verified the adequacy of both the depth and the width of cure of the bulk fill RBCs when using different LCUs. Therefore, this study determined the light output characteristics of four different LCUs and investigated their ability to light cure two bulk fill RBCs in one exposure. The null hypotheses were:

1. There will be no difference between the light emitting characteristics of the four LCUs;
2. The effective tip diameters and light beam homogeneity of the LCUs will not influence the curing profile of the two bulk fill RBCs;
3. The emission spectra of the LCUs will not influence the curing profile of the two bulk fill RBCs;
4. There will be no correlation between the radiant exposure delivered and the microhardness results.

2. Methods

The details of the four light emitting diode (LED) LCUs (Bluephase 20i, Celalux 3, DeepCure-s, Valo Grand) are reported in Table 1. These LCUs were used to photo-cure two commonly used bulk fill resin-based composites: Filtek Bulk Fill Posterior Restorative – A2 (3M Oral Care, St. Paul, MN, USA) and Tetric EvoCeram Bulk Fill – IVA (Ivoclar Vivadent, Amherst, NY, USA).

2.1. *Characterization of the LCUs*

The light tip diameter, radiant power, radiant emittance, emission spectrum and light beam profile of the four LCUs were analyzed. Both the external and the internal fiber to fiber tip diameters were measured with a digital caliper (Mitutoyo, Kawasaki, Kanagawa, Japan). The effective tip diameter from where light could be emitted was taken to be the maximum fiber to fiber distance. For the Valo Grand, the diameter of the lens was used as the effective tip diameter (Fig. 1).

Five measurements of the total radiant power (mW) emitted between 350 and 550 nm and spectral radiant power (mW/nm) from each LCU were measured using a 6″ integrating sphere (Labsphere, North Sutton, NH, USA) that was attached to a fiber-optic spectrometer USB4000 (Ocean Optics, Dunedin, IL, USA). An internal traceable light source inside the SCL-600 sphere (Labsphere) was used to calibrate the system before the measurements were made. When measuring the LCUs, the tip of the LCU was positioned 2-mm from the 16-mm aperture into the sphere and all the light that was emitted from the LCU was captured by the sphere. The radiant emittance for each LCU was calculated as the quotient of the radiant power and the effective tip diameter values shown in Fig. 1.

The light beam profiles from the LCUs were evaluated using a Laser Beam Profiler (Ophir Spiricon, Logan, UT, USA). This device uses a digital camera with a 50-mm focal distance lens (USB-L070, Ophir Spiricon) positioned at a fixed distance from a 40-degree holographic screen (Edmund Industrial Optics, Barrington, NJ, USA). A custom-made blue filter (International Light Technologies, Peabody, MA, USA) was used to flatten the spectral response of the camera and BeamGage v.6.6 software (Ophir Spiricon) was used to determine the photonic count received by each camera pixel. With the 40° holographic screen positioned 2-mm away from the light tip, the distribution of the radiant power was recorded for each LCU. In addition, to evaluate the distribution of the violet light (~400 nm) only, the beam profile was also recorded through a 400 nm narrow band-pass filter (Edmund Industrial Optics) with a full width half