Journal of Dentistry 53 (2016) 44–50

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.intl.elsevierhealth.com/journals/jden

Transmission of violet and blue light through conventional (layered) and bulk cured resin-based composites

J.E. Harlow[a], F.A. Rueggeberg[b], D. Labrie[c], B. Sullivan[a], R.B. Price[a,*]

[a] Dental Clinical Sciences, Dalhousie University, P.O. BOX 15000, Halifax (NS), B3H 4R2, Canada
[b] Department of Oral Rehabilitation, Section of Dental Materials, Dental College of Georgia, Augusta University, Augusta, GA, United States
[c] Department of Physics and Atmospheric Science, Dalhousie University, P.O. BOX 15000, Halifax (NS), B3H 4R2, Canada

ARTICLE INFO

Article history:
Received 6 April 2016
Received in revised form 8 June 2016
Accepted 28 June 2016

Keywords:
Restorative dentistry
LED curing lights
Product design
Emission spectrum
Light transmission through dental resins
Incremental (layered) vs. bulk filling and bulk curing resins

ABSTRACT

Objectives: This study measured the transmission of light in the 'violet' ($350 \leq \lambda \leq 425$ nm) and 'blue' ($425 < \lambda \leq 550$ nm) spectral ranges from a polywave® LED curing light through different thicknesses of four commercial, resin-based composites (RBCs).
Material and methods: Samples of conventional layered RBCs (Tetric EvoCeram A2, Filtek Supreme Ultra A2B), and bulk-curing resins (Tetric EvoCeram Bulk Fill IVA, and SureFil SDR Flow U) were prepared. Three samples of each RBC were made at thicknesses of 0.1, 0.7, 1, 2, and 4-mm. The uncured RBC specimens were affixed at the entrance aperture of a 6-inch integrating sphere and light-cured once for 20 s using a polywave® LED curing light (Bluephase G2) on its high power setting. The spectral radiant power transmitted through each RBC in the 'violet' and 'blue' regions was measured using a fiberoptic spectrometer.
Results: As RBC thickness increased, an exponential attenuation of transmitted light was measured ($R^2 > 0.98$). Attenuation was greater for the 'violet' than for the 'blue' spectral regions. At the light tip, the violet light component represented 15.4% of the light output. After passing through 4-mm of RBC, the violet light represented only between 1.2–3.1% of the transmitted light depending on the RBC. Depending on RBC, approximately 100 mW from the Bluephase G2 was transmitted through 0.1-mm of RBC in the 'violet' range, falling at most to 11 mW after passing through 2-mm of RBC, and to only 2 mW at 4-mm depth.
Conclusions: Increasing RBC thickness results in an exponential decrease in light transmission. This attenuation is RBC-dependent with shorter wavelengths (violet) attenuated to a greater extent than longer wavelengths (blue).
Clinical relevance: Despite the increased translucency of bulk curing RBCs, spectral radiant power shorter than 425 nm from a curing light is unlikely to be effective at a depth of 4-mm or more.

1. Introduction

Resin-based composites (RBCs) and light curing units (LCUs) have become an essential part of contemporary dentistry to the extent that the process of light curing generates most of the dentist's income. With the introduction of bulk-filling/bulk-curing RBCs, some manufacturers claim that their RBCs can be adequately photo-cured in up to 6-mm thick increments [1]. The most common photoinitiator used in RBCs is camphorquinone (CQ), which is a Type II photoinitiator having a maximum absorbance close to 468 nm [2]. When exposed to light of the appropriate wavelengths, CQ absorbs a photon to generate a short-lived, excited-state species that complexes with the tertiary amine to promote a sequential electron and proton transfer, which creates the active α-aminoalkyl-initiating radical [2]. Some manufacturers have now added a Norrish Type I monoacylphosphine oxide photoinitiator, Lucirin-TPO or derivatives of dibenzoyl germanium (Ivocerin®), to their resins. These initiators are considered Type 1 compounds that undergo a unimolecular reaction upon light exposure, and, because they have a greater quantum yield than CQ, they have the potential to increase the depth of cure [2–8]. The majority of the alternative Type I initiators used in dentistry are more sensitive to light shorter than 420 nm [5,6,9], although the

* Corresponding author at: Department of Dental Clinical Sciences, 5981 University Avenue, Faculty of Dentistry, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada.
E-mail addresses: Jessie.Harlow@Dal.Ca (J.E. Harlow), frueggeb@augusta.edu (F.A. Rueggeberg), daniel.labrie@dal.ca (D. Labrie), Braden.Sullivan@Dal.Ca (B. Sullivan), rbprice@dal.ca (R.B. Price).

http://dx.doi.org/10.1016/j.jdent.2016.06.007
0300-5712/

recently introduced benzoylgermanium initiators exhibit good activation potential up to 450 nm [2].

Some manufacturers are now producing light emitting diode (LED) curing lights that contain two or more different wavelengths of LED emitters (broad banded, multi-peak, multi-wave) in order to deliver both the shorter (violet) wavelengths to activate Type I initiators, and longer wavelengths (blue) to activate CQ [10,11]. Although these broad-band LCUs should be more compatible with a wider range of photoinitiators, they may not be the ideal choice for large or bulk-cured RBC restorations. This is because the spatial positioning of the different LED emitters within the LCU means that not all regions of the emitting surface deliver similar wavelengths, and this affects the uniformity of light output [12,13]. If the LCU is held stationary, this inhomogeneity can affect the quality of resin polymerization [12,14–16] such that a strong, positive correlation exists between beam profile irradiance values and both the hardness and elastic modulus values across the surface, as well as within the depths of a RBC [12,14,15].

Several studies report that, as RBC thickness increases, overall, exponentially fewer photons reach the bottom surface of the RBC [17–20], but the effect of a 4-mm thickness of RBC on the transmission of specific wavelengths of light is not well recognized. With the suggestion that broad-spectrum LED units can be used to cure RBCs that claim a 4-mm or more depth of cure [1,21,22], it is necessary to know how specific regions of LCU emission spectrum have the potential to interact with the RBC photoinitiators, as the thickness of the RBC increases beyond the customary 2-mm.

2. Objectives

This study compared the transmission of the 'violet' ($350 \leq \lambda \leq 425$ nm) and 'blue' ($425 < \lambda \leq 550$ nm) components of light emitted from a broad-spectrum polywave® LED curing light through five thicknesses (0.1–4-mm) of two conventional (layered) filling, and two bulk-curing RBCs. The null hypotheses are:

(1) There will be no differences in attenuation of 'violet' and 'blue' light through different thicknesses of two conventional and two bulk-curing RBCs,
(2) The normalized emission spectrum seen after passing through cured RBC will not be different from the emission spectrum at the LCU tip.

3. Materials and methods

3.1. LCU light output

A six-inch integrating sphere (Labsphere, North Sutton, NH, USA) connected to a fiberoptic spectrometer (USB 4000, Ocean Optics, Dunedin, Fla, USA) was used to measure the spectral radiant power and the photon count from a polywave® LED light curing unit (Bluephase G2, Ivoclar Vivadent, Amherst, NY, USA) used on its high power setting for 20 s. The LCU was positioned at the 16-mm diameter entrance aperture of the integrating sphere with the integration time of the spectrometer adjusted to provide the best signal-to-noise ratio.

3.2. Emitted light transmitted through the RBCs

Light from the LCU transmitted through different thicknesses of two conventional and two bulk-curing RBCs was then measured in real time during the light curing process. Supplemental Table 1 lists the manufacturer's information [21–24] about the RBCs used in the study. Tetric EvoCeram A2 (TEC) and Filtek Supreme Ultra A2B (FSU) are conventional RBCs, intended for placement and photocuring in up to 2-mm thick increments, while Tetric EvoCeram A2 (TECBF) and SureFil SDR U (SDR) are designed for bulk-filling and bulk-curing in up to 4-mm thick increments. One of each type of RBC was a CQ-only system (FSU and SDR), while the other two RBCs contained multiple photoinitiators (TEC and TECBF).

RBC specimens of 0.1, 0.7, 1, 2, and 4-mm thickness were prepared. The 0.7, 1, 2, and 4-mm thick specimens were prepared in metal rings having a 12-mm internal diameter hole. The 0.1 mm specimens were prepared between two Mylar cover slips without a ring. To produce flat top and bottom surfaces, all samples were covered with Mylar cover slips on either side and were pressed between two glass slabs. The uncured RBC samples were affixed at the entrance port of the integrating sphere, and the RBC was light-cured on the high setting for 20 s at 0 mm distance. The spectral radiant power and the photon count transmitted through each RBC was measured in real-time using software (Spectrasuite, Ocean Optics) and reported at 1-s, 5-s, and at the end of the 20-s exposure. The total power and the number of photons transmitted in the 'violet' ($350 \leq \lambda \leq 425$ nm) and 'blue' ($425 < \lambda \leq 550$ nm) spectral regions were determined. Three replicates were prepared for each RBC at each thickness (total = 60 specimens).

3.3. Beam profile of light transmitted through the RBCs

The light beam profile of 'violet' and 'blue' light transmitted measured through cured RBC was also measured using a laser beam profiler camera, as previously described [12,13,25]. Three specimens of each RBC were cured in rings that were 0.5, 1, 2, 3, and 4-mm thick with a 12-mm diameter internal aperture. The LCU guide tip was then placed on one side of the cured RBC and the transmitted light beam was examined from the other side using a profile camera having a 50 mm focal length lens (USB-L070, Ophir-Spiricon, Logan, UT, USA) with a custom made blue filter from International Light Technologies, Peabody, MA, USA to flatten the spectral response of the CCD camera. Separate images of the transmitted light beam were taken through narrow bandpass filters that had a 10-nm full width half maximum bandwidth centered at either 410 nm or 450 nm (Items #65-679 and #65-685, Edmund Industrial Optics, Barrington, NJ, USA). The resulting images were collected using Beamgage v 6.6 software (Ophir-Spiricon, North Logan, UT, USA).

4. Spectral data analysis

To compare effect of RBC thickness on the location of the peak spectral radiant power output under the different conditions, the emission spectra from the LCU and the specimens were analyzed using nonlinear, curve fitting software (Fityk v 0.9.8, http://fityk.nieto.pl) [26]. To minimize residuals, a split Pearson VII analysis was selected to fit the violet and blue peak emissions. The Pearson VII function is represented by equation 1:

$$y = \frac{a_0}{\left[1 + \left(\frac{x - a_1}{a_2}\right)^2 \left(1^{1/a_3} - 1\right)\right]^{a_3}} \quad (1)$$

where fitting parameters are: a_0 = peak height (mW), a_1 = center wavelength (nm), a_2 = half width half maximum (HWHM), and a_3 = shape

Using this split function takes into account peak asymmetry and allows the left and right sides of a peak to be fitted independently, and then matched at the center. There is a common a_0 and a_1 (height and center) for each peak, but distinct HWHM and shape parameters are applied for each side of the emission peak, as