DENTAL MATERIALS 30 (2014) 1345–1357

Available online at www.sciencedirect.com

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

Correlation between the beam profile from a curing light and the microhardness of four resins

Richard B.T. Price[a,*], *Daniel Labrie*[b], *Frederick A. Rueggeberg*[c], *Braden Sullivan*[a], *Ivan Kostylev*[b], *John Fahey*[d]

[a] *Dental Clinical Sciences, Dalhousie University, Halifax, NS, Canada*
[b] *Department of Physics and Atmospheric Science, Dalhousie University, Halifax, NS, Canada*
[c] *Department of Oral Rehabilitation, College of Dental Medicine, Georgia Regents University, Augusta, GA, USA*
[d] *Biostatistician, Halifax, Nova Scotia, Canada*

ARTICLE INFO

Article history:
Received 14 April 2014
Received in revised form
29 July 2014
Accepted 7 October 2014

Keywords:
Light curing units
Beam uniformity
Irradiance beam profile
Localized spectral emission
Resin photopolymerisation
Photoinitiators
Knoop microhardness
Computer-assisted image processing

ABSTRACT

Objective. To demonstrate the effect of localized irradiance and spectral distribution inhomogeneities of one LED-based dental light-curing unit (LCU) on the corresponding microhardness values at the top, and bottom surfaces of four dental resin-based composites (RBCs), which contained either camphorquinone (CQ) alone or a combination of CQ and monoacylphosphine oxide (TPO) as photoinitiators.

Methods. Localized irradiance beam profiles from a polywave LED-based LCU were recorded five times using a laser beam analyzer, without and with either a 400 nm or 460 nm narrow bandpass filter placed in front of the camera lens. Five specimens of each of the four RBCs (two containing CQ/TPO and two containing CQ-only) were exposed for 5-, 10-, or 30-s with the light guide directly on the top surface of the RBC. After 24 h, Knoop microhardness values were measured at 45 locations across the top and bottom surfaces of each specimen. Microhardness readings for each RBC surface and exposure time were correlated with localized patterns of the LCU beam profile, measured using the 400 nm and 460 nm bandpass filters. Spearman rank correlation was used to avoid relying on an assumption of a bivariate normal distribution for the KHN and irradiance.

Results. The local irradiance and spectral emission values were not uniformly distributed across the light tip. There was a strong significant positive correlation with the irradiance beam profile values from the LCU taken through bandpass filters and the microhardness maps of the RBC surfaces exposed for 5 and 10 s. The strength of this correlation decreased with increasing exposure time for the RBCs containing CQ only, and increased for the RBCs containing both CQ and TPO.

Conclusions. Localized beam and spectral distributions across the tip end of the light guide strongly correlated with corresponding areas of microhardness in both the top and bottom surfaces among four RBCs with different photoinitiator contents.

Significance. A light-curing unit with a highly inhomogeneous light output can adversely affect localized microhardness of resin-based composites and this may be a contributing factor for premature failure of a restoration.

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[*] *Corresponding author at*: Department of Dental Clinical Sciences, Dalhousie University, Halifax, Nova Scotia, B3H 4R2, Canada. Tel.: +1 902 494 1226; fax: +1 902 494 1662.

E-mail address: rbprice@dal.ca (R.B.T. Price).

http://dx.doi.org/10.1016/j.dental.2014.10.001
0109-5641/

1. Introduction

More than two hundred sixty million direct resin-based composite (RBC) restorations are placed annually worldwide [1]. Premature failure of these restorations will have significant health and financial implications. Several recent reports indicate that the median longevity of posterior RBCs placed in dental offices worldwide is close to a mere 6 years [2–4]. A recent Cochrane review reported that posterior RBCs are almost twice as likely to fail as amalgam restorations [5]. The two most common causes of failure are secondary caries and bulk fracture. [2,5–7] Both these outcomes may be the result of inadequate photo-polymerization of the RBC, which is known to adversely affect both the RBC properties and the bond strength between the RBC and preparation walls [8–17]. Thus it is important to examine the likely causes of inadequate photo-polymerization of RBC restorations.

To ensure optimal photo-polymerization of the RBC, the radiant exposure and spectral range requirements of the RBC must be fulfilled by the radiant output from the light-curing unit (LCU), while avoiding damage to the oral tissues caused by excessive temperature increases [17–20]. The most commonly used photosensitizer in RBCs is camphorquinone (CQ). However, CQ is bright yellow and it only moderately photobleaches upon exposure to a LCU when using clinically relevant times [21,22]. Alternative photoinitiators that are not as chromogenic as CQ are used by some RBC manufacturers [17,19,20,23–26]. These alternative photoinitiators, such as monoacylphosphine oxide (TPO) and derivatives of dibenzoyl germanium [26–28], have peak absorbance values below 420 nm [19,25–30]. Consequently, these photoinitiators will not be efficiently activated by monowave LED-based LCUs that deliver light mostly in the 445 nm to 480 nm spectral range [17,19,20,31–33]. Although these alternative photoinitiators are more reactive than CQ, fewer of these photons will reach the bottom of the RBC due to the effects of filler particle size and increased Rayleigh scattering of the lower wavelengths of light [19,31,34–38].

Manufacturers do not commonly list all the photoinitiators or the exact filler particle sizes used in their products [19,23,39] making it difficult to predict the performance of narrow band, single-peak blue LED-based LCUs on a specific brand of RBC. To overcome this limitation, third-generation, polywave blue–violet LED-based LCUs have been introduced [29,31] that claim to polymerize all resin-based restorations. These blue–violet LCUs use a combination of up to three different "colors" of LED chips, with spectral emissions peaking near 440–460 nm (blue) and near 400–410 nm (violet) [29,31,32,40–43].

Differences in the light outputs among LCUs are often not readily detectable by visual inspection, nor by a "dental radiometer". The ISO 6050 standard for calculating irradiance from a LCU assumes that the irradiance and spectral emission profile of the LCU light beam are homogeneous and can be fully characterized by a single irradiance value [44,45]. Similarly, the ISO 11405 bond strength test [46] and the ISO 4049 depth of cure tests [47] assume that light output from the LCU is uniformly distributed and that the specimen will receive the same irradiance and spectrum of light across its entire surface. It is now well established that the irradiance distribution from many dental LCUs can be very inhomogeneous [40,41,48–51] and this inhomogeneity can cause non-uniform polymerization of the RBC [49,50,52]. Additionally, there is a problem with the method used to calculate the irradiance – the physical diameter of the light guide is used instead of the functional diameter of the light beam within the light guide [44,45] which will produce an erroneously low averaged irradiance from the LCU. These shortcomings in the standards lead to incorrect and misleading irradiance and depth of cure values being stated by both manufacturers and researchers alike.

As early as 1983, researchers were reporting discrepancies in the uniformity of the beam profiles of UV curing lights [53]. Laser beam analyzers are now commonly used to measure the distribution of power across light beams and the dimensions of the functional diameter of that light beam [40,41,48,49,51,54,55]. Use of these more sophisticated beam analyzers has shown that the problem of irradiance inhomogeneity has been further compounded by the introduction of polywave blue–violet LED-based LCUs. For one area of the light tip, the relative contributions of the violet and blue portions of the emitted radiation spectrum to the total irradiance at that point can be dramatically different from another, such that some regions only deliver blue light (~450–470 nm) and some only violet light (~400–410 nm) [40,41]. Additionally, these units deliver a wide range of irradiance values that can vary by more than a factor of 10 across their tip ends.

The combination of polywave LED units and resins using multiple photoinitiators that absorb different wavelengths, and use different filler particle sizes complicates research on dental resins. TPO is highly reactive to wavelengths less than 420 nm [25,26,30,33,56] and therefore requires a lower irradiance to achieve the same degree of conversion as a CQ containing resin. Therefore, the commonly used averaged irradiance and spectral emission across a LCU cannot fully describe the result the light output has on resin polymerization. Instead, the relative interactions of these inhomogeneous light outputs at the specific locations across resin surfaces that contain different filler particle sizes should be considered.

Surface microhardness using Knoop indenters is a reliable method to determine an important material property of the cured RBC [57], and a strong positive correlation exists between the degree of monomer conversion and microhardness value [58–60]. Such microhardness measurements are often taken 1-mm apart across the surface of the specimen [24,25,49,50,61]. Microtensile bond strength test specimens are commonly sectioned into 1 mm^2 sticks [62,63] and a previous study showed how the irradiance from a LCU can be reported within specified 1 mm^2 regions across the light guide tip [41].

The purpose of this study is to use this technique [41] to correlate specific irradiance beam profile values taken through narrow bandpass filters centered at 460 and 400 nm with the microhardness values measured within the same targeted region. The research hypotheses tested were that (1) the localized microhardness maps across the top and bottom surfaces