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Localised irradiance distribution found in dental light curing units

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ABSTRACT

Objective: To measure the localised irradiance and wavelength distributions from dental light curing units (LCUs) and establish a method to characterise their output.
Methods: Using a laboratory grade integrating sphere spectrometer system (Labsphere and Ocean Optics) the power, irradiance, and spectral emission were measured at the light tips of four LCUs: one plasma-arc (PAC) unit, one single peak blue light-emitting diode (blue-LED) unit, and two polywave LED (poly-LED) units. A beam profiler camera (Ophir Spiricon) was used to record the localised irradiance across the face of the light tips. The irradiance-calibrated beam profile images were then divided into 45 squares, each 1 mm^2. Each square contained the irradiance information received from approximately 3200 pixels. The mean irradiance value within each square was calculated, and the distribution of irradiance values among these 45 squares across the tip-ends was examined. Additionally, the spectral emission was recorded at various regions across each light tip using the integrating sphere with a 4-mm diameter entrance aperture.
Results: The localised irradiance distribution was inhomogeneous in all four lights. The irradiance distribution was most uniformly distributed across the PAC tip. Both the irradiance and spectral emission from the poly-LED units were very unevenly distributed.
Conclusions: Reporting a single irradiance value or a single spectral range to describe the output from a curing light is both imprecise and inappropriate. Instead, an image of both the irradiance distribution and the distribution of the spectral emission across the light tip should be provided.
Clinical significance: The localised beam irradiance profile at the tip of dental LCUs is not uniform. Poly-LED units may deliver spectrally inhomogeneous irradiance profiles. Depending on the photoinitiator used in the RBC and the orientation of the LCU over the tooth, this non-uniformity may cause inadequate and inhomogeneous resin polymerisation, leading to poor physical properties, and premature failure of the restoration.

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1. Introduction

Light-activated resins must not only receive sufficient energy, but they must also receive this energy within the appropriate wavelength range in order that sufficient numbers of free radicals are produced for adequate polymerisation.[1–3] When insufficient free radicals are produced, inadequate polymerisation occurs and this will adversely affect the properties of resin-based composite (RBC) restorations. Clinically, inadequate polymerisation can be associated with complications such as increased discolouration,[4] increased marginal defects,[5] decreased hardness,[6–11] decreased flexural and fracture strengths,[12,13] decreased dynamic elastic modulus,[14] decreased resistance to abrasive wear,[15] decreased bond strength,[16,17] and decreased biocompatibility of the restoration.[18–20] These complications are often only considered to result in changes to the bulk property of the restoration as a whole. However, because there are localised differences in the irradiance and spectral emission within the light beam,[10,21–27] a spatially inhomogeneous distribution of light will be received by the resin-based restoration. As a direct consequence of different regions within the restoration receiving different irradiance, energy and wavelengths of light, this discrepancy may cause localised differences in the extent of polymerisation, as well as the rate of reaction.[1,2,9,10,22,23,27–32]

Several intrinsic factors can influence the degree of conversion of RBCs, including thickness, shade and translucency, type of photoinitiator, filler particle composition and filler content.[1,3,8,11,29,33] Other factors may be related to characteristics of the light curing unit (LCU): irradiance (intensity), light exposure duration, radiant exposure, emission spectrum (wavelengths emitted), tip end temperature rise, type of light guide, and distance between the light guide tip and the RBC.[6,11,13–16,24,25,33–37] The requirement that the spectral output from the LCU should be matched to the wavelength-dependent photosensitivity of the photoinitiator[1,2,6,10,30,38,39] was not an issue when quartz–tungsten–halogen (QTH) units were popular, because these units can deliver a broad spectral emission, ranging from ~375 to ~510 nm that is evenly distributed across the tip of the LCU.[25] The same is true for at least one broad-spectrum plasma arc curing (PAC) light unit.[9,25] More recently, light-emitting diode (LED) units have been introduced and they are rapidly replacing QTH and PAC units in dental offices.[40–42] Early LED units produced only a narrow spectral emission, with the majority of output delivered in the blue spectral region between 450 and 470 nm.[25,38,40,41] These wavelengths are very effective in polymerising RBCs that contain camphorquinone (CQ) as their sole photoinitiator, since the peak absorbance of CQ is close to 470 nm.[1,2] However, CQ is bright yellow and photobleaches only slightly upon exposure using a LCU for clinically relevant times.[41,43] This can create chromatic difficulties when CQ is used in translucent or very light shades of RBCs.[38] To overcome this problem, alternative photoinitiators that are not as chromogenic as CQ are used by some resin manufacturers.[1,30,41,44] These alternative photoinitiators, such as monoacylphosphine oxide (Lucirin TPO), derivatives of dibenzoyl germanium,[45,46] and 1-phenyl 1,2-propanedione (PPD), have peak absorbance values below 420 nm. Thus, these initiators are not efficiently activated by single peak LED units that deliver blue light mostly in the 440–470 nm range.[1,9,10,16,40,41] Unfortunately, manufacturers do not commonly list all of the photoinitiators used in their products.[1,29,38,47] This lack of information makes it difficult to predict the performance of a narrow band, single-peak LED unit on a specific brand of RBC. To compensate for this limitation, third-generation polywave LED-curing lights have been introduced and they claim to cure all resin-based restorations.[40,41,48,49] These LCUs use a combination of different wavelength LED chips to produce a broader spectral output that covers both the wavelengths needed by CQ and the shorter wavelengths below 420 nm required by the alternative initiators.[9,10,25,40,41]

The common methods used to describe the output from a dental LCU are both imprecise and inappropriate.[50,51] The output from a dental LCU is usually stated as a single irradiance value,[48,49] leading one to believe that all portions of the light beam at the tip end will deliver close to this value. Additionally, the current ISO standard 10650 for testing curing lights requires the light output to be measured in three broad spectral ranges (below 385 nm, between 400 and 515 nm, and above 515 nm), using a thermopile with appropriate filters. The irradiance is then calculated from the quotient of the radiant power values and the optical area of the light tip end.[52] This method assumes that the radiant power and the spectral emission are uniformly distributed across the light tip. However, this rarely occurs,[21,22,24–27] and the presence of inhomogeneity in the light beam may adversely affect the localised polymerisation of a resin-based restorative material upon which the beam falls.[10,21–27,30,34]

The need to report the beam uniformity from medical lasers has been understood for more than 10 years,[53] but only recently has the importance of measuring the beam uniformity from dental LCUs been recognised.[23–25,34,41] Beam profilers provide a qualitative assessment of a light source and can quantitatively characterise the quality of the light beam. The beam profile is usually measured using a digitising camera that reports the irradiance values received by each pixel on a digital image of the light beam. This level of detail provides a much more detailed description of the light output compared to reporting a single average irradiance value from across the entire light tip.

Localised differences in irradiance and wavelength distribution can have a significant impact on the relevance of measurements made to describe the properties of a light cured RBC.[10,22–27,41] For example, some regions across the light tip may deliver a high irradiance and other regions may deliver a low irradiance with a completely different spectral emission. The ISO standard 4049 for measuring the depth-of-cure does not expose the RBC to all of the light emitted from the LCU tip, but instead uses a metal mould having a 4-mm diameter opening that is held directly against the distal end of the light guide tip.[54] Thus, if any inhomogeneity is present in the light beam, the resin in the mould will not receive the average irradiance or spectral emission from the LCU and the test may produce misleading results.

Although it is recognised that there will be some dispersion of the light within the RBCs, somewhat mitigating the effect of beam inhomogeneity, the beam profile has been reported to be mirrored in the microhardness distribution across the RBC.[22,23,27] Such microhardness measurements are often taken