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Literature Review

Contemporary Issues in Light Curing

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Clinical Relevance

Clinicians should not take for granted what appears to be the easy task of light curing. Evidence-based steps are provided that will help clinicians improve their light curing technique.

SUMMARY

This review article will help clinicians understand the important role of the light curing unit (LCU) in their offices. The importance of irradiance uniformity, spectral emission, monitoring the LCU, infection control methods, recommended light exposure times, and learning the correct light curing technique are reviewed. Additionally, the consequences of delivering too little or too much light energy, the concern over leachates from undercured resins, and the ocular hazards are discussed. Practical recommendations are provided to help clinicians improve their use of the LCU so that their patients can receive safe and potentially longer lasting resin restorations.

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INTRODUCTION

Premature failure of resin restorations has great health and financial implications. According to the most recent ADA Survey of Dental Services Rendered,[1] at least 146 million resin-based composite (RBC) restorations and sealants are placed annually in the USA. Worldwide more than two hundred sixty one million direct RBC restorations are placed annually.[2] Several reports indicate that the median longevity for posterior resin-based restorations placed in dental offices is only about 6 years[3-5] with the primary reasons for replacement being secondary caries and bulk fracture of the resin.[2,3,5-7] A recent study[8] of 2,318 Class II resin composite restorations and 1,691 Class II amalgam restorations placed in the student clinic at an American dental school reported that the RBC restorations were 10 times more likely to fail prematurely and require replacement than amalgam restorations. The authors speculated that improper positioning of the curing light may have contributed to these failures.

Appropriate light curing of the entire restoration is a basic requirement when placing RBCs; however, the role of the dental light curing unit (LCU) is an often misunderstood and undervalued part of the procedure in many dental offices.[9,10] There is a need for training and guidance in this aspect of primary dental care.[9,11-13] The energy and spectral requirements of the RBC must be matched to the output from the light curing unit (LCU) to ensure optimal polymerization but limit excessive temperature increases within the pulp chamber.[14,15] There is ample indirect evidence that undercured resins are a significant cause of restoration failure due to fracture, secondary caries, or excessive wear of the restoration.[13,16-30] Additionally, when dental RBCs are not optimally cured (and thus do not reach a sufficient degree of monomer conversion), they are more likely to leach toxic substances.[31-42] At the same time, since light curing delivers energy that causes a temperature increase in the tooth and surrounding oral tissues,[13-15,43-51] arbitrarily increasing exposure times in an effort to prevent under-curing may damage the pulp and surrounding tissues.

Contemporary LCUs deliver a wide range of spectral emissions and irradiance levels.[10,15,36,51,52] These differences among LCUs are often not detectable by the eye,[53] nor accurately by a dental radiometer, but they can affect the polymerization of the RBC. According to Jandt and Mills,[50] light emitting diode (LED) LCUs have become the gold standard for photopolymerization of resin based dental materials. Using the current literature, this article will present evidence to help clinicians understand the important issues to consider when choosing and using a curing light, so their patients can receive safe and potentially longer-lasting resin restorations.

Definitions: The following radiometric terms will be used in this article:[54]

Term	Units
Radiant Flux or Power	Watt (W)
Radiant Energy (Power x Time)	Joule (J)
Irradiance (sometimes incorrectly called power density)	Watt/Area (W/m^2)
Radiant Exposure (Irradiance x Time) (sometimes incorrectly called energy density)	Joule/Area (J/m^2)

1. THE LIGHT CURING UNIT (LCU)

a) A Single Irradiance Value?

Previous studies[23,24] have reported that a quartz-tungsten-halogen (QTH) unit must deliver a minimum irradiance between 300 to 400 mW/cm^2 to adequately polymerize a 1.5-to 2-mm thick increment of resin composite. The light output from a LCU is usually reported in terms of a single irradiance value.[55-58] However, this output is not uniformly distributed over the end of the light tip,[10,59-64] and so providing only a single value may be very misleading.[62,65] Conventional methods of measuring the light output from a LCU, such as using a thermopile or an integrating sphere, measure the total power emitted and then divide this power by the tip area to provide an average irradiance value at the tip. These methods do not detect how uniform the light beam is and do not show if there are 'hot spots' across the tip end of the LCU. For example,[62] one LED unit delivers an average tip-end irradiance of 1129 mW/cm^2, but the beam profile shows that at the light tip there are 'hot spots' delivering an irradiance in excess of 4,500 mW/cm^2 and 'cold spots' delivering less than 100 mW/cm^2. If the light is held steady, this may result in some of regions of the resin receiving an inadequate amount of energy when light curing.

b) Spectral Emission

The spectral emission from the LCU and the spectral requirements of the RBC should be matched both to ensure optimal polymerization[50,52,66] and to minimize intra pulpal temperature increases.[15] If the LCU is a QTH unit, the spectral emission is sufficiently broad to adequately polymerize any dental RBC material. Most LED units produce a very narrow spectral emission[10,15,50,59,64] and are usually optimized to activate the commonly used camphorquinone photoinitiator that has highest absorption at ~468 nm.[50] Because some RBCs use alternative photoinitiators that require shorter wavelengths (~410 nm), it is possible to use a LED unit that is not ideally matched to the RBC.[15,52,66,67] Recently, "polywave" LED units (with 2 or more spectral peaks) have been introduced that use two or more different colors of LED, meaning that their spectral output ranges from blue (~460 nm) to violet wavelengths (~410nm) of light. These lights can polymerize RBCs containing both conventional and alternative photoinitiators. However, in some of these "polywave" LED units the spectral emission is not uniformly distributed across the light tip, further compounding the effects of beam inhomogeneity.[59] Thus, some areas of the resin may not receive the required wavelengths. Until the manufacturers of dental LCUs address the problem of beam inhomogeneity from their LCUs, the light tip should be moved around by a few millimeters when light curing.[10] This movement should compensate for the non-uniform irradiance and spectral distributions from the LCU, however the light exposure time will have to be increased at the risk of overexposing some of the oral tissues, unless carefully managed.[10]

c) Effect of Distance

In some LCUs, the irradiance may be high close to the tip but declines rapidly as the distance from the tip end increases.[26,63,64,68-70] Most Class II resin restorations fail at the gingival portion of the proximal box.[71] This is the region that is the most difficult to reach with the LCU and is furthest away from the light source.[68,72] Consequently, the resin here will receive the least amount of light and may be undercured.[13,26,63,64,68,69] Manufacturers should provide data that reports the output or performance of the LCU not only at 0 mm distance from the tip, but also at clinically relevant distances.[70] Some manufacturers and researchers are now starting to provide this information.[13,26,43,56,63,64,68-70] Ideally, the LCU should deliver a well collimated beam of light with minimal reduction in irradiance over clinically relevant distances (up to 8 mm from the tip).

d) Monitoring the LCU

Dental LCUs should be monitored on a regular schedule.[10,50,53] A South African study reported a 100% satisfaction level by dentists with the performance of their LCUs, although nearly half of their units delivered an inadequate output when tested.[12] Whilst it is recognized that the output from QTH units diminishes as the light source and filter age, it is less known that the output from LED units can also decline with age or as a result of misuse.[10,50] Every study of LCUs in use in dental offices has reported that many of these LCUs deliver less than 400 mW/cm^2, most likely due to inadequate maintenance.[12,53,73-77] The introduction of higher power LCUs has not reliably solved the problem of inadequate light output because many light guides on LCUs are either damaged or covered with resin contaminant.[73-76,78,79] Although hand-held dental radiometers are affected by beam inhomogeneity and are inaccurate,[10,80-83] they can be of practical benefit when used to monitor the time-based performance of the same LCU/light guide combination over time.[10,79] Depth of cure scrape tests carried out by the dentist[18] can also be used to evaluate the performance of their light. These two evaluative methods can be used to monitor the LCU and adjust exposure durations to help ensure optimal and predictable light curing results.[18]

e) Infection Control Methods

The LCU can be a source of cross contamination among patients.[78,84,85] Best practice from a cross-infection viewpoint is met by LCUs that have removable, autoclavable light guides and easily disinfected surfaces. Autoclaving light guides may produce "boiler scale" across the light tip of the LCU that reduces the light output.[86] Also, some disinfection solutions may reduce the light transmitting ability of glass-fibered light guides.[87] Since surface disinfectants may degrade the LCU plastic case, lenses, reflectors, fiberoptic light guide, and electronics over time,[78,87,88] care needs to be taken to use the appropriate disinfectant recommended by the manufacturer. LCUs with textured, non-watertight (non-blistered) activation buttons are particularly difficult to clean and can retain microbes between the button and the LCU body. A barrier to prevent cross-infection must be used to cover LCUs with these types of buttons. These plastic barriers will reduce the irradiance from the LCU, so the light exposure time must be increased accordingly.[89-92]

2. RECOMMENDED LIGHT EXPOSURE TIMES

Both light and resin manufacturers' recommendations for light exposure times are often based on a "best case" scenario using a new LCU, a known material thickness, and ideal laboratory conditions where the LCU is stabilised directly over the RBC.[13,24,93,94] Even under these "best case" conditions, some exposure times are deemed to be too short by some dental researchers using objective test methods.[15,18,24,94-97] The manufacturer's instructions usually take no account of the diversity of clinical situations, where the dentist may be using a LCU in a location where it is difficult for the operator to hold the LCU steady, close, and normal to the RBC surface throughout the entire light exposure time.[13,98] Also, curing depths within the RBC will vary significantly depending on the material composition, shade, and light output characteristics of the LCU.[15,52,60,66,99,100] Although some manufacturers recognize this fact, for example one manufacturer recommends light exposure times of 5 to 40 seconds[55] to effectively light-cure different shades and types of their own RBCs, dentists may choose one exposure time and then use it for all shades and situations. Depending on the situation, this may deliver either too much or too little energy to the RBC.

Furthermore, many LCUs are marketed as requiring only a short exposure time,[58] some as short as one second, because they deliver such a high irradiance.[57] This advice incorrectly assumes that similar material properties can be achieved when the same radiant exposure is delivered, regardless how high the irradiance or how short the exposure time, but this is not always the case.[18,94-97,101] There is concern that rapid light curing of dental resin may increase polymerization contraction stress and decrease the bond strength of resins to the tooth.[28,102-106] Current information indicates that the effects of using different light exposure modes are highly dependent on the specific material used, the LCU, and the clinical situation.[94,97]

3. OPERATOR TECHNIQUE

Operator technique will affect the radiant exposure delivered to the RBC.[11,13,107,108] To maximize the amount of energy delivered, the operator should wear appropriate eye protection. They can watch what they are doing to ensure that the LCU is held both close to and perpendicular to the restoration.[98] Positioning the light tip at 45° to the surface of the restoration will result in a 56% reduction in the amount of energy received by the restoration.[98] A recent study using correctly functioning LCUs tested the ability of 20 dental professionals to deliver adequate energy to simulated restorations in a dental mannequin. Having established 10 J/cm^2 as the minimum radiant exposure required for the bottom of 2 mm thick specimens of Filtek Supreme A2B (3M ESPE, St. Paul, MN) to reach 80% of the top hardness value,[98] the radiant exposures delivered by 20 operators were measured. Using the same LCUs for the same exposure times, there was a large variation among the radiant exposures delivered by the operators with 27% of clinicians delivering less than 10 J/cm^2 to the same simulated Class I restoration, and 82% delivering less than 10 J/cm^2 to the same posterior Class V restoration.[107] Recent studies have shown that this variability can be reduced and radiant exposure improved by providing immediate feedback on how much irradiance and energy was delivered together with instruction on how to avoid mistakes using a patient simulator.[11,98] A similar study from Germany[108] has shown that using proper technique that includes correctly positioning the patient to improve access and ensuring that the LCU is optimally positioned throughout the light curing process, are critical factors for delivering sufficient energy to a restoration.

4. CONSEQUENCES OF DELIVERING TOO LITTLE ENERGY

Delivering too little light energy to the RBC may account, at least to some extent, for the high incidence of early failure of large posterior direct resin-based restorations provided in dental offices due to secondary caries and bulk fracture.[3,5-8] Indirect evidence suggests that the poor clinical performance of many resins seen daily by dentists (e.g., recurrent marginal caries, bulk fracture, bulk and marginal discoloration, loss of anatomical form, and lack of retention) may be related to the failure to deliver sufficient light to adequately cure the resin. Numerous laboratory studies have been published showing impaired mechanical and physical properties,[13,16,17,19-22] weaker bonding to the tooth,[25,26,29] increased bacterial colonization of the resin,[30] and reduced color stability[109,110] in RBCs that have received insufficient curing energy. One clinical study that placed light-cured RBC restorations in denture teeth[20] verified that a purposely undercured resin restoration showed significantly increased and clinically unacceptable occlusal wear after only 2 years.

5. POTENTIAL TOXICITY OF UNDERCURED RESINS

Inadequately polymerized RBCs will have a lower degree of monomer conversion and consequently greater potential to leach toxic substances.[31-42] One study evaluated the cytotoxic potential of RBCs on primary human gingival fibroblast cultures.[39] For each resin, as the percentage of monomer conversion increased, cellular toxicity decreased. Another study assessed the release of bisphenol A (BPA) from an orthodontic adhesive that was light cured at various distances from the light curing tip and correlated the release of BPA to the degree of resin conversion.[41] They found that resins exposed at the 5 and 10 mm away from the LCU tip were significantly less well cured and released significantly more BPA compared to those cured at 0 mm from the light tip. In a recent study, three nano-hybrid RBCs were exposed to light for varying amounts of time. A strong inverse correlation between the degree of conversion and elutable substances from the RBCs was found.[40] The authors emphasized the importance of an adequate light exposure (20 s or 40 s), because shorter exposure times (5 s or 10 s) resulted in a lower degree of conversion and eluted greater amounts of toxic substances in these RBCs. These studies show that for health reasons alone, the RBC should be adequately light cured.

6. HAZARDS OF DELIVERING TOO MUCH ENERGY

Clinicians are taught to avoid unnecessary trauma to the pulp and would not prepare vital teeth without adequate water coolant to reduce the intrapulpal temperature rise.[111] Light curing a restoration delivers energy to the tooth and surrounding oral tissues that can also cause a temperature increase in these areas, but this temperature rise is often overlooked. The temperature rise that can be tolerated by human dental pulp has been reported to be between 5.5 °C to 11 °C,[112,113] but the effect of heat on the pulpal tissue has only been examined in healthy young dental pulps, or in animal teeth. Heavily restored teeth or teeth traumatized by caries may react differently, but these factors have yet to be determined. When the first generation LED lights were marketed, they were advertised as 'cool' lights that produced less of a temperature rise in the pulp compared to QTH lights.[114-117] This was only true because of the very low power output from the initial versions of these LED units. As the power output from LED units has increased, the potential for generating damaging temperature values in pulp and oral tissues has also increased.[13,43,44,46,47,50,51,118] Leprince et al.[15] assessed the effects of light source characteristics and irradiation time on temperature increase in the pulp chamber of an extracted molar tooth. They reported that the temperature rise increased with longer exposure times and as the LCU light output increased. Where the pulp is at greater risk, such as in deep cavities with little overlying dentin, consideration should be given to the choice of LCU and light exposure program. Also, intrapulpal temperature rise can be minimized by directing a stream of air across the coronal part of the tooth using a syringe or a high-volume suction tip.[119]

Pulpal temperature rise is not only related to the irradiance from the LCU, but also the exothermic polymerization reaction of the light activated resin.[13,45-47,118] Flowable resin composites can generate a higher polymerization exotherm with a greater intrapulpal temperature rise compared to their restorative analogues because of their greater resin content.[47] Thus, the potential for an unacceptable temperature rise is even greater when using flowable resins with high output power LCUs.

In 2012, three clinical cases were reported where a LED curing light burned the lips of patients.[120] Because the patients were anaesthetized, the soft tissue burns were only recognized after the treatment had concluded. It was also reported that the presence of a rubber dam offered no significant protection to soft tissue. The authors recommended that the LCU should be activated over the RBC material only; furthermore, they recommended placing gauze under the rubber dam to reduce heating the soft tissues underneath the rubber dam. This may be difficult to achieve when the cavity margin is close to the gingival tissues such as in a Class V, or the proximal box of a Class II restoration.

7. OCULAR HAZARDS: BLUE LIGHT HAZARD

The dentist has a duty to protect both the patient and employees from harm. Personnel who use LCUs on a daily basis may be at risk for ocular damage from the LCU. While it is well known that UV-A radiation can cause corneal injury or photokeratitis as well as cataractogenesis and transient or permanent opacification of the lens,[121] the blue light from LCUs is particularly damaging to the retina. This Blue Light Hazard is greatest at 440 nm,[122] which is within the output range from dental LCUs.[10,15,51,62] While the natural aversion response of the eye to bright light usually limits single exposures to less than 0.25 seconds, the relatively narrow-band of blue light radiation from LED units does not always evoke this protective aversion response.[123]

Blue light is transmitted through the ocular media and absorbed by the retina. While high levels of blue light cause immediate and irreversible retinal burning, chronic exposure to low levels of blue light may cause accelerated retinal aging and degeneration. This chronic photochemical injury to the retinal-pigmented epithelium and choroid can accelerate age-related macular degeneration (ARMD).[123,124] Most countries follow international guidelines on optical radiation, such as those from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and American Conference of Governmental Industrial Hygienists (ACGIH) for the maximum cumulative permissible exposure to light within an 8-hour period.[122,123] The ACGIH threshold limit for the blue-light hazard is harmonized with the ICNIRP guidelines and the weighted blue-light hazard function, should not exceed 100 J/cm^2-sr over a total viewing time of 167 minutes in an 8 hour day.[122] Previous studies in the 1980's that assessed the hazards from QTH curing lights found that these units had little potential to cause ocular injury.[125,126] However, most lights studied in the 1980's delivered less than 400 mW/cm^2 over a broad spectral range between 400 and 500 nm. Contemporary QTH, high power plasma arc (PAC), and LED curing lights may deliver much higher irradiances, (up to and greater than 5,800 mW/cm^2) and in some lights the peak spectral emission is close to 440 nm.[57-59,62,101,125,127,128] A recent study[129] found that with these LCUs, the ACGIH limits[122] may be reached during an 8 hour workday. If an operator, not wearing orange protective glasses, looked at the light tip for the first second of each curing cycle before looking away, it would take as little as seven light exposure cycles to exceed the maximum daily exposure to the tested PAC light.[129] It should be noted that the maximum recommended exposure time in the ACGIH guidelines is for individuals with normal photosensitivity; patients or dental personnel who have had cataract surgery or who are taking photosensitizing medications have a greater susceptibility to blue light, and retinal damage may occur with shorter exposure times.[122,123] Some blue light filtering glasses ('orange blue-blockers') have been shown to reduce the transmission of light below 500 nm to less than 1%.[125,130,131] When blue light filtering glasses are used, instead of looking away from the bright blue light from the LCU, the operator can safely watch what they are doing when light curing. This will improve the amount of light delivered to the restoration.[11,98,108] Unfortunately, despite the fact that most manufacturers of dental curing lights supply this protective eyewear, these items are not universally used.[132]

EVIDENCE-BASED ADVICE TO CLINICIANS WHEN USING A CURING LIGHT

The following recommendations are provided to help clinicians improve their use of the LCU so that their patients can receive safe and potentially longer lasting resin restorations.

1. Know the properties of your LCU. Does the LCU deliver a homogeneous light output, or will you need to move the light tip around as you cure the resin? How much does the irradiance decrease as the distance from the tip increases, will you need to increase your exposure time in deep preparations? Does the spectral emission from the LCU match the sensitivity of the RBC being used? Is the exposure mode appropriate for the RBC being used, could excessive polymerization contraction stress be generated? Could the high LCU output cause thermal damage to the pulp or soft tissues if not used carefully?
2. Use appropriate infection control on the LCU and adjust exposure time accordingly.
3. Monitor the performance of your LCU and keep a logbook of the output from each LCU from the date of purchase. To guide any adjustments in exposure duration, the dentist can carry out depth of cure scrape tests using different shades of their RBC light-cured at clinically representative distances.
4. Maximize the output from the LCU by examining the light tip for damage and remove remnants of previously cured RBCs. Clean or replace tip as necessary.
5. Protect the eyes of everyone in the operatory who could be exposed to the bright light, with appropriate orange (blue light blocking) safety glasses.
6. Learn how to use the LCU to maximize energy delivered to the RBC. Place the central axis of the tip of the LCU directly over and normal to the RBC surface; the emitting end should be parallel to the RBC surface being exposed. When using a LCU with an inhomogeneous light output, move the light tip around and increase the exposure time. This should also be done where undercuts are present that prevent straight-line access to the RBC. Additionally, in this situation, use supplementary bucco-lingual curing (but beware of overheating).
7. Develop a technique to prevent uncured resin from adhering to the tip of the LCU and thus reducing the light output. For example, begin the exposure with the tip approximately 1 mm away from the RBC. Then, when the top surface of the RBC is hard (after 1 second), move the tip of the LCU as close as possible to the surface of the RBC.
8. Protect the oral mucosa from the light with gauze and air-cool or wait several seconds between each light curing cycle when using a powerful curing light that has the capacity to produce a damaging temperature rise.

CONCLUSIONS

Evidence has been presented to help clinicians understand that the LCU is a vital, yet often misunderstood and undervalued, item of equipment. The choice of LCU and how it is used are important factors in determining whether the patient will receive a safe and potentially longer-lasting resin restoration.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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