Successful Light Curing — Not As Easy As It Looks

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Dentists assume that activating a light-curing device reliably and predictably light cures restorative materials. There are many factors that must be considered when light-curing resin adhesives, resin-based composites, resin cements, etc., to ensure the quality and durability of the restorations being placed. Clinicians have choices in the light-curing devices they use. Despite appearances that all curing lights are adequate, research has demonstrated that not all light-curing devices are equivalent! Recent studies demonstrate that the light probe tip diameter and its orientation can significantly impact the degree of light curing with respect to better physical properties and improved adhesion.[1-9]

The placement of composite resins poses many challenges: adequate isolation, exacting etching parameters, adhesive placement, insertion of leak-free, well-adapted composite, light curing, contouring, adjusting occlusion, finishing and polishing. Light curing, however, is central to insuring the success of the restoration. Under-polymerized adhesives and composites risk premature restorative failure due to reduced bond strengths, microleakage, postoperative sensitivity, pulpal toxicity, recurrent caries, color instability, and increased wear and fracture. Recurrent caries and fracture are two significant consequences from inadequate light curing of composites.[1-9]

Most composite resin or porcelain veneer placement articles elaborate extensively on technique, yet mention only five words: "and then you light cure", for the most critical phase of the technique. Light curing is more complex than those five words. It involves specific devices and techniques, not all of which are equivalent. This article provides an understanding to the successful management of these variables.

MANAGING THE CORE VARIABLES

Light curing has often been perceived to be as simple as using an on and off switch. In some cases, polymerization is delegated to the chairside assistant while the clinician focuses on other aspects of treatment.

Resin composites are light cured when a specific dose of energy is delivered to the resin, with the dosage varying significantly between different brands and shades. While seemingly simple and routine, the process involved is complex. The durability and longevity of the restoration is greatly dependent on the accurate delivery of the energy required to polymerize the resin. Managing four sets of variables (CORE variables) is the key to adhesive clinical success (identified by Dr. Richard Price of Dalhousie University):[10]

1. Curing light
2. Operator's technique
3. Specific restoration characteristics
4. Energy requirement of the composite resin

Understanding the CORE variables associated with light curing develops confidence that restora-

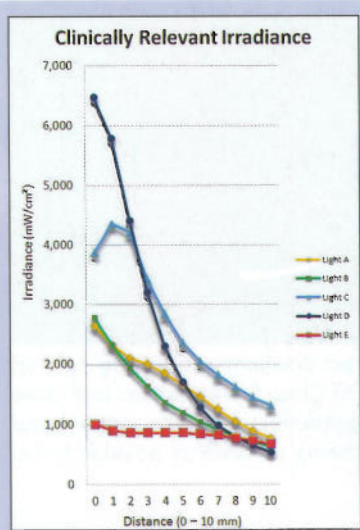

FIGURE 1—Changes in irradiance over distance from light guide.

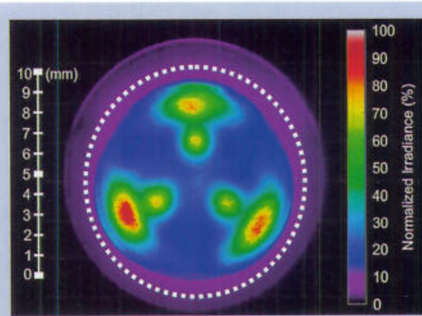

FIGURE 2—Beam profile of 4 different LED curing lights as it relates to an MOD cavity preparation on a premolar. Note that colors represent irradiance. The higher the irradiance the better the light curing (hot spot); the lower the radiance the less likely there will be complete photopolymerization (cold spots).

FIGURE 2B

FIGURE 2C

FIGURE 2D

FIGURE 2E

tions are adequately photo-polymerized, maximizing their clinical durability and success.

Curing Light —the intra-oral performance differences are apparent

Similar to measuring a room to decide how much paint is needed, a curing light must be analyzed. How much energy does a light deliver? Currently, the International Standards Organization (ISO) has very few requirements pertaining to curing light performance, all related to limiting ultra-violet range emissions. No lower or upper limits exist for the intensity of the violet/blue light used to activate the resin photoinitiators. In addition, ISO performance measurements are always taken at the light tip; clinically, the curing light is rarely that close to the composite surface.

Unfortunately, the minimal ISO requirements have resulted in a flood of inexpensive, poorly performing curing lights. The price differential between recognized and tested curing lights and their inexpensive, untested counterparts can be a factor of 10 or more! Evaluations of these very inexpensive curing lights have shown significant operational differences that can greatly impact restoration quality. All curing lights emit blue light, generally in the 400 – 515 nm range, and they have on/off switches. Beyond that, the differences are extensive and substantial.

CHOICES IN CURING LIGHTS

Over the past 2 years, I have worked with Dr. Richard Price at Dalhousie University and BlueLight Analytics Inc. (www.curingresin.com) to investigate curing light differences using scientific measuring devices and techniques. As a member of BlueLight Analytics scientific advisory board, I have seen data for the evaluation of more than 145 different models of curing lights from 42 manufacturers. The prices of these lights range from $27-$4,900, with stated irradiance values ranging from 400-5,000 mW/cm². While irradiance is the most common and easiest technique to measure curing light tip energy, it only provides a small piece of the puzzle for light curing composites. In fact, the in-office curing light radiometers have been shown to be unreliable.[11,12] Recently, more sophisticated instruments have been utilized to

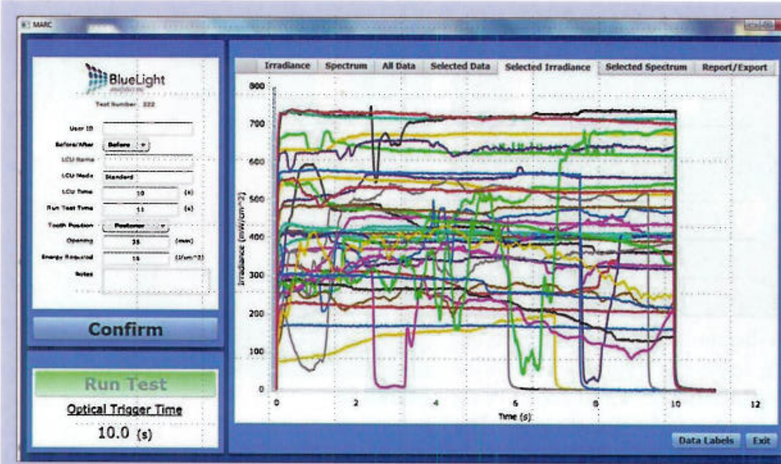

FIGURE 3—Graphic representation of variation in irradiance delivery over curing time of 35 operators.

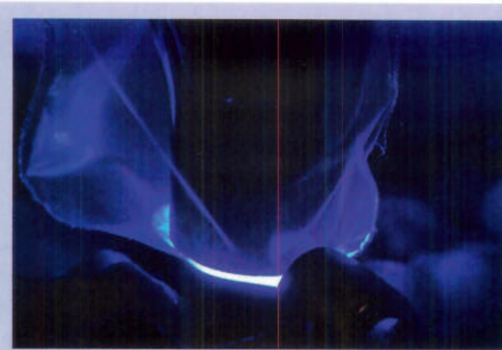

FIGURE 4—Correct positioning of curing light tip perpendicular to Class II preparation and close to the tooth preparation. Note the matrix band interferes with being as close as possible to occlusal surface.

FIGURE 5—Incorrect positioning of the curing light tip. Tip is angled and held too far away from the Class II preparation.

FIGURE 6—Correct positioning of the curing light tip to polymerize a Class V composite resin.

evaluate curing light irradiance and to describe the beam profile. Beam profile refers to the mapping of energy transmission at the surface of the light tip. Some lights deliver power evenly and uniformly over the light tip surface while others have hot and cold spots of energy delivery over the light tip surface delivering energy ununiformly.

Light-curing devices vary greatly:

1. Light source: quartz-halogen, LED, or plasma arc
2. Irradiance: the output at the curing light tip.
3. Recommended curing time
4. Accessory line
5. Curing probe/tip or lens configuration ,
6. Energy source (battery or plug in)
7. Cooling mechanism (if applicable)

The time-reducing competition among manufacturers is fierce; some claim to cure an increment of composite in one second, while others recommend 10-20 seconds. Dentists simply wish to know which curing light should I buy and how long should I light cure so that I am confident that my composites are properly polymerized?

Prior to deciding which curing light to buy, the following manufacturer's data (as well as evidence to that effect) must be analyzed:

1. **What is the irradiance at the curing light tip, and what is the change in irradiance as the tip is moved to a clinically relevant distance of 8 mm from the composite surface?** (Fig. 1). Many curing lights exhibit a rapid drop in irradiance (75 percent or more) over that distance. The practitioner may purchase a seemingly "powerful" curing light that actually cures very little at the composite surface. Consider the high power Light D (center tip irradiance 7,000 mW/cm^2) that delivers the same irradiance as the low power Light E at the clinically relevant distance of 8 mm.

There is a significant challenge in light-curing Class II composite resins at the gingival margin of the proximal box. The clinical implications of inadequate light curing include significantly higher rates of gingival marginal caries when compared to amalgam restorations.[13-15] The reasons for these significant differences can be related to: dentin adhesive technique sensitivity, composite

FIGURE 7—Prepared incisal edges to be restored.

FIGURE 8—Placement of composite resin to restore incisal edges.

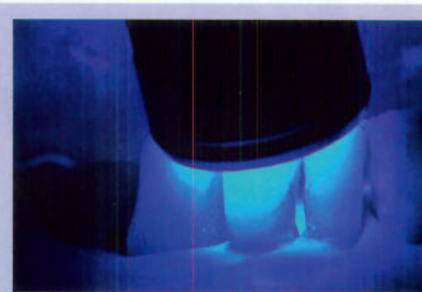

FIGURE 9—Correct orientation and proximity of the light tip to photopolymerize the incisal edge restorations for the mandibular incisors.

FIGURE 10A

FIGURE 10B

FIGURE 10A—Nanohybrid composite resin light-cured in a translucent cylindrical matrix holding the light at right angles to and within a 0.5-mm distance to the cylinder—note the complete depth of cure for the 5-mm length (20 seconds of light-curing with LED curing light measured at 1200 mW/cm^2).

FIGURE 10B—Nanohybrid composite resin light-cured in a translucent cylindrical matrix holding the light at a 45° degree angle and within 0.5-mm distance to the top surface of the cylinder—note incomplete depth of cure for the length and the angle due to the position of the curing light (20 seconds of light-curing with LED curing light measured at 1200 mW/cm^2).

resin polymerization shrinkage, trapped air bubbles leading to poor marginal adaptation, contamination due to poor isolation, poor adhesive and composite polymerization (inadequate curing light output)[16,17] and excessive light guide distance from the gingival margin.[18-20]

Inadequate light curing may, in fact, be a significant culprit for premature Class II composite failure at the gingival margin of the proximal box. The gingival marginal area is the high-risk area for recurrent caries where defects first initiate. Xu and coworkers investigated composite resin adhesion as the distance from the light guide increased, a study prompted by the number of publications demonstrating poor marginal seal and increased microleakage at the gingival margins when compared to the occlusal enamel margins. Their conclusion was that to ensure optimal polymerization of adhesives in deep proximal boxes, the curing time (at 600 mW/cm^2) should be increased to 40-60 seconds.[21] Other researchers have made similar recommendations to increase curing time for initial composite resin increments in proximal boxes, even with 1,000 mW/cm^2 curing lights.[22,23]

2. **What is the curing light's beam profile? Is the irradiance evenly distributed across the guide tip surface?** Beam profile refers to the distribution of polymerizing blue light across the surface of the light guide tip.[24] Many curing lights have an unevenly distributed blue light emission across the light tip; intense hot spots provide effective polymerization while intense cold spots do not. Figure 2A illustrates a beam profile and the relative changes in irradiance across the curing light tip. Figure 2B overlays four beam profiles on a premolar MOD preparation to illustrate the impact of an uneven beam profile on polymerization. The table indicates how the beam profile color translates to irradiance. It is important to note that violet in the beam profile signifies inadequate irradiance to cure a composite resin within 20 seconds, as in the gingival margin and proximal box areas with some of the curing lights portrayed.

3. **What are the heating effects associated with the curing light?** Some curing lights can increase surface temperature up to 80° Celsius in just a few seconds. Other curing lights

may increase pulpal temperatures dangerously, more than 5.5° Celsius, even when within recommended curing times.[25-27] The risk of dangerous pulpal temperature increase is exacerbated when curing times are arbitrarily increased without concomitant heat management techniques such as increasing the waiting time and/ or air cooling the tooth between polymerization cycles. When utilizing extended curing times, a wait-time of 1-2 seconds between every 10 seconds cycle or air-cooling is recommended. In polymerizing Class V restorations, the curing light's heat can cause gingival tissue damage. The practitioner must assure that increased curing times do not damage hard, soft, or pulpal.

It is the manufacturer's responsibility to have this critical performance data about their intra-oral curing light; if not available, the clinical effectiveness of the curing light should be questioned.

Operator Technique: reducing variability in light delivery

Various studies have investigated the effect of the curing light's position on composite polymerization.[28-30] While most preparations allow excellent clinical curing access, some areas are hard to reach. The curing light tip itself may be a limiting factor in approaching the surface or orienting towards it. Many dentists and dental assistants (who most often hold the light and activate it) have little training or instruction in the art and science of light curing. Typically, clinical articles mention only "light cure for X seconds". The diameter of the light tip, orientation of the light tip, and light source relative to energy output are rarely noted.

Even when using the same brand and model of curing light, in the same mode and for the same time, different curing light operators get very different results. This has been well demonstrated in studies using BlueLight's MARC® Patient Simulator, a unique curing light operator-training device now used in dental schools throughout Europe and North America.[29-31] MARC® is a laboratory-grade, clinically relevant light curing energy measurement tool. The light energy measuring sensors are embedded in a typodont head and provide immediate data collected by a chairside computer. The MARC® measures the useful light-curing energy delivered to simulated restorations and provides immediate feedback enabling the user to improve their light-curing skills. In an evaluation of 35 dentists, even though the dentists being tested knew they were being evaluated using the MARC®, there was a ten-fold variation in energy delivery between operators (Fig. 3).

The research recommends maximizing curing energy during restoration placement: the operator, wearing orange blue-light blocking glasses or using orange shields for eye protection, must stabilize the light during curing, and should hold the light both close and perpendicular to the restoration (Fig. 4-9).[29] If the light source is not perpendicular to the cavity preparation, incomplete photo-polymerization may result (Fig. 10).

Restoration Characteristics

Restoration characteristics are factors that can affect light-curing a composite resin.

- Patient access (mouth opening) can limit light guide positioning. The size and angulation of some light guides may make proper surface positioning and orientation in the posterior areas impossible. Increased curing times may be necessary. Access limitation can result in sub-optimally light tip orientation, resulting in light reflection, refraction and shadowing issues.
- Many LED curing light tip diameters are as small as 7 mm. This necessitates curing larger restorations as multiple smaller restorations to ensure complete photo-polymerization.
- Curing through tooth structure or translucent restorative materials (porcelain) requires increased curing time and results in increased heat generation. The tooth and pulp should be air-cooled during polymerization.
- Curing time for Class II proximal boxes, and deeper than routine restorations requires increased curing time. The guide tip should be at right angles to the preparation and as close as possible to the tooth. Matrix band height can move the light guide an additional 1-2 mm further from the tooth surface. Cusp height can block the light guide approach 1 mm away from the occlusal surface. As curing time increases, so must tooth cooling time.

Energy Requirements for Complete Photo-Polymerization of the Composite

Every brand and shade of composite has its own energy requirement that must be achieved to deliver the manufacturer's intended properties and performance. Many manufacturers do not specify energy requirements. As an added complication, some manufacturers have changed or added composite photoinitiators, often requiring a combination of both blue and violet sources for light curing. While some curing devices have both blue and violet

LEDs to compensate for these changes, there is not enough clinical implication data at this time to make any recommendations.

With the current generation of composites, increasing curing time can assure adequate polymerization. Guidelines include:

1. Opaque and darker composite shades require increased curing times.
2. Flowable composites require increased curing times.
3. Microfilled composites require increased curing times.

Verify the instructions for specific light curing time recommendations with the composite instructions or by contacting the manufacturer.

Curing Light Monitoring and Maintenance to Ensure Optimal Light-Curing

The optimal operation of a curing light requires routine status evaluations. The quantity and quality of the curing light output cannot be measured during clinical utilization. The brightness of the light can provide a false sense of security, implying that adequate polymerization is occurring. Numerous studies have demonstrated that the light energy delivered by many private practice curing lights are inadequate and are not capable of accurately photo-polymerizing the material in the selected curing time.[32,33] Over time, there is a decrease in the output of halogen curing lights due to bulb degradation (QTH)[34] autoclaving the fiber-optic light probe,[35] breakage and fracture of the light tip,[36] and the presence of cured composite resin and debris on the tooth side of the light tip.[36,37]

The light intensity and energy delivered by a curing light can only be reliably evaluated by using scientifically accurate equipment. Hand-held or integrated radiometers are known to be unreliable, as evidenced by testing a single curing light with different brands of radiometers.[38-40] Additional light-curing times are necessary for very opaque white shades of composite resin (bleaching shades), very dark composite shades, flowable composite resin, and micro fill composite resins.[5,41-43]

Managing Infection Control

Infection control barriers for curing lights and light guides are recommended. Unfortunately, preformed IC barriers that slip over a light guide are not standardized for optimized light transmission. Research has shown that some barriers can reduce curing light irradiance up to 40 percent.[44,45] Food wrap has been shown to be a highly effective and inexpensive infection control barrier with minimal effect on light delivery.[44] When using cold sterilizing curing light tips, ensure that approved cleaning solutions are used. Remove the light guides occasionally to verify that the curing light housing and both ends of the guide are clean. Non-approved sterilization fluids can erode the "O" rings that stabilize the light guide and the residual fluid may damage the lens inside the housing.

CONCLUSION

Do not take light curing for granted. Many factors affect optimal photo-polymerization of restorative materials. First, know the curing light. Check the curing light unit and light-guides for defects. If in doubt, have the light examined and tested by the distributor or manufacturer. Once the curing light is functioning optimally, certain specific guidelines ensure high-quality photo-polymerized restorations: the light tip must be as close to the tooth and restorative material as possible. The tip must be as close to perpendicular to the target surface as possible. The light-guide diameter must cover the entire target surface. If the tip is smaller, multi-step polymerization is indicated. The operator must use a protective blue-light blocking orange screen (handheld sheet, glasses or light guide shield). The light source must be stabilized to deliver adequate energy for light curing, including darker and more opaque shades. Following the above guidelines will ensure accurate photo-polymerization of composite restorations placed in the mouth. OH

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Oral Health welcomes this original article.

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