

Light-Curing Considerations for Resin-Based Composite Materials: A Review. Part II

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Abstract: As discussed in Part I, the type of curing light and curing mode impact the polymerization kinetics of resin-based composite (RBC) materials. Major changes in light-curing units and curing modes have occurred. The type of curing light and mode employed affects the polymerization shrinkage and associated stresses, microhardness, depth of cure, degree of conversion, and color change of RBCs. These factors also may influence the microleakage in an RBC restoration. Apart from the type of unit and mode used, the polymerization of RBCs is also affected by how a light-curing unit is used and handled, as well as the aspects associated with RBCs and the environment. Part II discusses the various clinical issues that should be considered while curing RBC restorations in order to achieve the best possible outcome.

Since their introduction to dentistry, resin-based composite (RBC) materials have been evolving, by improving in composition, material aspects, condensation techniques, esthetic qualities, technical aspects, polymerization methods, and clinical applications. Good bonding to the tooth structure and adequate polymerization of the resin material are the most important factors for a successful restoration. Clinical efficiency of a light-curing unit is critical for obtaining the optimal polymerization and

a successful outcome of RBC restorations.^{1,2} As discussed in Part I, many modifications have been introduced regarding light-curing units and polymerization techniques and/or methods of RBCs.^{1,3,4} Part II discusses and highlights the factors that influence the efficiency of light-curing units, as well as the various clinical considerations and precautions for handling and using these units, so as to obtain the maximal efficiency.

Learning Objectives

After reading this article, the reader should be able to:

- discuss the various clinical issues that should be considered while curing RBC restorations.
- explain how the factors associated with RBCs, light-curing units, and the surrounding environment can influence polymerization kinetics.
- list clinical tips that may help in proper curing of RBCs.

CLINICAL CONSIDERATIONS

The effectiveness of a light-curing unit to cure efficiently a composite resin material depends on several factors,^{1,5} such as wavelength of emitted light, type of photoinitiator, bulb intensity, exposure time, distance and angulation of light tip from the composite surface, type of RBC, and shade of the resin composite. Clinical factors influencing the efficiency can be broadly divided into four categories (Figure 1):

- Factors related to RBCs.
- Factors associated with light-curing units.
- Environmental aspects.
- Other issues.

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FACTORS RELATED TO RBCs

Type and Concentration of Fillers and Other Components

A light beam has the maximal intensity near the restoration surface; as it becomes scattered and reflected within the RBC material, it loses intensity. The RBC filler particles tend to scatter the light, and both filler content and size influence the light dispersion.⁵ Smaller filler particles (0.1 μm to 1.0 μm) have the maximal scattering because these particle sizes correspond to the wavelength range of the photoinitiator. Microfilled composites with smaller or greater particles scatter more light than microhybrids. If the refractive indices of the matrix and filler particles have an increased difference, light scattering is also increased. Therefore, the size and concentration of filler particles should be controlled depending on the refractive indices of the filler and resin matrix, as it influences the color of RBCs.⁶ Shorter curing times at a given depth or an increased depth of cure for a given exposure time is recommended for overcoming the issue of light scattering by filler particles. The best method is to cure the RBCs in increments of 1.5 mm to 2.0 mm.⁷ Both the type of curing-light unit used and the RBCs have been shown to interfere with the material's resistance to abrasion.⁸ Thus, apart from filler particles, the type of light-curing unit used can influence the material's wear rate. Also, darker colorants, ultraviolet absorbers, and fluorescent dyes present in RBCs tend to absorb light and can influence the effectiveness of light-curing units.

Shade of RBC Materials

Darker shades and/or more opaque resins tend to absorb more light and thus require longer curing times.^{5,9} Manufacturers usually specify a recommended curing protocol for individual shade and type of RBCs.

Type of Photoinitiator

A photoinitiator should be present in sufficient concentration so as to react to the proper wavelength of the light-curing unit. An excessive concentration can detrimentally affect the complete curing of RBCs. Most RBCs contain camphorquinone photoinitiators, which can cause an undesirable yellowing of the final esthetics. Thus, whiter and more transparent compounds derived from acylphosphine



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oxides (eg, monoacylphosphine oxide) and α -diketones (eg, phenylpropanodione [PPD]), also are being used.⁵ The type of photoinitiator in RBCs significantly influences the curing efficiency of the material across the width of a restoration.¹⁰ It also determines the most appropriate light-curing unit to cure a particular type of RBC,⁵ as the wavelength emitted by a curing unit should match the absorption spectrum or absorption peak of the photoinitiator in that RBC. Camphoroquinone-containing RBCs can be readily cured with QTH units and, to a certain extent, by other units.⁵ The major problem is with PPD- and monoacylphosphine oxide-containing RBCs because most commercially available units either match their spectrum partly or totally fail to do so.⁵ It is also difficult to cure whiter initiators, such as monoacylphosphine oxide, with LEDs and plasma-arc units (PACs). The wavelength of laser units generally coincides only with the absorption peak of camphoroquinone.¹¹ To overcome this, pairing of these initiators is suggested because it shows a higher conversion rate.¹² Thus, for a clinician to appropriately select a light-curing unit

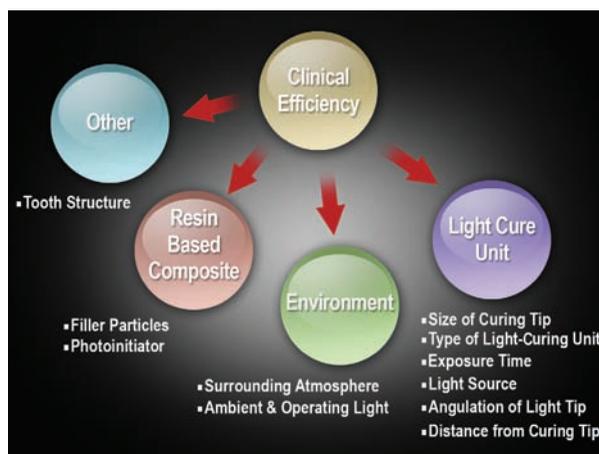


Figure 1 Diagram of factors influencing the clinical efficiency of a light-curing unit to adequately cure RBCs.

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for an RBC, the manufacturers should specify on the product labels the required energy output and the spectral bandwidth for the photoinitiated RBCs.¹³

FACTORS ASSOCIATED WITH LIGHT-CURING UNIT

Size of Light-Curing Unit Tip (Tip Geometry)

Light guides are available in diameters of 3 mm, 8 mm, 10 mm, 11 mm, 13 mm, and 14 mm. In a light-curing unit that has a standard diameter tip (11 mm), the light energy is more diffused, whereas in a light-curing unit with a smaller tip (3-mm turboguide), it is more concentrated (Figure 2). These small-diameter tips of light-curing units increase the output of light energy by 8-fold but also raise the temperature of the restoration and tooth structure during curing.¹⁴ Therefore, they should be used cautiously. Also, the light intensity from the light-curing unit tip falls off from the center to the edges, forming a bullet-shaped curing pattern (Figure 3). This variability in light intensity across the curing-tip face can cause improper curing of RBCs in proximal box restorations and extensive restorations.¹⁰ Recently, it has been suggested to use an R value to describe the light guide shape rather than words such as “normal” or “turbo.”¹⁵ An R value is the ratio between the entry diameter and exit diameter of the light guide tips. A higher R value tip is more efficient if the tip to composite distance is less than 5 mm. For more than 5 mm, tips with a lower R value are better.¹⁵ The R value also influences the curing depths of the RBCs.

Type of Light-Curing Unit

Each light-curing unit has its own wavelength specifications, advantages, disadvantages, and curing efficiency. It has been observed that more light is absorbed by the RBCs with the laser units and scattering is greater with the quartz-tungsten-halogen (QTH) units.¹⁶ Due to the broad wavelengths spectra available for QTH units, the decrease in light penetration caused by increased light scattering of shorter wavelengths is compensated by the longer wavelengths, which can easily transmit through the material and reach the deeper layers. Although the lights of laser units have better absorption, the devices have limited bandwidth and emit wavelengths closer to the absorption peak of the photoinitiator. Thus, QTH units are more efficient than laser ones for visible light-cured RBCs. Conversely, due to its inherent property of coherency, there is no loss of power in the distance in laser

units as seen in QTH units. Therefore, they are the units of choice for inaccessible areas.⁵

Exposure Time

Adequate curing of RBCs and dentin bonding agents not only depends on curing-light units but also on the exposure duration or exposure time.^{7,17} A standard time of 20 secs is usually required to cure to a depth of 2.0 mm to 2.5 mm by most curing-light units having a power density of 800 mW/cm². For a unit emitting 400 mW/cm², an exposure time of 40 secs is required to cure through a 2-mm thick layer of an RBC. Thus, increasing the power density of the lamp reduces the required exposure time at a given depth and also increases the rate and degree of cure.² Also, because the energy density is a product of intensity multiplied by exposure time,¹⁸ the same energy can be consumed at high or low intensities by modifying the exposure time to maximize the energy efficiency. An exposure time of 40 secs is considered optimal for all curing-light units used for RBCs.^{19,20}

The required exposure time can be influenced by the type of light-curing unit, shade of RBCs,⁹ and RBC formulation.²¹ Thus, a universal exposure time as recommended by the manufacturers cannot be used for all clinical scenarios and operating conditions. It has been observed that exposure times longer than those recommended are required to optimize the flexural strength for an incremental thickness of an RBC.²² To determine the exact exposure durations required to obtain optimal properties of RBCs, a compule-scrape test has been advocated, which is a simple in-office chair-side scraping procedure designed to develop a customized exposure guide.²² Compules of RBCs are modified to form cylinders in which their contents are forced to one end and photopolymerized (at a 2-mm distance) for various exposure durations. Compule contents are extruded 24 hours later, and the unpolymerized residue is removed using hand scraping with a plastic spatula. The thickness of the resulting specimen is measured as a function of exposure duration.

Light Source (Lamp Output Intensity)

The lamp intensity is determined by its power rating and light-guide diameter.⁵ An adequate energy density (ie, intensity multiplied by exposure time) is required for proper curing of RBCs.²³ Therefore, lamp output intensity should always be maintained for a longer clinical life of the curing unit. Usually, light output of the lamp and its curing effectiveness reduces with time. This is mainly caused by the alternate heating and cooling of the tip surface, leading to dulling or clouding of

the tip due to the condensation of mercury vapors, vapors from bonding system solvents, or moisture. At times, the resin adheres to the tip during curing, scattering the light, and reduces the effectiveness of curing-light unit. Therefore, it is important to routinely clean the mirror surface with cotton swabs dipped in alcohol or methyl ethylketone solvents or by using a rubber wheel on a slow-speed handpiece. This tends to preserve and renew the reflection effectiveness of the bulb.

Angulation of Light Tip

A light beam creates a circular spot of light when held perpendicular to the restoration surface. The wand tip of the curing-light unit should always be parallel to the restoration surface to achieve maximal light intensity at the surface. As the wand is tipped, the circular shape changes to an ellipse (greater surface area) and thus decreases the light intensity as energy is spread over a greater area.²⁴

Beam Spreading

The light beam usually disperses from its origin from the curing-light unit tip, leading to inhomogeneous distribution of light intensity (Figure 3). Thus, as the wand is moved away from the resin surface, both the light intensity and amount of curing decreases. At distances beyond 6 mm for QTH lights, the output may be less than one third that at the tip. This inhomogeneity can result in inhomogeneous polymerization below the light guide tip.²⁵ Therefore, it is necessary to “step” the light across a large restoration so as to adequately cure the entire surface. Also, to permit closer approximation to an RBC restoration, light-transmitting wedges have been promoted for interproximal curing and light-focusing tips to access proximal boxes. A simple test to check for beam spreading is to note the diameter

of the light spot. If the diameter that is created by a light beam directed perpendicularly onto a surface from a distance of about 100 mm is the same as the diameter from that of the wand tip, then there is no beam spreading.²⁴ It is also advocated to use an exposure time of 60 secs with larger emitting tips.

Color Changes in RBCs Following Light Curing

RBC materials often show perceptible color changes during polymerization, which are usually unacceptable.^{26,27} QTH-curing lights tend to demonstrate more yellowing of RBCs than light-emitting diodes (LEDs).²⁸ Thus, for a precise shade match for RBCs, a custom shade guide should be fabricated using cured resin samples. This is employed with a universal shade guide for the shade selection of RBCs.

Distance of Curing Tip From the RBC Surface

The light intensity striking the RBC restoration surface is inversely proportional to the distance from the tip of the fiber optic bundle of the curing light to the composite surface.⁵ Also, for all light-curing units, the depth of cure generally decreases as the distance from the tip increases.²⁹ Ideally, the tip should be within 3 mm of the RBC to be effective.³⁰ For the darkest shades, increments should be limited to 1 mm of thickness. While both intensity and depth of cure decrease with increasing distance,^{29,30} the relationship between these factors and distance may not be similar for all curing lights.³¹

Temperature Rise During Curing

A potential risk of heat-induced pulpal injury has been proposed during light curing of RBCs because the temperature

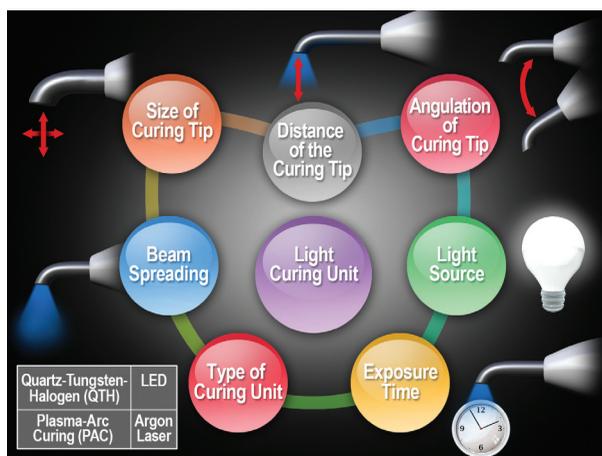


Figure 2 Illustration depicting the variables of light-curing units affecting the degree of polymerization of RBCs.

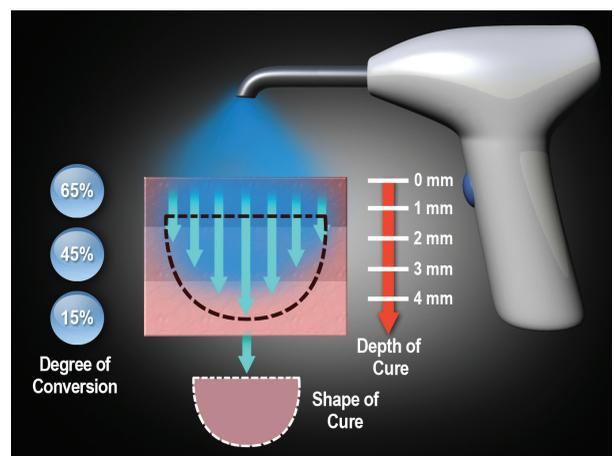


Figure 3 Diagram of degree of conversion, depth of cure, and shape of cure of RBC by light-curing unit.

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rise during curing can be in excess of the values normally quoted as causing irreversible pulp damage.³² The risk is greater with high-energy as compared with low-energy output systems.^{33,34} Light intensity and exposure time appear to be the most important factors causing temperature change when curing RBCs.^{33,35} The mean pulp temperature rise produced by different light-curing units in ascending order is: QTH, LEDs, enhanced halogen curing lights, and PAC units. The major rise in temperature occurs during the curing of the bonding agent as compared with curing of RBCs.^{35,36} Recent studies have shown that although the light-curing units cause a temperature rise in the pulp chamber, none has exceeded the critical value of 5.5°C.^{37,38} Thus, to avoid any thermal damage to the pulp, a correct choice of a light-curing unit and curing time is important when polymerizing light-activated RBCs. Also, the curing of bonding agents should be performed with low-intensity light, and high-intensity should be used only for curing of RBCs regardless of the light-curing unit used.

Effect of Autoclaving on Light-Curing Tips

During autoclaving, boiler scale tends to form on the instruments being sterilized, including the light-curing tip. This can compromise the intensity of irradiation transmitted from the bulb of light-curing units.³⁹ The effect can be minimized by polishing the tip regularly between autoclaving processes.

Degree of Conversion/Degree of Cure

The degree of conversion (DOC) is the percentage of carbon-carbon double bonds that have been converted to single bonds to form a polymeric resin. Bisphenol A diglycidylether methacrylate (bis-GMA)-based RBCs have a DOC of 55% to 65%, which implies 55% to 65% of the methacrylate groups has been polymerized following curing of the material. This is due to the steric hindrance of the reacting molecules. The higher the DOC is, the better the mechanical properties (strength, wear resistance) of the RBCs. It is directly proportional to the light intensity and exposure time and inversely proportional to the depth of cure into an RBC material.^{30,40} There is no difference between

the DOC of chemically activated and light-activated RBCs with the same monomer formulations. Recently, certain high-conversion, high-strength monomer systems have been introduced to reduce the effects of residual unsaturation that may impair the mechanical and chemical properties of RBCs. These include:

- Increasing the content of triethyleneglycol-dimethacrylate (TEGDMA) in a bis-GMA:TEGDMA comonomer. This will increase conversion but will make the material very brittle and fracture prone.
- The use of a more reactive diluent monomer (α -methylene- γ -butyrolactone) has shown to increase the conversion rate without hampering the mechanical properties.⁴¹ The degree of crosslinking in the polymer matrix could be increased by the addition of carboxylic anhydrides to develop a mechanically stronger and more wear-resistant RBC.⁴² Aldehyde and diketone are thought to increase the degree of crosslinking by reacting with methacrylate double bonds and other pendant and backbone functional groups.

FACTORS ASSOCIATED WITH ENVIRONMENT

Effect of Surrounding Atmosphere

The light intensity at the surface of an RBC restoration is inversely proportional to the distance from the tip of the light-curing unit to the RBC surface.⁵ This is due to the scattering of light by air molecules on the path to the restoration surface. Thus, the tip should be within 3 mm of the RBC's thickness and for darkest shades within 1 mm of thickness of RBC to effectively cure the restoration.

Effect of Ambient and Operating Light

In single-handed dentistry, usually there are high chances of exposure of RBC material to the ambient and/or the operating light, which can initiate premature curing. This results in difficulty in handling the RBC and reduced working time. The use of yellow filters and polyester-based photographic filters is effective in avoiding this unwanted activation and

The light intensity striking the RBC restoration surface is inversely proportional to the distance from the tip of the fiber optic bundle of the curing light to the composite surface.

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in extending the working time.⁴³ Employing prepacked composites of RBC material also may help prevent this premature curing of the material.

OTHER FACTORS

Effect of Tooth Structure

As the light passes through tooth structure (enamel or dentin), it is absorbed and scattered, resulting in incomplete curing of RBC material, especially in areas such as proximal boxes. This effect depends on the thickness and optical behavior of intervening material.¹ Enamel is very transparent and allows the passage of a great deal of light, whereas dentin is considerably less transparent and allows virtually no light to penetrate. Thus, the exposure time has to be increased by a factor of 2 to 3 when attempting to polymerize the restoration through the tooth structure.⁴⁴

CONCLUSION

Apart from the type of light-curing unit employed, the clinician's knowledge and clinical skill in handling and maneuvering these units play a decisive role in the polymerization and final outcome of RBC restorations. Many factors associated with RBCs, light-curing units, and surrounding environment can influence the polymerization kinetics of RBCs and clinical effectiveness of curing units. Clinical tips that may help in proper curing of RBCs are as follows:

1. Select a light-curing unit, taking into consideration the composition (photoinitiator and fillers) and shade of RBCs.
2. Cure the RBCs in 2-mm increments, using a light-curing tip of appropriate R value.
3. Cure the restoration for at least 40 secs from a distance of 1 mm to 3 mm, keeping the unit tip perpendicular to the restoration surface.
4. "Step" the light-curing unit across a large restoration.
5. Use yellow or polyester-based photographic filters to extend the working time.
6. Increase the exposure time to two to three times when curing through the tooth structure. Use light-transmitting wedges and focusing tips during curing of proximal restorations.
7. Use a custom shade guide fabricated from cured resins, as well as a universal shade guide for shade selection.
8. Routinely clean the mirror surface and polish the unit tips to preserve the reflection effectiveness of the light-curing unit.

9. Choose low-intensity light-curing units for curing of bonding agents.
10. Regularly check the output intensity, energy density, and beam spreading of a light-curing unit.

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This article provides 2 hours of CE credit from AEGIS Publications, LLC. Record your answers on the enclosed answer sheet or submit them on a separate sheet of paper. You may also phone your answers in to (215) 504-1275 or fax them to (215) 504-1502 or log on to www.compendiumlive.com and click on "Continuing Education." Be sure to include your name, address, telephone number, and last 4 digits of your Social Security number.

1. If the refractive indices of the matrix and filler particles have an increased difference, light scattering is:
 - a. propagated by the etchant.
 - b. propagated by the unfilled resin.
 - c. also increased.
 - d. decreased.
2. Which tend to absorb more light and thus require longer curing times?
 - a. microfilled composites
 - b. macrofilled composites
 - c. darker shades and/or more opaque resins
 - d. microhybrid composites
3. The wavelength of laser units generally coincides only with the absorption peak of:
 - a. mono-acylphosphine oxide.
 - b. camphoroquinone.
 - c. α -diketones.
 - d. acylphosphine oxide.
4. Small-diameter tips (3 mm) of light-curing units increase the output of light energy by:
 - a. 2-fold.
 - b. 4-fold.
 - c. 8-fold.
 - d. 16-fold.
5. Energy density is a product of:
 - a. exposure depths multiplied by refractive index.
 - b. refractive index multiplied by composite particle size.
 - c. refractive index divided by composite particle size.
 - d. intensity multiplied by exposure time.
6. A light beam creates what shape of a spot of light when held perpendicular to the restoration surface?
 - a. circular
 - b. elliptical
 - c. hexagonal
 - d. tetrahedral
7. If the diameter that is created by a light beam directed perpendicularly onto a surface from a distance of about 100 mm is the same as the diameter of the wand tip, then:
 - a. only lighter shades of composite will polymerize.
 - b. polymerization will occur only to a depth of 1 mm.
 - c. there is no beam spreading.
 - d. the frequency of the light is within 25 Hz of accurate.
8. The major rise in temperature occurs during:
 - a. the excavation of decay with a hand instrument.
 - b. the curing of the bonding agent.
 - c. the curing of the first layer of the RBC.
 - d. the curing of the second layer of the RBC.
9. How is the light intensity at the surface of an RBC restoration related to the distance from the tip of the light-curing unit to the RBC surface?
 - a. directly proportional
 - b. inversely proportional
 - c. by the square of the distance
 - d. by the square root of the distance
10. The exposure time has to be increased by a factor of how much when attempting to polymerize the restoration through the tooth structure?
 - a. 1 to 2
 - b. 2 to 3
 - c. 3 to 4
 - d. 4 to 5

Please see tester form on page 603.