

The Influence of Tip Geometry and Distance on Light-curing Efficacy

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Clinical Relevance

Among the factors that significantly influence the depth of cure of resin composite restorations—the distance between the tip of the light source and the restorative material—as well as the geometry of the tip, are crucial parameters. Increasing the ratio between the entry and exit diameter of the tip will result in an improvement in the depth of cure for lower distances between the tip of the light source and the restorative material, while decreasing the ratio of the depth of cure, which will be higher for greater distances.

SUMMARY

This study investigated the influence of the light guide shape on the polymerization efficacy of a light-activated resin-based composite cured with LED units as a function of the distance between the tip and the restoration.

Two different LED units, each with different light guides and shapes, were used. Their ability to cure a single restorative material was investigated. The efficacy of the light-curing system was evaluated by measuring the depth of cure using the Acetone Shake test.

Considering the ratio (R) between the entry diameter and the exit diameter of the light guide, the tips with a higher R-value proved to be more efficient if the tip and composite distance (D) was less than 5 mm, while for $D > 5$ mm, the tips with a lower R-value showed better results.

The tip geometry of the tested light guide had a significant influence on the depth of cure of the tested resin composites. Therefore, depending on the distance, the more suitable light guide should be selected, based on the clinical situation. An R-value may be a better descriptor for the light guide shape than words such as “normal” or “turbo.”

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INTRODUCTION

Light-curing units significantly influence the polymerization efficiency of light-activated resin-based composites. The curing efficiency and shrinkage stresses induced during polymerization may affect the integrity of a resin-based composite, with possible subsequent distortion of the bond to tooth structure.¹ For this reason, investigating the factors influencing the composite's curing reaction is of scientific and clinical interest.

LED lamps have proven to be as efficient as halogen lamps when curing resin-based composites.²⁻⁵ However, some advantages, such as improved longevity of the LED, lower heat production and less energy dissipation, make them more versatile when compared to halogen lamps.⁶ The curing efficacy of LED lamps was evaluated by measuring the degree of conversion and the depth of cure of the resin composite.^{3-4,6-8}

It is well known that the effectiveness of a light-curing unit depends on the output light intensity and the way the light photons reach the photo-initiators within the composite.⁹ As a result, researchers raised the lamp light output in an attempt to optimize light-curing performance. This approach improved the depth of cure and the degree of monomer conversion, while, at the same time, the higher light intensities significantly increased both the shrinking stress⁷ and heat production in the composite restoration.¹⁰

The effective light intensity available for the photo-activation of resin monomers is also influenced by the distance between the light curing tip and the restorative material.¹¹ The intensity decreases according to the square of the distance.¹² The clinical significance of this physical law is particularly relevant to Class II restorations, where distances up to 10 mm may occur between the cervical step and the tip of the lamp.¹¹

Another factor affecting the polymerization reaction is the geometry of the tip used for light transmission.^{6,13-14} A wide variety of commercially available light guides claim to fit different operative procedures based on different clinical situations.

This study evaluated the polymerization efficacy of two new curing units by a quantitative analysis, paying special attention to the distance between the tip and

the composite material to be cured and the geometry of the light guide.

METHODS AND MATERIALS

Two different types of light-curing unit were selected for this study: Elipar Freelight 2 (3M, St Paul, MN, USA) and LE Demetron 1 (Kerr, Danbury, CT, USA).

Experiments were performed on a single restorative system (Filtek Supreme, 3M) in one shade: A2 Body (Lot 4FA).

For light-curing unit emission spectrum measurements, a spectrophotometer (PSD1000, Ocean Optics, Dunedin, FL, USA) equipped with an integrating sphere (ISP-REF, Ocean Optics) with a 10 mm opening, was used. The spectrophotometer was connected to a computer running spectrum measurement software (OOIBase 32, Ocean Optics).

Four different types of light guide tips were selected (Light Guide Curved 13/8 mm Diameter Turbo Tip 952211, Kerr) (Light Guide Curved 11 mm 1020898, Kerr) (Maxi Fiber Rod 131390, 3M) (Turbo Light Guide 8 mm 76941, 3M), each used with their respective curing systems (Table 1) (Figure 1).

In a cylindrical stainless steel mold (Figure 2), 8-mm thick sample discs of resin composite 4 mm in diameter were made. After placing the material into the mold, a mylar strip was pressed over the surface with a glass

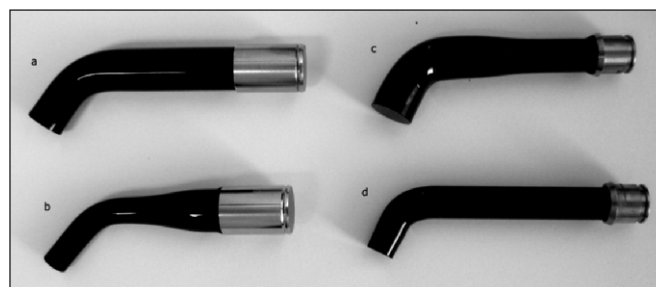


Figure 1: Types of light guide tips selected.

- a) Light Guide Curved 11 mm 1020898, Kerr, Danbury, CT, USA.
- b) Light Guide Curved 13/8 mm Diameter Turbo Tip 952211, Kerr, Danbury, CT, USA.
- c) Maxi Fiber Rod 131390, 3M, St Paul, MN, USA.
- d) Turbo Light Guide 8 mm 76941, 3M, St Paul, MN, USA.

Table 1: Types of Light Guide Tips Used

Lamp	Tip Model	Lot	Ø Entry	Ø Exit	Ratio Entry/Exit
Kerr LE Demetron 1	Light Guide Curved 11 mm	1020898	13 mm	11 mm	1.18
Kerr LE Demetron 1	Light Guide Curved 13/8 mm Diameter Turbo Tip	952211	13 mm	8 mm	1.63
3M FreeLight 2	Maxi Fiber Rod	131390	11 mm	13 mm	0.85
3M FreeLight 2	Turbo Light Guide 8 mm	76941	11 mm	8 mm	1.38



Figure 2: Cylindrical stainless steel mold used for specimen manufacturing.

plate in order to obtain a flat surface. Great attention was given to prevent voids inclusion.

The mold was placed on a wood table surrounded by a graded camera tripod. The tripod wing held the tested light-curing unit, in order to gradually increase the mold in 1 mm increments—the distance between the lamp and the mold (from 0 mm to 10 mm). These distances were always verified by an electronic digital caliper (1651 DGT, Beta, Milan, Italy) with a 10 μ m resolution.

After 10-second curing, the resin composite disk was extracted from the mold and put into a hermetically sealed steel container.

For each increment of increased distance of a single tip, five specimens were tested, for a total of 55 specimens for each light guide tip.

The depth of cure was determined according to ISO 4049 standard; however, instead of scraping off the uncured material with a spatula, as described in the specification, the uncured material was removed by shaking the samples with 99.9% pure acetone (2004/000113, Polichimica srl, Bologna, Italy) in a mixing device (TAC-135/A n°3437, Tac Dental, Asti, Italy) for 15 seconds, as previously reported by de Gee¹⁵ and Kleeverlaan and de Gee.¹⁶ The acetone's carboxylic group, by linking to unreacted C=C double link, solubilized the

residual un-polymerized Bis-GMA portion, leaving the polymerized portion undamaged.

Within one minute after mixing, the container was opened and the sample was dried and measured by an electronic digital caliper (1651 DGT, Beta) with a 10 μ m resolution.

Statistical Analysis

The Kolmogorov–Smirnov test was used to check the normality of data distribution. The strength of the correlation between the depth of cure and the distance between the tip of the light curing unit and the composite was measured by Pearson's correlation coefficient. The statistical significance of the correlations was also assessed ($p < 0.05$). Then, in order to determine the significance of the differences in depth of cure, recorded by the two curing tested systems with each different testing modality, a two-way analysis of variance was applied, assuming the depth of cure as the dependent variable and the type of light and distance as factors. For the “distance” factor, the two levels “greater than 5 mm” and “equal to or less than 5 mm” were defined. The Tukey's test was applied for post-hoc comparisons of significant interactions. The Spearman's correlation coefficient ($p < 0.05$) was calculated to assess the strength of the correlation between the “R” value (entry diameter/exit diameter ratio) of the light guide and the depth of cure as a function of the distance between the tip of the light guide and the composite surface. The software used was SPSS 12.0 (SPSS, Chicago, IL, USA)

RESULTS

The results of these findings are shown in Tables 2 and 3. The data distribution is shown in Figure 3.

For each table, the values of the depth of cure (mean $\pm$ standard deviation) are reported in relation to the distance between the light guide and the tested resin composite. In the left column are the distances given, while the other two columns feature the depth of cure

Table 2: Filtek Supreme A2B Cured for 10 Seconds with Elipar Freelight 2

	Normal (R. 0.85)	Turbo (R. 1.38)
0 mm	4.64 $\pm$ 0.02 mm	5.06 $\pm$ 0.02 mm
1 mm	4.60 $\pm$ 0.01 mm	4.92 $\pm$ 0.02 mm
2 mm	4.58 $\pm$ 0.02 mm	4.79 $\pm$ 0.02 mm
3 mm	4.57 $\pm$ 0.02 mm	4.67 $\pm$ 0.02 mm
4 mm	4.55 $\pm$ 0.01 mm	4.60 $\pm$ 0.03 mm
5 mm	4.50 $\pm$ 0.02 mm	4.41 $\pm$ 0.02 mm
6 mm	4.40 $\pm$ 0.02 mm	4.27 $\pm$ 0.02 mm
7 mm	4.36 $\pm$ 0.02 mm	4.03 $\pm$ 0.01 mm
8 mm	4.22 $\pm$ 0.03 mm	3.95 $\pm$ 0.02 mm
9 mm	4.18 $\pm$ 0.01 mm	3.71 $\pm$ 0.02 mm
10 mm	4.08 $\pm$ 0.02 mm	3.64 $\pm$ 0.01 mm

Table 3: *Filtek Supreme A2B Cured for 10 Seconds with LE Demetron 1*

	Normal (R. 1.18)	Turbo (R. 1.63)
0 mm	4.77 ± 0.02 mm	5.31 ± 0.02 mm
1 mm	4.73 ± 0.02 mm	5.25 ± 0.01 mm
2 mm	4.62 ± 0.01 mm	5.15 ± 0.03 mm
3 mm	4.62 ± 0.02 mm	4.98 ± 0.02 mm
4 mm	4.54 ± 0.01 mm	4.66 ± 0.01 mm
5 mm	4.52 ± 0.02 mm	4.44 ± 0.03 mm
6 mm	4.42 ± 0.02 mm	4.30 ± 0.02 mm
7 mm	4.35 ± 0.01 mm	4.04 ± 0.03 mm
8 mm	4.20 ± 0.01 mm	3.79 ± 0.02 mm
9 mm	4.14 ± 0.01 mm	3.47 ± 0.02 mm
10 mm	4.10 ± 0.01 mm	3.26 ± 0.02 mm

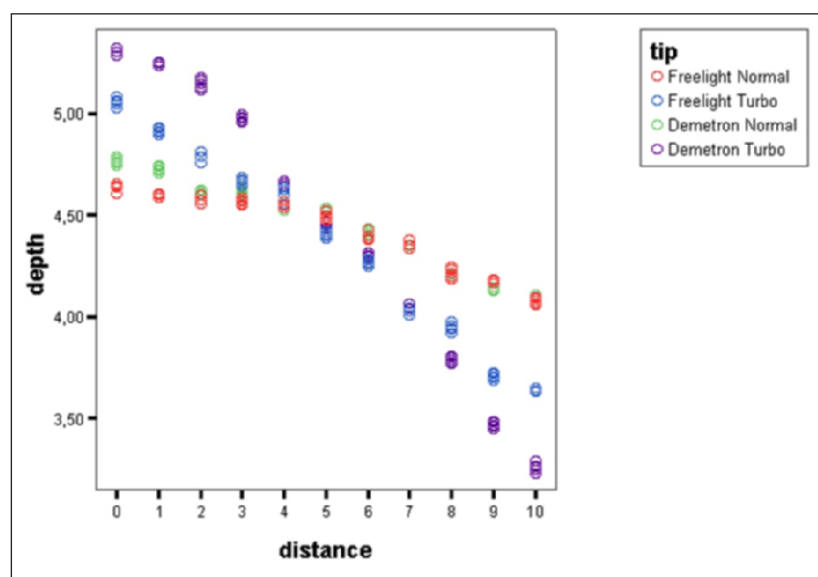


Figure 3: Graphic representation of the values of the depth of cure as a function of the four types of light guide tips tested.

values. The results of the depth of cure were analyzed as a function of the type of light guide (tip) and light curing unit used.

In Table 2, the results of the depth of cure for 10 seconds in the composite, as radiated with Elipar Freelight 2 equipped with two different tips (Maxi Fiber Rod R=0.85; Turbo Light Guide 8 mm R=1.38), are shown. Observing the values shown in this table, it is possible to point out how, when the tip of the light guide is in contact with the restorative material, the tip with a higher R-value is more efficient. Between 4 mm and 5 mm of distance, there is a change in efficacy between the two tips, and the tip with R=0.85 produces a value of depth of cure (4.50 ± 0.02 mm) higher than the tip with R=1.38 (4.41 ± 0.02 mm). For D> 5 mm, the authors of the current study observed that the normal light guide was more efficient than the turbo.

In Table 3, the results of the depth of cure of the composite cured for 10 seconds with the LE Demetron 1 equipped with two different tips (Light Guide Curved 11 mm R=1.18; Light Guide Curved 13/8 mm Diameter Turbo Tip R=1.63) are shown. From the data reported in this table, it is possible to highlight how the Elipar Freelight 2 curing system and the LE Demetron 1 curing system follow the trend stated previously. Therefore, for lower distances between the light guide and the restorative material, the tip with a higher R-value is more efficient. Between 4 mm and 5 mm of distance, there is a change in efficacy between the two tips, and the tip with R=1.18 generates a higher depth of cure (4.52 ± 0.02 mm) than the tip with R=1.63 (4.44 ± 0.03 mm). Likewise, the Elipar Freelight 2 system and the LE Demetron 1 system produced a higher value of depth of cure with the normal light guide for D> 5 mm.

The Kolmogorov–Smirnov test revealed that the recorded data were normally distributed ($p>0.05$).

The overall Pearson's correlation coefficient showed a significant inverse relationship between the depth of cure and the distance ($r=-0.874$; $p<0.001$), not considering the tips.

Analyzing Figure 3, it is possible to note that, at a distance of 5 mm from the tip of the light curing unit and the composite, a change in the polymerization pattern has occurred between the two tips tested (normal and turbo).

Two-way ANOVA showed that the factor “tip” was not statistically significant ($p=0.06$); whereas, the factor “distance” significantly influenced the depth of cure ($p<0.001$). In particular, a distance greater than 5 mm resulted in a significantly lower depth of cure. Also, the distance-tip interactions were statistically significant ($p<0.001$). When evaluated at the univariate level, the significant interactions highlighted in Table 4 resulted (Tukey test for pairwise comparisons, $p<0.05$).

The Spearman's correlation test showed a significant direct relationship between the R-value and the depth of cure for distances less than or equal to 5 mm ($p=0.519$; $p<0.001$) and a significant inverse relationship between the R-value and the depth of cure for distances greater than 5 mm ($p=-0.604$; $p<0.001$).

DISCUSSION

The procedure (as described in the ISO specification) of scraping off the uncured resin from the upper surface of

Table 4: Different Letters Highlight the Significant Differences That Emerged When the "Distance by Tip" Interactions Were Univariately Examined

Interact	Mean	N	Std Deviation	Significance
DTL	4.9650	30	0.32297	a
FTL	4.7417	30	0.21697	b
DNL	4.6333	30	0.09375	b
FNL	4.5733	30	0.04626	c
FNG	4.2480	25	0.12135	d
DNG	4.2420	25	0.12596	d
FTG	3.9200	25	0.23231	e
DTG	3.7720	25	0.38351	e

DTL = Demetron Turbo Less or equal to 5 mm
 FTL = Freelight Turbo Less or equal to 5 mm
 DNL = Demetron Normal Less or equal to 5 mm
 FNL = Freelight Normal Less or equal to 5 mm
 FNG = Freelight Normal Greater than 5 mm
 DNG = Demetron Normal Greater than 5 mm
 FTG = Freelight Turbo Greater than 5 mm
 DTG = Demetron Turbo Greater than 5 mm

because it was less technique-sensitive. As previously reported,¹⁵⁻¹⁶ this method offers the advantage that all the unreacted C=C double link is chemically removed by the acetone's carboxylic group in a reproducible manner, leaving a clean surface. Therefore, the test condition produced by the Acetone Shake Test is repeatable, overcoming the subjective judgement of the operator scraping off the uncured material, and it is not influenced by the strength and pressure of the scraping procedure.

In this study, two variables that may significantly affect the resin-based composite photo-polymerization efficacy were evaluated. Such variables were the geometry of the light guide and the distance between the light tip and the restoration.

The results gathered in this study seemed to confirm the physical law stating that the amount of light received by an object declines progressively at the increasing distance from a spot light source. As a consequence, the distance (D) between the light guide tip and the restoration becomes a crucial parameter.¹¹

Commercially defined "standard" or "normal" tips have similar entry and exit diameters; whereby, the light beam is canalized. On the contrary, "turbo" tips concentrate the light beam through a smaller exit diameter. In this study, two light curing units were tested. In a preliminary evaluation of the light emission spectrums of the two units (Figure 4 and 5) without light guides, the units showed the same power in light emission. When a certain amount of light is generated (the real power of the light source), the tip with a smaller exit diameter (higher R-value) is prone to emit more light energy at the proximal portion of the light cone generated.^{6,14} In both curing systems in the current study, the turbo tip (higher R-value) was more efficient for $D \leq 5$ mm from the tip (DTL^a vs DNL^b and FTL^b vs FNL^c). From the data reported in Tables 2 and 3 and Figures 6 and 7, it can be observed that, at a distance of 5 mm, the normal tip becomes more efficient than the turbo, because, for $D > 5$ mm, the normal light guide (lower R-value) was more efficient (FNG^d vs FTG^e and DNG^d vs DTG^e) as shown in Table 4.

Light in optic fibers follows the physical law of specular reflection. The cone of light generated in the optic fibers is reflected in an outward specular way (Figure 6). If the light guide exit diameter is smaller than the entry diameter, a narrower cone of light is created. For the same reason, the cone emitted by a "Turbo" light guide will be wider, and the light intensity will decrease considerably with increasing distances. For the tips considered in this study, the data supports a higher

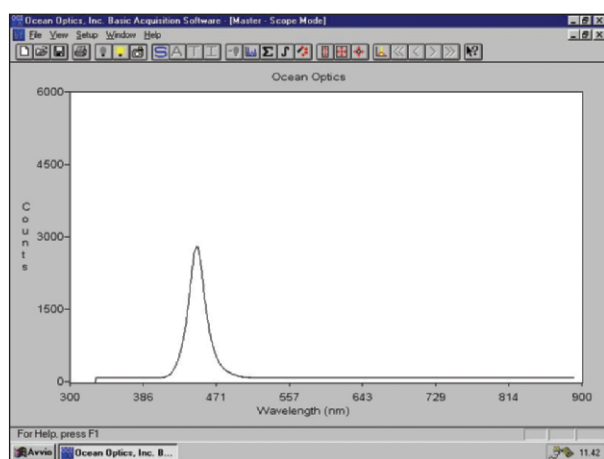


Figure 4: Elipar Freelight 2 light emission spectrum.

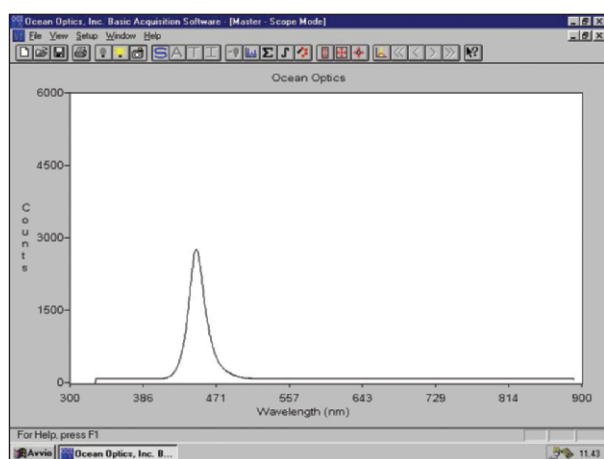


Figure 5: LE Demetron 1 light emission spectrum.

composite samples was modified by removing the uncured material by shaking the composite cylinders in a mixing device. This methodology was preferred,

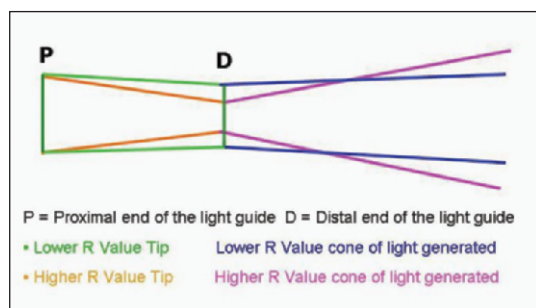


Figure 6: When the tip's exit diameter is smaller than the entry one (higher R value), a narrower cone of light is created where, in the proximal section of the top, there is a higher light intensity among the standard tip, while, after 4-5 mm from the top, the light intensity will considerably decrease, being lesser in comparison with the standard tip's one (lower R value).

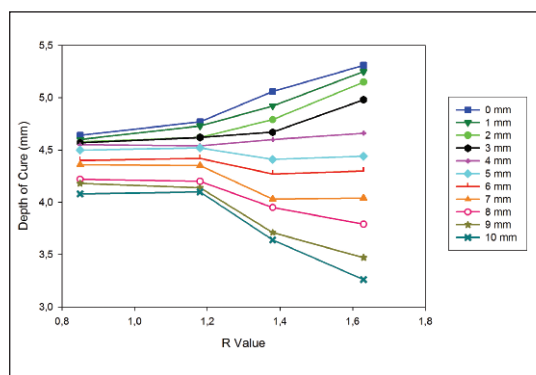


Figure 7: This figure shows the relationship between R value and the depth of cure. It can be observed that if R value increases it will be an improvement in depth of cure for $D \leq 5$ mm and if R value decreases the depth of cure will be higher for $D > 5$ mm.

light intensity for the "Turbo" light guide in the first 5 mm from the tip as being lesser after this distance compared to the standard tip. As indicated in the correlation test, a significant direct relationship between the R-value and the depth of cure for $D \leq 5$ mm ($p < 0.001$) and a significant inverse relationship between the R-value and the depth of cure for $D > 5$ mm ($p < 0.001$) was shown. This indicates that, if the R-value increases, it will be an improvement in depth of cure for $D \leq 5$ mm and, if the R-value decreases, the depth of cure will be higher for $D > 5$ mm (Figure 7).

The ISO 4049 standard for Class II materials states that the value of the depth of cure obtained has to be divided by two to get the correct polymerized layer.¹⁷ In this procedure, it should be taken into account that all of the dimethacrylate monomers exhibit considerable residual unsaturation in the final product, with a degree of conversion (DC) ranging from 55% to 75% under conventional irradiation conditions.^{7,18} Analyzing

the results in Tables 2 and 3, it can be noted that the two tested tips with a higher R-value up to 7 mm of distance from the composite restoration generated a polymerized layer lower than 4 mm. Considering these values of depth of cure, following the ISO 4049 standard,¹⁷ the authors of the current study obtain correctly polymerized layers lower than 2 mm. Moreover, the authors had to consider that these values were obtained using an A2 Body composite shade for experimental purposes. The use of a darker color and composite of a higher opacity, for example, which was generally used in the first layer to mask tertiary dentin color, further reduces the values of the depth of cure, enhancing the clinical relevance of the observations stated in this test.

The "turbo" tip is usually deemed an option to boost polymerization performance of the lamps. However, clinicians should be advised that, when used in a Class II cervical area at a certain distance from the emission tip, instead of obtaining a boost, the turbo tip will obtain a reduction in the performance down to a borderline value and, for that reason, its use in this clinical condition is not recommended.

Based on these findings, it may be speculated that, by using tips with a higher R-value in deep cavities, exposure time should be increased beyond the values generally indicated for layering techniques or by the composite manufacturer. Moreover, reducing the thickness of the first composite layer is likely to be advisable to ensure proper polymerization of the restorative material also in the deepest areas of the cavity preparation.

In view of the remarkable availability of the different light guides, it is too simplistic to divide the tips into "normal" and "turbo." It would be more appropriate to identify a tip as having the Ratio (R), which expresses the ratio between the index of the tip's entry diameter and its exit diameter.

CONCLUSIONS

By analysis of the observations found in this study and within the limits of the test used, the following conclusions can be drawn:

1. The distance between the tip of the light source and the restorative material is a crucial parameter, because it significantly influences the depth of cure of the resin composite polymerization reaction.
2. The geometry of the tip significantly influences the depth of cure. Considering the curing system tested, tips with a greater ratio of entry diameter/exit diameter are more efficient in the nearest 5 mm of distance between the tip and the composite, while at greater distances, tips with a lower R-value are more efficient.

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