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# Evaluation of the Influence of Polymerization Light Intensity, Irradiation Time, and Source Distance on the Depth of Cure of Resin Based Composite

SUMMARY

***Background/Aim:*** *To evaluate the effect of curing light parameters (intensity, duration, and distance of curing tip) on the depth of cure of conventional resin-based composite.* ***Material and methods:*** *Cylindrical specimens made of nanohybride resin-based composite are cured with 12 different curing protocols, combined with 3 different light intensities (300, 650, and 1100 mW/cm²), 2 distances of curing tip (0 and 8 mm), and 2 exposure times (20 and 40 seconds). The specimens were measured after scraping the uncured composite material according to the ISO 4049 standard. The depth of cure was calculated by dividing the length of the remaining composite by 2. Data were analyzed using: Levene's test and Multivariate Analysis-of-variance (MANOVA). The level of significance was set at P<0.05.* ***Results****: The highest depth of cure (3.332 mm) was observed for curing protocol 1100mW/cm²/0mm/40s. The lowest depth of cure had specimens cured with curing protocol 300 mW/cm²/8mm/20s (2.034mm). MANOVA showed a significant influence of the distance of the curing tip (P=0.014; P=0.001) regardless of light intensity and duration of exposure time. Exposure time was a significant factor (P=0.009) when cured from different distances. Although higher light intensity produced a higher depth of cure, light intensity was not a significant factor.* ***Conclusions****: The depth of cure can be increased by reducing the distance of the curing tip, when it is possible. At a distance of 8 mm, the depth of cure can be increased by a longer exposure time, regardless of curing light intensity.*

**Keywords:** Resin-Based Composites, Polymerization, Light Curing, Depth Of Cure, ISO 4049, Distance of Curing Tip, Exposure Time, Light Intensity

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## Introduction

Dental caries treatment has grown to be a major public health concern, with more than 260 million direct resin-based composite (RBC) restorations made annually[1]. Unfortunately, secondary dental caries is one of the main reasons for the replacement of these restorations[2,3,4]. Most of these failures occur at the gingival proximal margin of class II RBC restorations[2,3,4]. This region is the furthest from the curing light source and is at the bottom of the RBC layer. It is well known that resin-based composites must be sufficiently photocured to polymerise adequately and to convert into successful, hard, and durable restorations[5,6,7].

This may be a contributing reason to the higher incidence of caries in this area since inadequate photocuring of the bonding agent[8,9,10] or the RBC may occur here[11,12,13]. According to reports, even when the upper surface of the RBC has been properly polymerized, there may be inadequate polymerization at the bottom side of the material, and this could be a weak link associated with clinical complications such as higher cytotoxicity[14], discoloration[14], susceptibility to marginal defects[15], reduced microhardness[16,17], reduced wear resistance[14], and reduced bond strength[14]. When explaining these results, some authors propose that inadequate light-curing of RBC in deep posterior restorations might be a result of poor operator technique[14,18], limited access of the light-curing unit to the material[19,20], increased distance between the light source and the material being polymerized[21,22], and limitations of the material to achieve a satisfactory degree of conversion at the deepest part of the restoration[23]. Although high-intensity LED devices have been in clinical use for more than a decade, studies have shown that there are still LCUs that emit low-intensity light in daily clinical use[24-28]. The most common sources of low-intensity curing light in dental practices are quartz tungsten halogen LCUs [24,25,28,29], outdated and old devices[29,30], light curing units (LCU) with weak batteries[31], and curing tips covered with debris[28,32]. The problems related to inadequate polymerization might become even more serious at deep posterior cavity restorations with a depth of ≥4 mm [33]. Some studies report that RBC may not be adequately polymerized at the bottom of the layer because of a heterogenous light beam in multiple-peak curing units[16,23,34], or incorrect matching of the curing unit emission spectrum and the absorption range of the RBC[19,34,35], especially in materials that contain photoinitiators different from the camphorquinoneamine system[36]. As a result, it has been suggested, that increasing the duration of irradiance could compensate for the factors that negatively affect the polymerization of the material at depth[22,34,37].

Research on the depth of cure can offer details regarding how effectively the RBC at the bottom of a restoration will polymerize in various conditions of photocuring. The depth of cure has been defined as the depth at which the resin matrix switches from a glassy to a rubbery state and is used as a measure of the capability of different thicknesses of RBCs to be polymerized by light curing[38]. ISO 4049 depth of cure (DOC) (ISO 4049, 2019)[39] standard is often used to assess and compare curing efficiency[40]. The ISO 4049 depth of cure test results can be easily and directly translated into clinical guidelines that help clinicians understand the limitations of different LCUs and RBCs. However, since most RBC restorations are often larger than 4 mm in diameter, some have modified this test to use a more clinically relevant 6 mm-diameter mold. Some have also used a ‘no-touch’ solvent dissolution method to remove the uncured RBC[40,41,42].

Thus, the first aim of this study was to evaluate the effects of different exposure durations, light intensities, and distances of curing tip on polymerization of conventional RBC with the DOC as the target value. The second aim was to evaluate the influence of increasing the exposure time on DOC when the curing tip distance is 8 mm. The third aim was to evaluate the influence of higher light intensity on DOC when the curing tip distance is 8 mm. The working hypotheses were: (i) there will be no differences in the DOC of RBC light cured by different curing light intensities, from different distances of curing tip, and in different exposure time durations; (ii) extended exposure duration to polymerization light from distance of 8 mm would not significantly increase depth of cure of resin-based composite, and (iii) a higher intensity of polymerization light from distance of 8 mm would not significantly increase depth of cure of resin-based composite.

## Material and Methods

A conventional nanohybride resin-based composite, Tetric EvoCeram (Ivoclar Vivadent AG, Schaan, Lichtenstein), shade A2, was used in this study (Table 1.).

*Table 1. Resin based composite used in research*

| Material | Shade | Manufacturer | Resin | Filler | Filler wt%/vol% | LOT |
|---|---|---|---|---|---|---|
| Tetric EvoCeram | A2 | Ivoclar Vivadent AG (Schaan, Liechtenstein) | BisGMA, UDMA, Ethoxylated Bis-EMA | Barium glass filler, YbF3, mixed oxide, prepolymers | 75-76/53-55 | J04088 |

### *Light curing units*

Two types of light curing units (LCU) were used to polymerize the samples: LED LCU Bluephase (Ivoclar Vivadent, Schaan, Lichtenstein) and QTH LCU ESPE Elipar II (ESPE Gmbh&Co.KG, Seefeld, Germany). Three light intensities were used: QTH 300 mW/cm² (very low intensity), LED 650 mW/cm² (low intensity), and LED 1100 mW/cm² (high intensity). For measuring curing light intensity, a digital radiometer, Bluephasemeter (Ivoclar Vivadent AG, Schaan, Lichtenstein) and analog radiometer (Spring Light Meter 3K, Spring Health Products, Norristown, USA) were used. For controlling a distance of the light curing tip from the RBC material, a PVC distance holder of 8 mm in height was used, imitating the II Class cavity.

### *Experimental groups*

Twelve experimental groups are created of 12 different curing protocols (CP) combined of: 3 different curing light intensities (300, 650, and 1100 mW/cm²), 2 distances of curing tip (0 and 8 mm), and 2 durations of exposure time (20 and 40 sec, Table 2). The number of samples for each experimental group was five (n = 5).

*Table 2. Experimental groups*

| | Experimetal groups for depth of cure | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
| Light intensity (mW/cm²) | 300 (mW/cm²) | | | | 650 (mW/cm²) | | | | 1100 (mW/cm²) | | | |
| Distance of curing tip (mm) | 0 mm | | 8 mm | | 0 mm | | 8 mm | | 0 mm | | 8 mm | |
| Exposure time (s) | 20 s | 40 s | 20 s | 40 s | 20 s | 40 s | 20 s | 40 s | 20 s | 40 s | 20 s | 40 s |
| Curing protocol (CP) | 300/0/20 | 300/0/40 | 300/8/20 | 300/8/40 | 650/0/20 | 650/0/40 | 650/8/20 | 650/8/40 | 1100/0/20 | 1100/0/40 | 1100/8/20 | 1100/8/40 |
| Number of specimens | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 | n=5 |

### *Specimen preparation*

The depth of cure (DOC) was determined using the scraping technique, described by the International Organization for Standardization (ISO 4049, 2019)[39]. The Tetric EvoCeram RBC was filled into a stainless-steel mold with a cylindrical opening 4 mm in diameter and 6 mm in height (Figure 1). The top and bottom surfaces of the RBC in the mold were covered with a polyester strip and pressed flat. Light irradiation was applied from the top surface to polymerize the composite in one of twelve curing protocols. Five samples were prepared for each curing protocol. Light intensity was controlled by radiomaters (digital and analog) before each experimental group. All sample preparation and testing were conducted at ambient room temperature of 23°C and humidity near 50%.

### *Measuring the depth of cure*

Immediately after curing, the specimens were removed from the mold, and the uncured material of the specimens was removed by scraping with a plastic spatula (Fuji spatula; GC America, Alsip, IL, USA) (Figure 1) until the first sign of resistance to removal was identified by the operator. After all softened material had been completely removed, the absolute height of the cylinder was measured three times to the nearest 0.01 mm using a digital micrometer (CD-20CPX, Mitutoyo, Kawasaki, Japan) (Figure 1). The measured length was divided by 2 and recorded as the ISO depth of cure. In situations where the thickness of the polymerized material was 6 mm or more, a new sample was made in a mold 8 mm high with the same inner diameter (4 mm), as required by the ISO 4049 standard. The depth of cure data was statistically analyzed by SPSS software using Levene's test and multivariate analysis of variance (MANOVA). The level of significance was set at $P<0.05$.

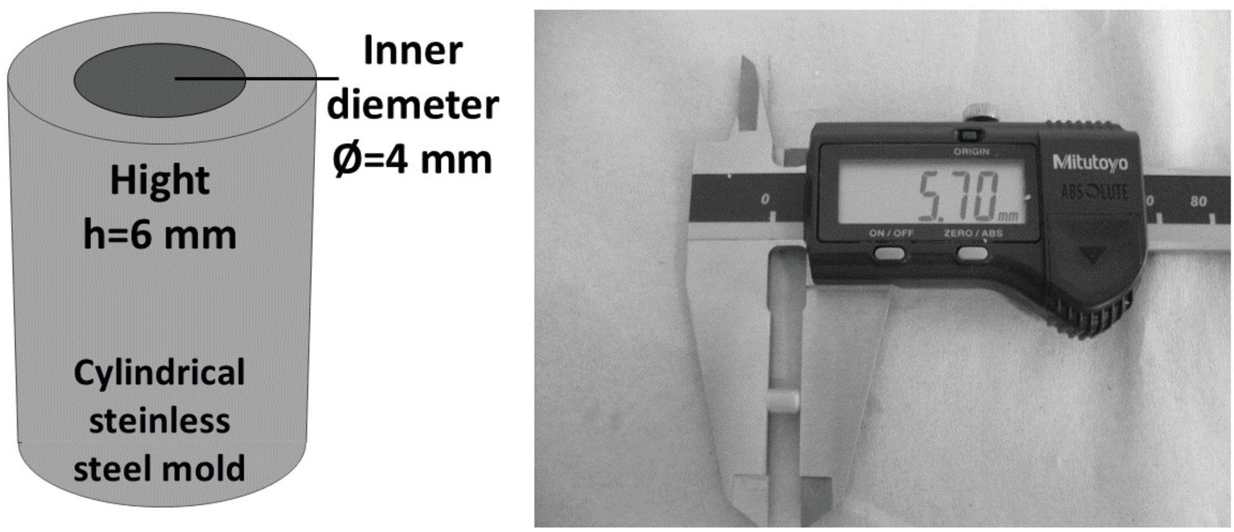


*Figure 1. Mold for DOC testing according to ISO 4049 (shema) and digital caliper*

## Results

The total average value of the depth of cure (DOC) in all 12 experimental groups was 2.677 mm, and ranges from 2.034 mm to 3.332 mm. All curing protocols resulted in a depth of cure of > 2 mm. The highest values of DOC were achieved with curing protocol (CP) 1100/0/40 (3.332 mm) and CP 650/0/40 (3.189 mm). The lowest DOC was measured for CP 300/8/20 (2.034 mm) and CP 650/8/20 (2.191 mm, Table 3). By multivariate analysis of variance (MANOVA), it was found that there were significant differences (P<0.05) in DOC of samples cured from different distances of curing tip (P=0.014), (P=0.001), and with different exposure durations (P=0.009) when irradiated from different distances. Specimens cured from a distance of 0 mm showed significantly higher values of DOC from samples polymerized from a distance of 8 mm (P=0.014), when different light intensities were used. Also, distance showed a significant influence on DOC (P=0.001) when cured with different durations of exposure time (Tables 3 and 4). Exposure time showed significant influence on DOC (P=0.009) when used from different distances of curing tip. Specimens irradiated from distance of 8 mm with longer exposure time showed significantly higher values of DOC. Although, extended exposure time increased DOC when different light intensities were used, these differences were not statistically significant (P=0.132) (Tables 3 and 4). In this study, light intensity did not show a significant influence on the DOC, regardless of the exposure time (P=0.420) or distance (P=0.221). Altough there was no statystical difference, descriptive statystical analysis shows that higher light intensity produce higher values of DOC. When specimens were iradiated from distance 0 mm, for 20 sec, light intensity of 1100 mW/cm² produced 0.384 mm (13%) higher DOC value than curing light intensity of 300 mW/cm². When specimens were iradiated from distance 0 mm, for 40 sec, light intensity of 1100 mW/cm² produced 0.408 mm (about 12%) higher DOC value than curing light intensity of 300 mW/cm². When specimens were iradiated from distance of 8 mm, for 20 sec, curing light with intensity of 1100 mW/cm² produced 0.325 mm (about 14%) higher DOC value than curing light intensity of 300 mW/cm². When specimens were iradiated from distance 8 mm, during 40 sec, curing light with intensity of 1100 mW/cm² produced 0.464 mm (about 16%) higher DOC value than curing light intensity of 300 mW/cm².

*Table 3. Depth of cure – staystical analysis*

| **Variables of curing light** | | | Results of measurements DOC (mm) (n=5) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Light intensity** (mW/cm²) | **Distance of curing tip** (mm) | **Exposure time** (s) | Exp. groups | 1 | 2 | 3 | 4 | 5 | Ar.sr. | SD± |
| 300 | 0 | 20 | 1. | 2.650 | 2.456 | 2.476 | 2.681 | 2.601 | 2.573 | 0.101 |
| | | 40 | 2. | 3.018 | 2.830 | 2.911 | 3.001 | 2.863 | 2.924 | 0.082 |
| | 8 | 20 | 3. | 2.020 | 2.080 | 1.991 | 2.115 | 1.965 | 2.034 | 0.062 |
| | | 40 | 4. | 2.386 | 2.316 | 2.370 | 2.301 | 2.466 | 2.365 | 0.065 |
| 650 | 0 | 20 | 5. | 2.753 | 2.715 | 2.670 | 2.810 | 2.855 | 2.760 | 0.073 |
| | | 40 | 6. | 3.125 | 3.228 | 3.188 | 3.215 | 3.191 | 3.189 | 0.039 |
| | 8 | 20 | 7. | 2.190 | 2.138 | 2.216 | 2.221 | 2.205 | 2.191 | 0.033 |
| | | 40 | 8. | 2.631 | 2.553 | 2.670 | 2.558 | 2.665 | 2.615 | 0.056 |
| 1100 | 0 | 20 | 9. | 2.970 | 3.071 | 2.976 | 2.905 | 2.865 | 2.957 | 0.078 |
| | | 40 | 10. | 3.185 | 3.335 | 3.345 | 3.420 | 3.375 | 3.332 | 0.088 |
| | 8 | 20 | 11. | 2.401 | 2.421 | 2.436 | 2.240 | 2.300 | 2.359 | 0.085 |
| | | 40 | 12. | 2.818 | 2.796 | 2.811 | 2.778 | 2.945 | 2.829 | 0.066 |

Descriptive statistics

| **Exp. groups** | **Light intensity** (mW/cm²) | **Distance of curing tip** (mm) | Mean | SD | N |
|---|---|---|---|---|---|
| 1./2. | 300 | 0 | 2.74850 | .248194 | 2 |
| 3./4. | | 8 | 2.19950 | .234052 | 2 |
| 5./6. | 650 | 0 | 2.97450 | .303349 | 2 |
| 7./8. | | 8 | 2.40300 | .299813 | 2 |
| 9./10. | 1100 | 0 | 3.14450 | .265165 | 2 |
| 11./12. | | 8 | 2.59400 | .332340 | 2 |

Multivariate analysis of variance (MANOVA)

| Variables | Sum of squares | df | Mean squares | F Value | Sig. |
|---|---|---|---|---|---|
| ***Intensity*** | .313 | 2 | .157 | 1.962 | 0.221 |
| ***Distance*** | .931 | 1 | .931 | 11.657 | 0.014* |
| Error | .479 | 6 | .080 | | |

| Exp. groups | Light intensity (mW/cm²) | Exposure time (s) | Mean | SD | N |
|---|---|---|---|---|---|
| 1./3. | 300 | 20 | 2.30350 | .381131 | 2 |
| 2./4. | | 40 | 2.64450 | .395273 | 2 |
| 5./7. | 650 | 20 | 2.47550 | .402344 | 2 |
| 6./8. | | 40 | 2.90200 | .405879 | 2 |
| 9./11. | 1100 | 20 | 2.65800 | .422850 | 2 |
| 10./12. | | 40 | 3.08050 | .355675 | 2 |

| Variables | Sum of squares | df | Mean squares | F Value | Sig. |
|---|---|---|---|---|---|
| ***Intensity*** | .313 | 2 | .157 | 1.007 | 0.420 |
| ***Exposure time*** | .472 | 1 | .472 | 3.034 | 0.132 |
| Error | .933 | 6 | .156 | | |

| Exp. groups | Exposure time (s) | Distance of curing tip (mm) | Mean | SD | N |
|---|---|---|---|---|---|
| 1./5./9. | 20 | 0 | 2.76333 | .192022 | 3 |
| 3./7./11. | | 8 | 2.19467 | .162531 | 3 |
| 2./6./10 | 40 | 0 | 3.14833 | .207018 | 3 |
| 4./8./12 | | 8 | 2.60300 | .232233 | 3 |

| Variables | Sum of squares | df | Mean squares | F Value | Sig. |
|---|---|---|---|---|---|
| ***Exposure time*** | .472 | 1 | .472 | 11.79 | 0.009* |
| ***Distance*** | .931 | 1 | .931 | 23.25 | 0.001* |
| Error | .320 | 8 | .040 | | |

*Table 4. Depth of cure (DOC) Significance of influence of different variables*

| **Light intensity** (mW/cm²) | **Distance of curing tip** (mm) | **DOC** (mm) |
|---|---|---|
| 300 | 0 | 2.74850 |
| | 8 | 2.19950 |
| 650 | 0 | 2.97450 |
| | 8 | 2.40300 |
| 1100 | 0 | 3.14450 |
| | 8 | 2.59400 |
| Distance of curing tip Sig. P = 0.014*<br>*Increased distance of curing tip significantly decreases DOC regardles of light intensity | | |

| **Light intensity** (mW/cm²) | **Exposure time** (s) | **DOC** (mm) |
|---|---|---|
| 300 | 20 | 2.30350 |
| | 40 | 2.64450 |
| 650 | 20 | 2.47550 |
| | 40 | 2.90200 |
| 1100 | 20 | 2.65800 |
| | 40 | 3.08050 |
| Exposure time Sig. P = 0.132 | | |

| **Distance of curing tip** (mm) | **Light intensity** (mW/cm²) | **DOC** (mm) |
|---|---|---|
| 0 | 300 | 2.74850 |
| | 650 | 2.97450 |
| | 1100 | 3.14450 |
| 8 | 300 | 2.19950 |
| | 650 | 2.40300 |
| | 1100 | 2.59400 |
| Light intensity Sig. P = 0.221 | | |

| **Distance of curing tip** (mm) | **Exposure time** (s) | **DOC** (mm) |
|---|---|---|
| 0 | 20 | 2.76333 |
| | 40 | 3.14833 |
| 8 | 20 | 2.19467 |
| | 40 | 2.60300 |
| Exposure time Sig. P = 0.009*<br>*Extended exposure time increases DOC significantly regardless of the distance of curing tip | | |

| **Exposure time** (s) | **Light intensity** (mW/cm²) | **DOC** (mm) |
|---|---|---|
| 20 | 300 | 2.30350 |
| | 650 | 2.47550 |
| | 1100 | 2.65800 |
| 40 | 300 | 2.64450 |
| | 650 | 2.90200 |
| | 1100 | 3.08050 |
| Light intensity Sig. P = 0.420 | | |

| **Exposure time** (s) | **Distance of curing tip** (mm) | **DOC** (mm) |
|---|---|---|
| 20 | 0 | 2.76333 |
| | 8 | 2.19467 |
| 40 | 0 | 3.14833 |
| | 8 | 2.60300 |
| Distance of curing tip Sig. P = 0.001*<br>*Increased distance of curing tip significantly decreases DOC regardles of exposure time | | |

## Discussion

The findings of the present study indicate that the first research hypothesis stating that there will be no differences in the depth of cure of composite specimen light cured by different curing light intensities, from different distances of curing tip, and in different exposure time durations was partially rejected. For all curing protocols tested, there were significant differences in the depth of cure when cured from different distances, regardless of exposure duration and light intensity. There were also significant differences in the depth of cure when different exposure times were used at different distances. However, exposure duration did not show a significant impact on the depth of cure when different light intensities were used. The second working hypothesis, stating that an extended exposure duration to curing light from a distance of 8 mm would not significantly increase the depth of cure of resin-based composite, was rejected. When irradiated from a distance of 8 mm, extended exposure time significantly increased the depth of cure, regardless of the light intensity used. The third working hypothesis of our research, stating that a higher intensity (irradiance) of curing light from a distance of 8 mm would not significantly increase the depth of cure of resin-based composite, was accepted. When irradiated from 8 mm, higher light intensity did not significantly increase the depth of cure. There were differences in depth of cure when different light intensities were used, but those differences were not significant.

When using conventional composites, clinicians assume that the polymerization light emitted from LCU can adequately polymerize a 2 mm-thick layer of material[33]. Many studies reported that the distance between curing tip and composite[21], the inclination of the light beam[19], the light beam heterogeneity[16,19,23], and the emission spectrum of the light-curing device[19,34,36] may affect the curing depth of resin-based composites in different clinical situations. Some authors suggest that ≥1000 mW/cm2 and 20 sec of exposure time are imperative to accomplish successful polymerization[43]. The results of our study show that conventional RBC cured with different curing protocols resulted in a depth of cure that exceeded the 2 mm depth indicated by the manufacturer and by far exceeded the requirements of the 1.5 mm minimum depth of cure of the ISO 4049 standard (Figure 2). However, the samples polymerized by CP 300/20/8 and CP 650/20/8 showed threshold values of 2.03 mm and 2.19 mm, respectively (Figure 2). This finding may indicate the possibility of inadequate polymerization in similar clinical situations.

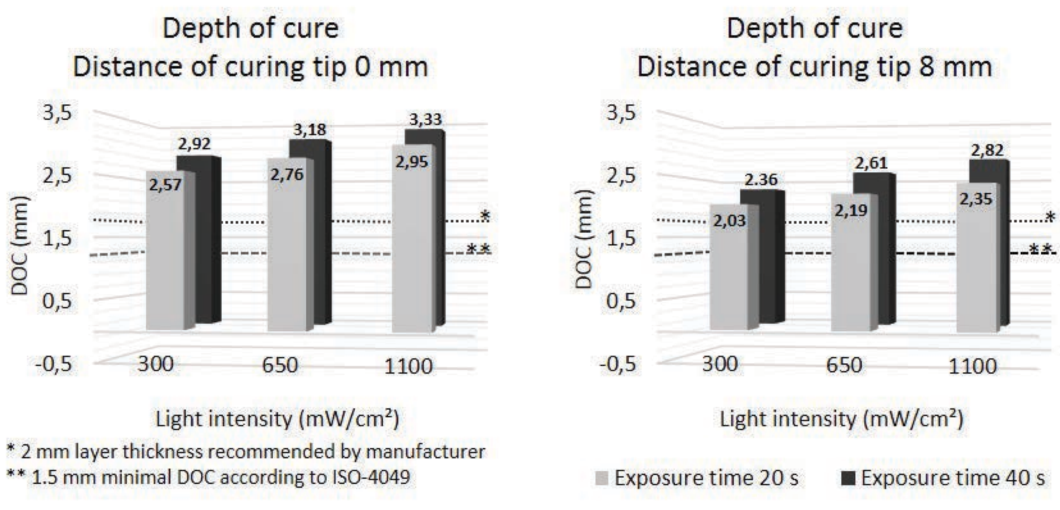


*Figure 2. Depth of cure (Distance of curing tip 0 and 8 mm)*

Distance showed a significant influence on the depth of cure in this study. With increased distance from the source of the polymerization light, the dispersion of light is also increased, which means that the polymerization potential of light decreases linearly with increasing distance from the source from the material[44]. Since the light intensity decreases with distance from the source, the curing tip should be in direct contact with the surface of the restoration or 1 mm away[45]. The polymerization time recommended by the manufacturers generally implies 1-2 mm between the curing tip and the surface of the material. In clinical situations of deep cavities in classes I and II, due to the distance of the curing tip, dispersion of light energy occurs, which can lead to deficient polymerization of the composite layer at the gingival floor of the cavity[46]. The distance between the curing tip and the cavity floor of a typical Class II preparation was reported by Price to be in the range of 6.3 mm with a standard deviation of 0.7 mm in 15% of restorations deeper than 8 mm[47]. This distance can be even increased when separation rings or matrices get in the way of the light tip. The distance between the tip of the curing tube and material is a factor that is difficult to control because it depends on the carious destruction of the tooth, the size and position of the cavity, and the morphology of the tooth crown[46]. As a result, in these clinical situations, the recommended exposure time may be insufficient for adequate polymerization of the material. By increasing the tip distance from 2 mm to 9 mm, the light intensity of different devices is reduced by 35 to 68% [44,48-50]. In order to achieve good polymerization of deep layers in deep civites, it is recommended to apply thinner layers of material, to use a brighter shade of composites, and have a longer exposure time[46,51]. Some authors recommend applying higher light intensity when cured from a distance[45]. However, with the incremental technique of placing the composite, the illumination of each subsequent layer of the composite has a positive polymerizing effect on the previous layer[52]. Our findings that increased distance has a significant impact on the depth of cure of RBC are in accordance with the results of Lindberg *et al*.[53] and Corciolani *et al*.[54] and Malhotra *et al*.[55], and Aravamudhan *et al*.[56], regardless of LCU type (QTH or LED).

The duration of exposure time at different distances from the source proved to have a statistically significant impact on the depth of cure. Although at different light intensities, by extending the irradiation time, a greater depth of cure is achieved, these differences were not statistically significant (Tables 3 and 4). These results are in accordance with the research of Lindberg *et al.*[53], Antonson *et al*.[57], and Rodriguez *et al*.[51], who found a significant increase in the depth of polymerization with an increase in exposure time (20 and 40 sec). Other researchers also concluded that extending the duration of exposure time increases the depth of cure of conventional and bulk-fill composites[42,58].

Light intensity in this study did not show a significant influence on the depth of cure, regardless of the exposure time and distance ($P=0.221$; $P=0.420$). The results of this research are in accordance with the results of the research of Scotti et al. and Odum *et al.,* which established that a greater depth of cure is not achieved by increasing the light intensity, but by extending the exposure time[59,60]. Ernst *et al.* examined the influence of LED and halogen LCUs of different light intensities and found that at 7 mm distance, a higher DOC is achieved with a higher light intensity or with an extension of the exposure time to 40 sec, which in terms of light intensity is not in agreement with the results of our research[61]. Malhotra *et al.* also concluded that light intensity and type of LCU (QTH or LED) did not have a significant impact on the cure depth of RBC [55]. Hasslen *et al*. reported that ultra-high light intensity (cca. 2500 mW/cm²) irradiated in 6 sec produced the same DOC of samples as high light intensity (cca. 1300 mW/cm²) in 12 sec, and standard intensity (cca. 820 mW/cm²) in 20 seconds did[62]. The theoretical basis for the reduction of irradiation time using high-power polymerization lamps is the validity of the exposure reciprocity law (ERL), which states that the degree of monomer double-bond conversion (DC) in light-cured composites depends on radiant exposure E (J/cm²) i.e., light energy delivered to the composite surface in the region of photoinitiator absorption wavelengths[63]. Jakupović *et al*. assessed high- and low-power curing on conventional and bulk-fill composites and stated that the quality of polymerization is more dependent on material composition (filler content, photoinitator system) than on the light-curing protocol[64]. Mousavinasab *et al*. found that the exposure time has a greater impact on the depth of cure than the light intensity[65]. Very short irradiance (3 sec) with ultra-high intensity of light (4500 mW/cm²) in the study of Daugherty et al. produced lower DOC values than 2000 mW/cm² in 20 sec, indicating that exposure time is a more important factor for adequate polimarization than light intensity[66].

## Conclusions

Finally, considering the limitations of this laboratory study that used depth of cure to define the impact of polymerization light intensity, distance of curing tip, and duration of exposure time, it was concluded that:

There were significant differences in the depth of cure depending on the curing protocol used.

The conventional resin-based composite (Tetric EvoCeram) achieved greater than a 2 mm depth of cure when different light intensities from different distances and different exposure durations were used.

The depth of cure is dependent on the distance of the light resource and the duration of exposure to polymerization light. The depth of cure decreases with increasing distance of the curing tip. In such clinical situations, extended irradiation time can increase the depth of cure, regardless of the light intensity.

The exposure reciprocity law cannot be used as a universal rule and is applicable only to some extent. Despite of high irradiance, lower DOC was observed at an increased distance of curing tip and a short irradiation time.

### *Author Contributions*

Conceptualization, D.D., S.J. (Selma Jakupović) , S.K., D.H. and N.P.; methodology, D.D., S.J. (Selma Jakupović), S.K. and N.P.; software, N.P.; validation, E.K., S.J. (Senka Jakupović); formal analysis, D.D., S.J. (Selma Jakupović), S.K., N.P. ; investigation, N.P., E.K.; resources, D.D., S.J. (Selma Jakupović), N.P., D.H.; data curation, D.D., S.J.(Selma Jakupović), and N.P.; writing-original draft preparation, D.D., S.J. (Selma Jakupović) and N.P.; writing-review and editing D.D., S.J. (Selma Jakupović); visualization, N.P.; supervision, N.P. and S.K.; project administration, S.J. (Selma Jakupović), D.D., N.P.; funding acquisition, N.P., S.J. and D.D. All authors have read and agreed to the published version of the manuscript.

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