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Correlation between Depth of Cure and Distance between Curing Light Tip and Resin Surface

SUMMARY

Aim: *to examine the relation between depth of cure and irradiation distance with different restorative composites and light curing units (LCUs).*

Materials and Methods: *3 different composite resins (Simile, Filtek Z250, Filtek Supreme XT) and 3 light curing units (Elipar High Light, Elipar Visio and LEDemetron) were used. Depth of cure was tested according to ISO 4049. A stainless steel mould was used for the preparation of specimens (8mm long, 4mm in diameter). The mould was filled with 1 of the composites and irradiated for 40sec. The distance between the exit window of the lamps and the surface of the composite resin was 0, 2, 4, 8, 16 and 32 mm. After polymerization, the height of the cylinder of the cured material was measured with a digital micrometer (accuracy ± 0.1 mm). The relation between the irradiation distance and the depth of cure was analyzed by linear regression (p<0.05).*

Results: *Analyses of regression coefficient ranked the LCUs in order of decreasing effectiveness as follows: LEDemetron > Elipar High Light > Elipar Visio. All composite resins had, with all LCUs, the same reduction in the depth of cure with increased irradiation distance.*

Conclusions: *The depth of cure of light-activated composites decreased in a moderate and linear manner with the distance between the exit window and the surface of the material.*

Keywords: Composite Resins; Depth of Cure; Polymerization; Light Curing Unit

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Introduction

Depth of cure of a light-activated composite resin is an important property because poorly polymerized resin can lead to undesirable effects, such as gap formation, marginal leakage, recurrent caries, adverse pulpal effect and ultimate failure of restoration[1]. Depth of cure can be defined as the extent of quality resin polymerization deep from the surface of composite restoratives.

The depth of cure of visible-light activated composites is affected by factors such as the materials' filler composition, resin chemistry, shade and translucency, catalyst concentration, intensity and spectral distribution of the light source and duration of irradiation[2]. Depth of cure of visible-light activated composites also depends on the separating medium (intervening plastic matrix or light tip sheath) and the distance between the light source and surface of the restorative material[3].

An array of methods, such as hardness tests[4-6], interaction with colour dyes[7], translucency changes[8], double-bond conversion[9,10], nuclear magnetic resonance microimaging[11], penetration tests[11-13] and scraping tests[14-18] have been used to measure the depth of cure of resin-based composites.

Layering of light-activated composites is a must in deep cavities to obtain a sufficient degree of conversion reduction of the polymerization shrinkage and thereby the risk of cuspal flexure and marginal gaps[19-21]. While light activating composite resins the light tip may not always be close to the surface of the restoration, when using a layering technique in the proximal part of class-II cavities. This problem has been identified by several authors, and a not infrequent citation in the dental literature has been that the loss of light intensity of curing units follows the law of *Inverse Square*.

Moseley et al[22] studied the intensity loss of curing units versus distance between the exit window and composite and found that the loss of intensity was linear. Hansen and Asmussen[23] found in a later study that a microfilled composite was cured to a depth of 4.1 mm with close contact between resin and exit window of the lamp tested; but the total curing depth was only reduced from 4.1 to 2.7 mm when the irradiation distance was increased to 18 mm. They also found that the depth of cure decreased moderately and in a linear manner with increasing irradiation distance[16].

The **aim** of this study was to examine the relation between depth of cure and irradiation distance with different restorative resins and with a range of low to high light intensity curing lamps.

Materials and Method

3 different composite resins were used in this study. Filtek Z250 (shade A2, 3M ESPE, St Paul, MN, USA) and Simile (shade A2, Pentron, Wallingford, USA) as micro-hybrid composites, and Filtek Supreme XT (shade A2, 3M ESPE, St Paul, MN, USA) as a nano-hybrid composite.

2 halogen light-curing units (Elipar High Light, Elipar Visio) and a LED unit (LEDemetron) were selected to provide lights of low to high output (Tab. 1). The intensity of the light sources was checked with a radiometer (Hilux, Curing Light Meter, Benlioglu Dental Inc, Turkey) before the start of each experimental session.

Table 1. Type, manufacturer and light intensity of the 3 light curing units used

LIGHT Curing Unit	Manufacturer	Intensity
LEDemetron (LED)	Kerr Corp, Danbury, USA	1220mW/cm^2
Elipar High Light (EHL)	3M ESPE, Seefeld, Germany	780 mW/cm^2
Elipar Visio (EV)	3M ESPE, Seefeld, Germany	400 mW/cm^2

These devices were selected to represent the range of light-curing units (LCUs) still in use in clinical practice. The composite resins were stored and used at room temperature prior to placement, as insertion temperature has been shown to influence polymerization of composite resin using different LCUs[24].

Scraping test methodology was performed according to methods of ISO 4049 (1988) - International Organization for Standardization for polymer based filling materials[25].

A stainless steel mould was used for the preparation of the specimens, 8 mm long x 4 mm in diameter (Fig. 1). The mould was placed onto a strip of transparent film (Directa AB, SE-194 27, Upplands Vasby, Sweden) on glass microscope slide. The mould was overfilled slightly and a second strip of the transparent film was placed on the top, followed by the second microscope slide. The mould and strips of film were pressed between the glass slides to excess the composite resin. The microscope slide covering the upper strip of film was removed and the composite resin light cured for 40 sec using a LCU. The distance between the exit window of the lamp and the surface of the composite resin was 0, 2, 4, 8, 16 and 32 mm (Fig. 2). 5 specimens were made for each composite resin and for each light-curing mode. This method has been used extensively by several researchers[3,15-18].

The rationale for using distances of 16 and 32mm, which are not clinically relevant, was to get a more comprehensive understanding of the relation between irradiation distance and depth of cure.

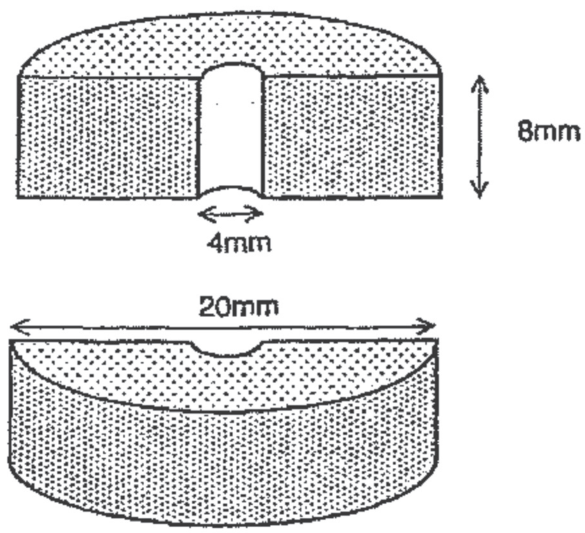

Figure 1. Illustration of the split stainless steel mould for curing depth study

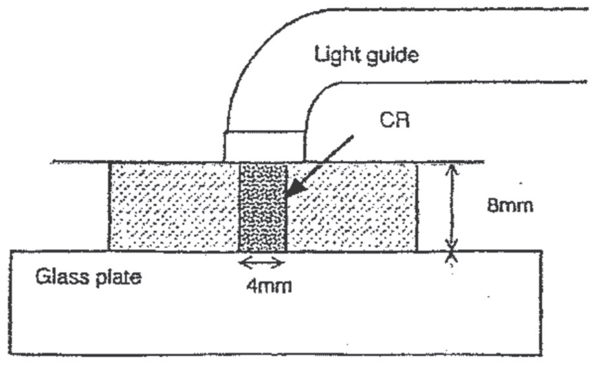

Figure 2. Illustration of the procedure for curing depth study

After polymerization, the specimens were removed from the mould and the inadequately cured soft restorative material was removed from the bottom of the mould with a plastic spatula. The length of the cylinder of the cured material was measured with a digital micrometer to an accuracy of ± 0.1 mm (Powerfix, Electronic Digital Caliper, Mod.Z22855, London, UK).

The relation between the irradiation distance and the depth of cure was analyzed by 3-Way ANOVA and linear regression[26]. The various combinations of LCU and composite resin were also analyzed as to differences, between regression coefficients a and b (*regression coefficient a* = depth of cure with close contact between light tip and restorative composite; *regression coefficient b* = reduction of the depth of cure with the increased irradiation distance). The significance level was set to $p<0.05$.

Results

The depths of cure calculated by measuring the thickness of cured composites remaining, according to the ISO 4049 test, at each separation and for each light curing unit, are presented in table 2. The LCU with the lowest light output had the least depth of cure and the LCU with the greatest light output had the greatest depth of cure.

Table 2. Mean depth of cure of composites (mm), following 40 seconds light-cure with halogen units and with LED light unit at increasing distances of the light tip from the composite

Distance (mm)	0	2	4	8	16	32
A. Filtek Z250						
LEDemetron	6.9 (0.32)	6.7 (0.28)	6.5 (0.30)	5.8 (0.24)	4 (0.12)	2.2 (0.14)
Elipar High Light	5.9 (0.28)	5.7 (0.22)	5.4 (0.20)	4.7 (0.20)	3.5 (0.18)	2.2 (0.10)
Elipar Visio	5.4 (0.26)	5.3 (0.18)	5.1 (0.16)	4.5 (0.16)	3.1 (0.12)	1.9 (0.12)
B. Filtek Supreme XT						
LEDemetron	6.1 (0.27)	5.9 (0.30)	5.6 (0.18)	4.5 (0.14)	3.5 (0.16)	1.9 (0.10)
Elipar High Light	5.3 (0.24)	5.1 (0.26)	4.9 (0.18)	4.3 (0.16)	3.2 (0.18)	2.1 (0.16)
Elipar Visio	4.7 (0.26)	4.6 (0.20)	4.5 (0.18)	3.8 (0.12)	2.6 (0.12)	1.6 (0.11)
C. Simile						
LEDemetron	4.9 (0.30)	4.7 (0.26)	4.3 (0.20)	3.9 (0.14)	2.8 (0.22)	1.6 (0.10)
Elipar High Light	4.5 (0.20)	4.3 (0.16)	4.1 (0.16)	3.7 (0.18)	2.7 (0.12)	1.7 (0.10)
Elipar Visio	3.9 (0.16)	3.8 (0.18)	3.6 (0.19)	3.3 (0.17)	2.3 (0.16)	1.3 (0.12)

Analyses of 3-Way ANOVA indicated that there were statistically significant differences between composite resins and LCUs (Fig. 3).

The correlation between depth of cure and irradiation distance is presented in Figs. 4-6, which also gave the linear regression lines.

Analyses of *regression coefficient a* (depth of cure with close contact between light-tip and surface of composite resin) ranked the LCUs in order of decreasing effectiveness as follows: LEDemetron > Elipar High Light > Elipar Visio. Analyses of *regression coefficient a* ranked the composite resins in order of decreasing depth of cure as follows: Filtek Z250 > Filtek Supreme XT > Simile.

As to *regression coefficient b*, there were statistically significant differences between the slopes of the 9 regression lines.

The 3 composite resins with the 3 LCUs had not the same reduction in the depth of cure with increased irradiation distance.

Discussion

This study evaluated the relationship between depth of cure and irradiation distance with 3 different restorative composite resins and 3 different light curing units. The 3 light curing units were selected to reflect a range of intensities from very low to high, as used in clinical practice, as identified in previous studies[16].

Posterior resin based materials required a high depth of cure rate for adequate cured restorations, because of thickness of restorative materials due to the cavity depth. Directing the LCU to the gingival margin in Class II cavities is difficult. Inadequate depth of cure can cause a weakening of adhesive properties and reduction of flexural strength, colour stability, micro-hardness and wear resistance of the composite restorations[27].

In light-curing composite resins, the light penetrates the upper part of the resin, but absorption in the material prevents the light from reaching the deeper parts. The free radicals generated in the upper parts initiate polymerization, but the polymerization will not propagate in depth beyond a certain limit.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Corrected Model	547,139(b)	17	32,185	351,275	,000	,960	5971,671	1,000
Intercept	3951,445	1	3951,445	43127,466	,000	,994	43127,466	1,000
Material	67,860	2	33,930	370,325	,000	,746	740,650	1,000
Lamp	37,620	2	18,810	205,301	,000	,620	410,602	1,000
Material * Lamp	2,381	4	,595	6,496	,000	,093	25,984	,991
Distance_mm	413,527	1	413,527	4513,379	,000	,947	4513,379	1,000
Material * Distance_mm	9,073	2	4,537	49,515	,000	,282	99,031	1,000
Lamp * Distance_mm	5,895	2	2,948	32,171	,000	,203	64,343	1,000
Material * Lamp * Distance_mm	,534	4	,134	1,458	,215	,023	5,833	,450
Error	23,089	252	,092					
Total	5070,470	270						
Corrected Total	570,228	269						

b R Squared = ,960 (Adjusted R Squared = ,957)

Figure 3. Comparisons between composite resins and LCUs (3-Way ANOVA)

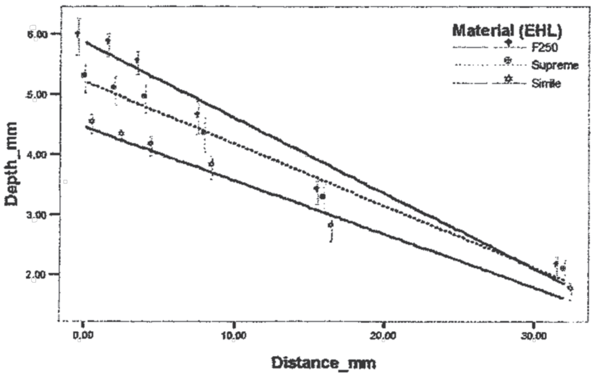

Figure 4. Elipar High Light: relation between depth of cure and irradiation distance (mean and standard deviation)

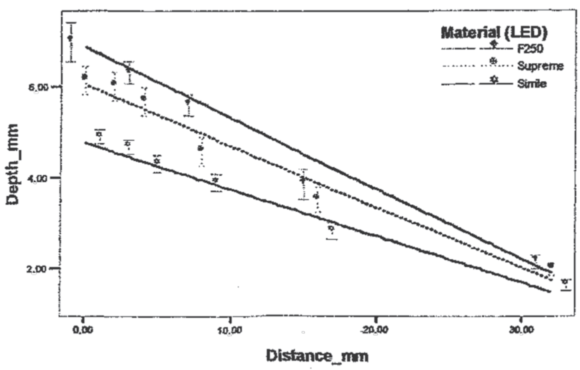

Figure 6. LEDemetron: relation between depth of cure and irradiation distance (mean and standard deviation).

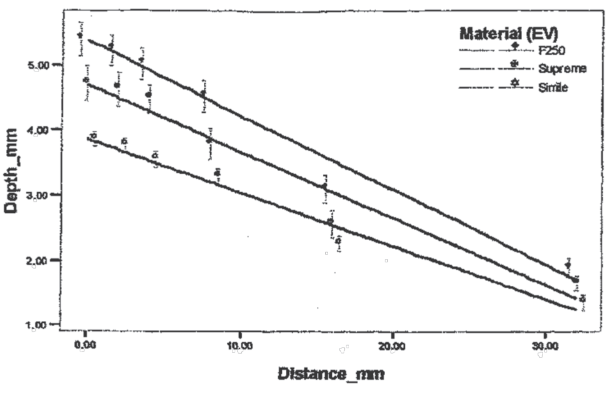

Figure 5. Elipar Visio: relation between depth of cure and irradiation distance (mean and standard deviation).

Within the limits of experimental error, the mean depths of cure obtained using LED LCU were about 15-23% higher than those obtained with the halogen LCUs, for the 3 composite resins used. The larger depth of cure obtained with the LED lamp can be explained by the greater light intensity of the irradiance produced by this LCU.

In this study depth of cure was greatly affected by light source-specimen distance. At a distance 8 mm, LEDemetron cured ~5.8 mm of composite resin Filtek Z250, ~4.7 mm of the Elipar High Light, and ~4.5 mm of the Elipar Visio. The maximum depth of cure was achieved when the LCU tip was in very close distance to the composite; at 0 mm LED cured ~6.9 mm composite Filtek Z250, ~5.9 mm Elipar High Light, and ~5.4 mm Elipar Visio.

Development of narrower LCU tips, which could be used within the cavity, may help overcome the limitations of curing from distance and ensure that the deepest parts of the restoration receive adequate irradiation.

Shortall et al[11] have described a relation between the depth of cure at increasing distances to $\log_{10}$ of the mean light intensity. Rueggeberg and Jordan[28] and Dunne and Millar[3] showed that the reduction light intensity did not obey the *Inverse Square* law over distances 0-10 mm. Our study did not measure light intensity but showed that increased distance was only reflected to a moderate extent in the depth of cure. We also found that the depth of cure did not follow a law of *Inverse Square* but was reduced in a linear manner with increasing distance between light-tip and composite surface. These findings are in agreement with the results of other studies showing that depth of cure decreased modestly and in a linear manner with increasing distance between light-tip and composite surface[23,24,29].

Depth of cure of light activated dental composites may be assessed directly or indirectly. Indirect methods of assessment include scraping method[14-16], visual method[8] and evaluation of surface hardness[4,5]. Direct methods assess the degree of conversion, such as infrared spectroscopy and laser Raman spectroscopy, and have not been accepted for routine use, as they are complex, expensive and time-consuming[30]. The ISO scraping method used to determine depth of cure is easy to perform and require minimal instrumentation. However, this test provides no indication of quality of cure at any point, including the lower layers adjacent to the soft resin that was removed[31]. While the ISO defines depth of cure as 50% of the length of composite specimens after removal of the uncured material, many studies[8,23,24,32], have defined depth of cure as the total remaining length after uncured material is removed. The LED LCU appeared to function well with light depths of cure even at greater distances and do not support the conclusion of the study of Cacciafesta et al[33]. The reduced values recorded in their study may have been due to the lower light intensity, not to the type of light source.

Conclusions

The results of this study show that the depth of cure of light activated composite resins does not follow a law of *Inverse Squares* but decreases in a moderate and linear manner with the distance between the exit window and the surface of the material. The reduction in depth of cure at different distances was less than expected. This finding implies that composite resins even in deep proximal cavities may be sufficiently cured if one uses an effective LCU and thin layers of restorative material.

LED LCU did not perform differently from other types of LCU as distance increased. Type of the restorative composite and LCU used influence the depth of cure of the restoration.

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