Effect of Distance on Light Transmission Through Polymerized Resin Composite

Keywords

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ABSTRACT

Objective: Light transmittance of dental composites varies between products and shades, but also light curing units differ to each other in their irradiance and fiber optic structure of curing tip. The aim of this study was to investigate whether there is linear relationship between the distance of the curing tip to the resin composite and irradiance at lower surface of the resin composite. Materials and Methods: Disks of 1 mm thickness (6mm diameter) were fabricated. Light transmittance (intensity) through the disk was measured at distance of 0, 2, 4, 6, 8, 10 mm from the light tip with two light curing units Elipar S10 (3M-ESPE) and Silverlight (GC). Irradiance ratio (irradiance on the sensor surface without the composite disk / with the composite disk) was calculated and plotted against the distance of the light curing tip. Statistical analysis was carried out using analysis of covariance (ANCOVA, Tukey's, α =0.05). Results: Irradiance ratio varied between 18% to 24% with Silverlight and 21% to 26% with Elipar S10 light curing units. There were statistically significant differences between the ratios with different distances of the light curing tip ($p<0.05$). Interestingly, the highest irradiance ratio for Elipar S10 unit was found with 4 mm distance of the tip, whereas Silverlight unit had the highest ratio with 6 mm distance. Out of two tested resin composites, the flowable composite showed higher irradiance ratio than regular packable resin composite. Conclusions: Increase of distance of the light curing tip from the composite surface decreased the absolute irradiance underneath of composite, as expected. However, there seemed to be device dependent optimal distance of 4-6 mm to reach the most efficient irradiance ratio through the composite resin keeping in mind that most efficient transmission of light through the material is reached by having light curing tip in contact to the material.

INTRODUCTION

Light-curing of dental resin composites has proved to be one of the key parameters for the clinical success of a resin based restoration. Resin composite materials used in dentistry consist of two main components: Organic resin matrix and inorganic fillers which are bound to the matrix by silane coupling agents.[1] The function of the organic polymer matrix is to bind inorganic filler particles together and protect the filler particles. As a consequence of the bonded filler phase, these materials had much better optical,[2] mechanical and other properties (eg. decreased polymerization shrinkage and higher wear resistance)[3-7] than that of unfilled resins.

Light transmittance of dental composites is important in two respects: to reach adequate polymerization of the resin matrix of the composite, and in the case of indirectly made restorations polymerization of resin adhesives and luting cements by light. Light transmittance varies between products due to differences in e.g. filler loading, composition of resin matrix and presence of colour pigments.[8] Coefficient of attenuation (extinction) determines the materials property to hinder light transmission. Flowable resin composites differ from universal resin composite mainly because of their lower filler loading [9,10] and also their light transmission properties may vary.

In currently used resin composites the composition of organic resin matrix is most commonly an aromatic or aliphatic monomer such as bisphenol-A-glycidyl-methachrylate (bis-GMA), triethyldimethachrylate (TEGDMA), or urethane dimethacrylate (UDMA). Other cross-linking monomers are ethoxylated bisphenol-A dimethacrylate (bisEMA), ethylene glycol dimethacrylate (EGDMA).[3, 6] These monomers have reactive double bonds at each end of the molecule that are able to undergo addition polymerization (C=C bonds) in the presence of free radicals. Polymerization of the monomers may be initiated by chemical means ("self cure" or autopolymerization) or by light activation. Dual cure is a combination of light and autopolymerizited curing.[7] Light refraction and attenuation coefficients of monomers change during polymerization allowing light to be better transmitted through the cured composite resin than through uncured resin composite.[11] Inorganic fillers used in dental composites are typically silicon dioxide (SiO_2), zirconium dioxide (ZrO_2) or different kind of silica whereas $BaAlSiO_2$. Size of the fillers vary 0.1-10 µm and nowadays also nano -sized (<100 nm) is being used and they influence polymerization e.g. by scattering the curing light.[6]

LED curing units differ to each other in terms of type of the light emitting system, irradiance and design of the curing tip.[12] It is known that by increasing the distance from light tip the irradiation intensity per surface area decreases.[13] It is also known according to the Beer-Lambert law, there is nonlinear relationship between the thickness of the material and transmitted light irradiance power. However, it is not well known to what extent an additional material between the curing tip of varying distances influences the radiation intensity underneath of composite material.[14] This could have an impact in reaching optimal curing of deepest parts of fillings and achieving proper bonding to adhesive resins.

The aim of this study was to investigate the influence of presence of solid resin composite materials of two types between the light curing tip irradiation sensor to the irradiance which was measured under the composite. For this comparison, the ratio of radiation intensity with certain distance of the light tip with and without additional solid material was calculated.

MATERIALS AND METHODS

In this study two LED light curing unites (LCU) were used: Elipar S10 (3M ESPE Elipar, St.Paul, USA) and Silverlight (GC, Tokyo, Japan). According to instruction manuals of the devices the maximum power output for Elipar was 1200 mW/cm^2 and for the Silverlight is minimum-maximum 1200-1500 mW/cm^2. Utilizable wave length range for Elipar S10 was 455 nm (+/-10nm) and for Silverlight 440 nm-465 nm. The light tip exit diameters of these LCUs were Elipar Ø10 mm and Silverlight Ø8 mm and the tips consisted of multiple coherent light transmitting optical fibers (*Figure 1*).

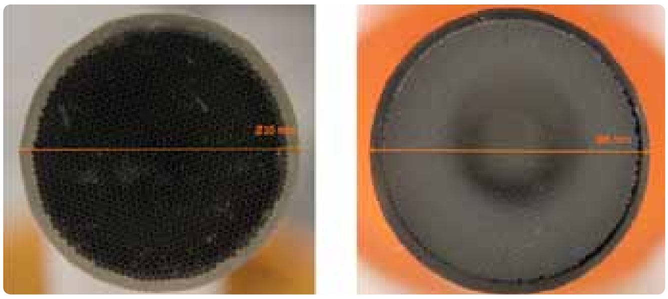

Figure 1: Light tip of Elipar S10 and Silverlight. Distribution of effective light flow could differ from due to diameter of the tip. (Elipar S10 Ø10 mm, Silverlight Ø8 mm). The tips are consisted of multiple coherent optical fibers

Table 1. Materials used in this study

Material/Brand Name	Composition	LOT number	Shade
3M ESPE Filtek™ Supreme XTE Flowable Restorative, (3M ESPE, St.Paul, USA)	Bis-GMA[1], TEGDMA[2] and Procrylate resins. Fillers: ytterbium trifluoride, 20 nm silica filler, 75 nm silica filler, zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia paricles). The in fillerloading is about 65% by weight.	N188467	A3
3M ESPE Filtek™ Supreme XTE Universal Restorative, (3M ESPE, St.Paul, USA)	Bis-GMA, UDMA[3], TEGDMA, PEGDMA[4], and bis-EMA[5] resins.. Fillers: combination of 20nm silica filler, 4 to 11nm zirconia filler, zirconia/ silica cluster filler (comprised of 20nm silica and 4 to 11nm zirconia paricles.) The inorganic filler loading is about 72,5% wt.	N563978	A3 Body

[1]Bis-GMA= Bisphenol A glycidylmethacrylate, [2]TEGDMA = triethyleneglycoldimethacrylate, [3]UDMA = urethane dimethacrylate, [4]PEGDMA = polyethylene glycoldimethacrylate, [5]Bis-EMA = ethoxylated bisphenol-A dimethacrylate

MARC® (Managing Accurate Resin Curing) -Resin Calibrator (©BlueLight analytics inc., Halifax, Nova Scotia, Canada) used in this study was a device by which dental manufacturers, researchers and dentists can control the amount, rate and type of energy delivery to light activated dental material. In this study, the device was used to determine transmission of curing irradiance through resin composite.

Distances of 0, 2, 4, 6, 8 and 10 mm of light tip of two LCUs were used to determine the influence of light tip exit distance to the radiation intensity. A solid piece of resin composite (disc, 1 mm in thickness, 6 mm in diameter) were made of two resin composites (high viscosity resin composite, 3M Supreme XTE A3; flowable composite, 3M Supreme XTE Flow A3). Nominally identical disk-shaped specimen discs were fabricated by round-shaped Teflon ring mold (ø 6 mm). Discs were light cured with 3M ESPE Elipar at room temperature of 22°C for 40s each and stored for 48h at the temperature of 37°C to ensure stabilization of polymerization before their use.[15] Discs were placed between the sensor of the MARC resin calibrator device and the light curing tip. LCU was attached to an adjustable stand. Corresponding distances from the sensor were used and irradiance under the composite disc was measured *(Figure 2)*. There were three discs of both composite materials. Ratio of the irradiance with and without presence of the composite disc was calculated for each curing distance. Statistical analysis was carried using analysis of covariance (ANCOVA, Tukey's, α =0.05)

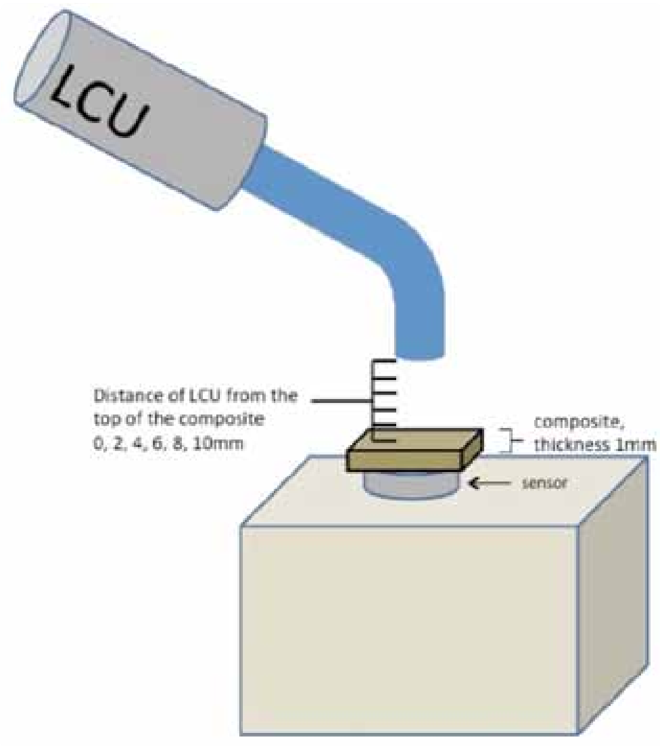

Figure 2: Schematic drawing of the test layout, light curing unit (LCU) was attached to adjustable stand. Round shaped composite covered the whole sensor. Distances varied between 0-10mm

RESULTS

Increase of distance of the light tip from sensor reduced the light power with both light curing units *(Figure 3)*. By placing the composite disc between the tip and the sensor, irradiation power decreased even more. However, by looking at the irradiance ratio, it was found that by using distance of 4-6 mm between the sample surface and the light tip, ratio was higher than in the cases of 0, 2, 8 and 10 mm. This was found for both light curing units and both composite materials *(Figure 4*a and b). Irradiance ratio measured at bottom of composite varied between 18% to 24% with Silverlight GC and 21% to 26% with 3M ESPE Elipar S10. There were statistically significant differences between measured values at different distances ($p<0.05$) (SAS® System for Windows, version 9.3 (SAS Institute Inc., Cary, NC, USA)). The flowable resin composite reached higher irradiance ratio compared to packable composite with both LCUs.

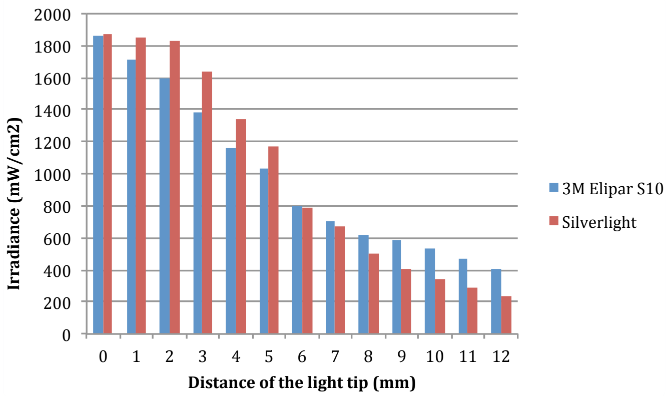

Figure 3: Irradiation power (mW/cm2) decreased with the increased distance (mm) of the light tip

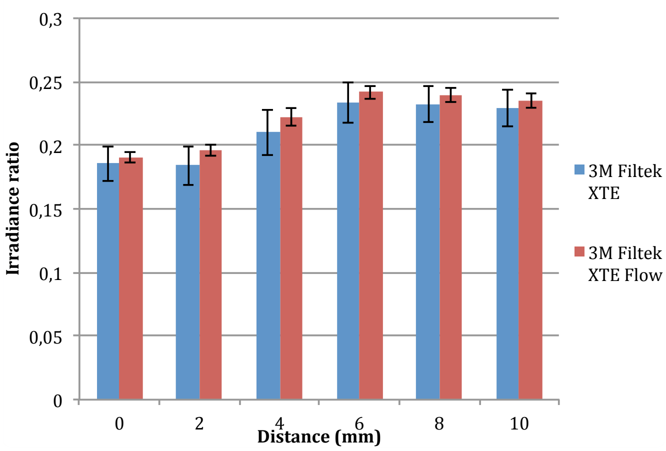

Figure 4a: Light intensity ratio with Silverlight curing device shows the highest ratio at 6mm distance

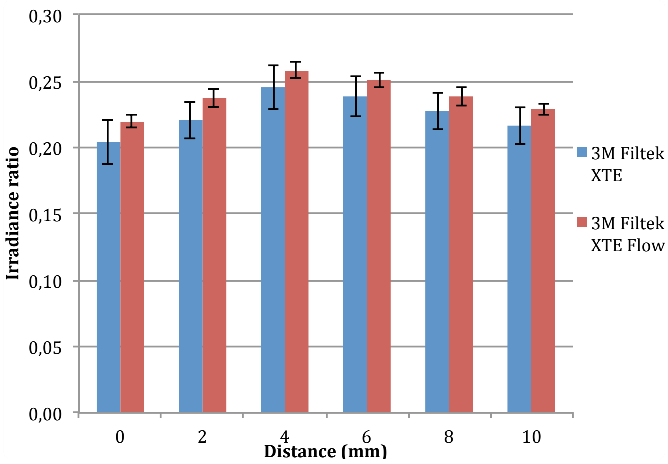

Figure 4b: Light intensity ratio with 3M Elipar S10 curing device shows the highest light intensity ratio at 4mm distance

DISCUSSION

The Clinical success of dental resin composite restorations is based on adequate physical properties of resin composite itself and its adhesion to the underlaying tooth substrate. Both of these are influenced by the degree of curing of the resin system by light initiators. This study found that curing intensity ratio under the resin composite was not linearly related to the distance of the curing light tip from the resin composite as it is normally thought. There are several explanations of what these results could relate to. Firstly, the light distribution and effective diameter (also diameter of the LCU tip) versus diameter of the composite disc and sensor could have affected the irradiance power under the composite. For example, the light tip of the Elipar S10 is larger in diameter than the sensor irradiation power testing device and therefore some of the light energy, which was passing through the light tip did not reach the sensor *(Figure 3*). If the diameter of the light tip and the sensor would have been the same the drop of the irradiance ratio may not have occurred. Secondly, some curing light units may have fiber optics, which focus the light to some extent. The sensor probe in this study was 4 mm in diameter, which was smaller than diameter of the curing light tips. Thus, if focusing of the light has occurred, the irradiance ratio could have been influenced.

The study design simulated clinically the cementation of indirectly made resin composite restorations. Therefore, it could be assumed that particulate fillers of the resin composite could slightly focus the light[2,16,17] and have an effect to the measured irradiance on the sensor underneath of the composite. These explanations require further investigations to be verified.

To ensure that the observed effect of irradiance ratio was not only occurring with the study material of 3M Supreme XTE, we also piloted two other particulate filler composites with light curing unit 3M Elipar S10 LCU. The composites G-aenial Posterior (GC, Tokyo Japan) and Grandio Flow (Voco, Cuxhafen, Germany) demonstrated similar effects with regard to the light attenuation coefficient as the study materials. 2 mm thickness disks were tested and also had similar effects (data not shown).

From the clinical perspective, the results of this study suggested that small distances of light tip of the curing unit from the composite surface did not decrease the irradiance underneath of the resin composite as much as might have been normally expected. However, since the scattering effect of air between the light curing tip and the resin composite material significantly affects light transmission, the distance between the light tip and the material to be polymerized should be as short as possible.[14]

CONCLUSIONS

In situations, where curing light transmission must pass through a polymerized resin composite material (e.g. indirect resin composite restorations), optimal distance of the light tip is obviously at 0mm distance from the resin composite material. However, the decrease of irradiance is not as high as expected, and may differ when increasing the distance of the light curing tip from the upper surface of the resin composite (up to 4-6 mm dependent upon the type of LCU).

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