

## THE EFFECT OF CERAMIC LIGHT SCATTERING ON AN INHOMOGENEOUS BEAM PROFILE

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## ABSTRACT

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**Aim:** The study aimed to measure light scattering of a broad spectrum light curing unit (LCU) as influenced by ceramic type, shade and thickness as well as exposure distance and LCU's position.**Methodology:** A broad spectrum LED LCU (ASCENT OL5) was mounted above a spectrometer (MARC Resin Calibrator, Blue, Light Analytics) at exposure distances of 1.0, 1.5 or 2.5 mm. The position of the center of the head was aligned with the spectrophotometer's sensor and then moved in 1 mm increments in the X-Y plane, while concomitantly recording the irradiance. The process was repeated with lithium disilicate and leucite glass ceramic slabs of similar thicknesses. The loss in irradiance related to the value measured at center position was analyzed by means of linear regressions and multiple ANOVA analysis.**Results:** The regressions showed a good fit (90% - 99%). Moving away from the center showed decreased irradiance. Values of slope obtained were divided by their respective intercept to eliminate the influence of the irradiance measured at the center. Two three-way ANOVA's were performed. One examined the influence of ceramic slab, direction and translucency/shade. It shows only the direction of measurement exhibited significant influence ( $p < 0.0001$ ) on the mean normalized slope values. The other one examined the influence of ceramic slab, direction and slab thickness. It shows the mean normalized slope values are significantly influenced by the direction of measurement and the slab thickness ( $p < 0.0001$ ). Values of the slopes indicated the ceramic scattering effect of the light. Thicker samples showed more scattering.**Conclusion:** The ceramic types, translucency/ shade had no significant effect on the light scattering. The thicker the ceramic the less irradiance changes were found indicating that the ceramics were scattering the light and thus slightly alleviating the effect of the inhomogeneous beam profile.**Keywords:** light curing, beam profile, glass ceramics, light scattering.**OPEN ACCESS** This is an Open Access article under the CC BY-NC 4.0 license.**Peer-Reviewed Article****Citation:** Roulet J-F, Khudhair MM, Shen C. The effect of ceramic light scattering on an inhomogeneous beam profile. *Stoma Edu J.* 2018;5(3):155-160**Academic Editor:** Nicoleta Ilie, Dipl-Eng, PhD, Professor, Ludwig-Maximilians-Universität München, München, GermanyReceived: June 19, 2018  
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## 1. Introduction

Bonded ceramic restorations have been used in dentistry for many decades and the first application was the resin bonded ceramic veneer [1,2]. A few years later, resin bonded ceramic inlays were tested first in vitro [3] and later in vivo [4]. In order to have enough time for the cementation process, clinicians prefer light-cure resin-based composites (RBC), which usually have a lower viscosity (luting agents) to facilitate the process of bonding veneers to teeth [5]. For inlays, which are usually thicker, dual-cure resin-based luting agents are preferred [5], because it is not clear if the blue light may penetrate the ceramic sufficiently to cure the resin-based luting agent. A clinical study has shown that after 12 years of observation, glass ceramic inlays and onlays (Empress, Ivoclar Vivadent) luted with dual-cure resin-based luting agent showed significantly fewer bulk fractures than those luted with a light-cured RBC (Tetric, Ivoclar Vivadent) [6]. Today we know that glass ceramics (leucite and lithium disilicate ceramics) are absorbing the blue light to a considerable amount [7-9]. The degree of light attenuation by overlying ceramics depends on the characteristics of the ceramic

restoration such as optical behavior, crystalline structure, grain size, defects, intrinsic porosity, thickness and shade [10]. After passing 0.5 mm thick ceramic, the irradiance of the light reaching the resin-based luting agent would be reduced by approximately 75% [7]. In order to fulfill its function as luting agent, the resin-based luting agent must be adequately polymerized. This depends on its composition, e.g. the resin mix, the refractive index of the filler, the filler size and size distribution, pigment, and the photo initiators used [11,12]. Using microhardness measurements, for Variolink Estetic (Ivoclar Vivadent) the minimum energy required for adequate curing was found to be approximately 5 J/cm<sup>2</sup> [13].

Modern broad spectrum LED light curing units (LCU), use different types of LEDs, emitting light with different wavelengths (violet light (380 – 420 nm) and blue light (420 – 495 nm) [14,15]. Therefore, they are able to activate different types of photoinitiators [16]. Historically, the most used photoinitiator is champhorquinone (CQ) which has an absorption peak at 470 nm and requires a tertiary amine as co-initiator, which reacts with the activated CQ to create a free

radical used for the polymerization of the resin [17]. These amines, unfortunately, create a yellowing effect on the material over time [17]. Recently manufacturers started to use alternative photoinitiators, such as phenylbis-(2,4,6-trimethylbenzoyl)-phosphine-oxide (TPO) [18] or bis-(4-methoxybenzoyl)diethyl-germane (Ivocerin) [19,20]. These photoinitiators are much more effective than the combination of CQ and tertiary amine, but have absorption peaks below 410 nm (TPO) or 430 nm (Ivocerin), thus requiring broad band LCUs which usually have two different LEDs, (blue and violet light). However, these LED LCUs show more or less pronounced inhomogeneity of the beam profiles [21-24]. This means that not every point on an irradiated surface gets exposed to the same level of irradiation from the different wavelengths, especially in depth [25-27]. Since ceramics scatter the light because its direction is changed at the grain boundaries, one can assume that the local irradiances may vary less, once the light has passed through the ceramic, thus moving the beam profile more towards homogeneity. Furthermore, since the light is absorbed and scattered more with the thicker ceramic, this should affect the homogeneity of the beam profile as well. The objective of this study was to measure the beam homogeneity of an LCU with known inhomogeneous beam profile after the light had passed ceramic slices of different thickness. The null hypothesis tested is that (a) the ceramic has no effect on the beam profile and (b) the thickness of the ceramic has no effect on the beam profile as well.

**2. Materials and Methods**

A broad spectrum LED LCU (ASCENT OLS5, CAO Group South Jordan, UT, USA) was attached to an x-y-z positioning device mounted on an optical bench in order to standardize the positioning of the light beam centered above the cosine corrector light signal collector of a spectrometer (MARC® Resin Calibrator, Blue light Analytics, Halifax, Canada) with the handle towards the right side ("EAST", Figure 1) at an exposure distance of 1.0, 1.5 or 2.5 mm. The diameter of the cosine corrector was 3.9 mm. Using the translation stage, the position of the geometrical center of the LCU was first aligned with that of the cosine corrector and then moved in 1-mm steps in the x-y plane ("EAST" – "WEST" and "NORTH" – "SOUTH") (Fig. 1). At each position, the irradiance was measured in triplicates. The process was repeated with ceramic slabs of 1.0, 1.5 or 2.5 mm thickness while applying the LCU directly on the ceramic slabs. The ceramics used and their translucency/shade are listed in Table 1. IPS Empress CAD slabs were used as cut from blocks with a diamond saw (Isomet 100, Buhler, Lake Bluff, USA), IPS e.max CAD slabs were cut from blocks and processed according to manufacturer's instructions in an oven (Programat P-500, Ivoclar Vivadent), under vacuum, using the following parameters: heating rate of 90°C/min up to 820 °C, holding time 0:10 min, then heating rate of 30°C/min up to 840°C hold for 7:00 min, followed by long-term cooling. The irradiance was assessed at each condition described above and related to the highest irradiance

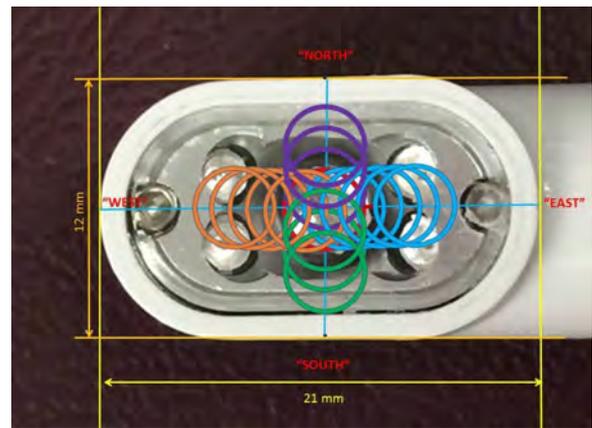


Figure 1. Measuring points as related to the position within the light exit window. Blue cross = geometrical center of the light exiting window. Orange circles = "WEST"; Light blue circles = "EAST"; Purple circles = "North" and green circles = "SOUTH" (From Roulet et al 2018).

Table 1. The ceramics used and their translucency/shade.

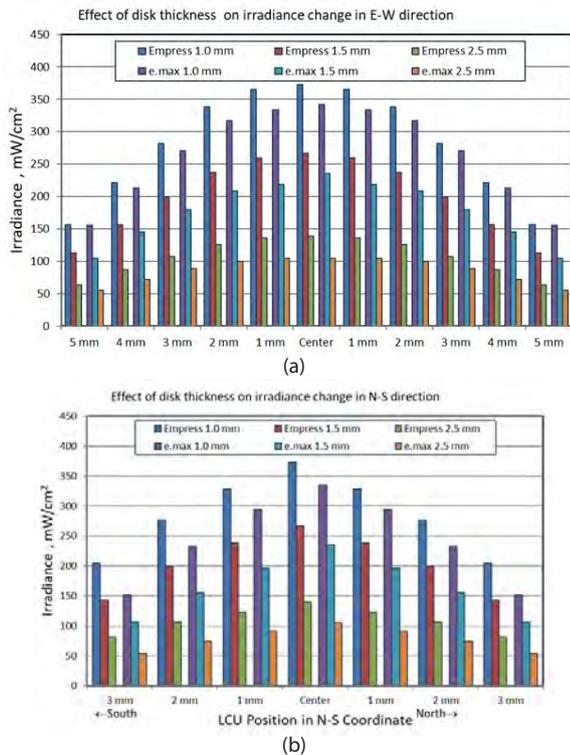
Material	Shade and Translucency					
IPS Empress CAD	A1LT	B1LT	C2LT	D3LT	B3HT	C2HT
IPS e.max CAD	A1LT	B1LT	C2LT	D3LT	B3HT	C2HT

Table 2. The ratio of slope to the intercept of linear regression for all ceramics.

Direction	Translucency /Shade	Empress			e.max		
		1.0 mm	1.5 mm	2.5 mm	1.0 mm	1.5 mm	2.5 mm
East	HTB3	0.135	0.130	0.115	0.135	0.130	0.115
	HTC2	0.129	0.123	0.126	0.129	0.123	0.126
	LTA1	0.130	0.136	0.126	0.130	0.136	0.126
	LTB1	0.132	0.123	0.123	0.132	0.123	0.123
	LTC2	0.134	0.128	0.123	0.134	0.128	0.123
	LTD3	0.130	0.134	0.119	0.130	0.134	0.119
West	HTB3	0.169	0.165	0.141	0.169	0.165	0.141
	HTC2	0.163	0.148	0.129	0.163	0.148	0.129
	LTA1	0.129	0.193	0.149	0.129	0.193	0.149
	LTB1	0.158	0.145	0.142	0.158	0.145	0.142
	LTC2	0.172	0.169	0.146	0.172	0.169	0.146
	LTD3	0.159	0.164	0.157	0.159	0.164	0.157
North	HTB3	0.141	0.140	0.120	0.141	0.140	0.120
	HTC2	0.146	0.132	0.132	0.146	0.132	0.132
	LTA1	0.156	0.141	0.141	0.156	0.141	0.141
	LTB1	0.145	0.142	0.132	0.145	0.142	0.132
	LTC2	0.144	0.137	0.129	0.144	0.137	0.129
	LTD3	0.149	0.143	0.137	0.149	0.143	0.137
South	HTB3	0.159	0.154	0.137	0.159	0.154	0.137
	HTC2	0.168	0.148	0.143	0.168	0.148	0.143
	LTA1	0.170	0.120	0.124	0.170	0.120	0.124
	LTB1	0.168	0.143	0.140	0.168	0.143	0.140
	LTC2	0.167	0.142	0.150	0.167	0.142	0.150
	LTD3	0.162	0.162	0.147	0.162	0.162	0.147

**Table 3.** The ratio of slope to the intercept of linear regression (pooled shades and translucencies).

Direction	No ceramic slabs			Empress			e.max		
	1.0 mm	1.5 mm	2.5 mm	1.0 mm	1.5 mm	2.5 mm	1.0 mm	1.5 mm	2.5 mm
East	0.117	0.122	0.091	0.132±0.002	0.129±0.005	0.122±0.004	0.132±0.020	0.124±0.014	0.116±0.015
West	0.190	0.175	0.141	0.158±0.015	0.164±0.017	0.144±0.009	0.193±0.009	0.187±0.009	0.168±0.009
North	0.163	0.161	0.156	0.147±0.005	0.139±0.004	0.132±0.007	0.155±0.009	0.151±0.008	0.141±0.006
South	0.187	0.172	0.186	0.166±0.004	0.145±0.014	0.140±0.009	0.139±0.015	0.130±0.005	0.114±0.010

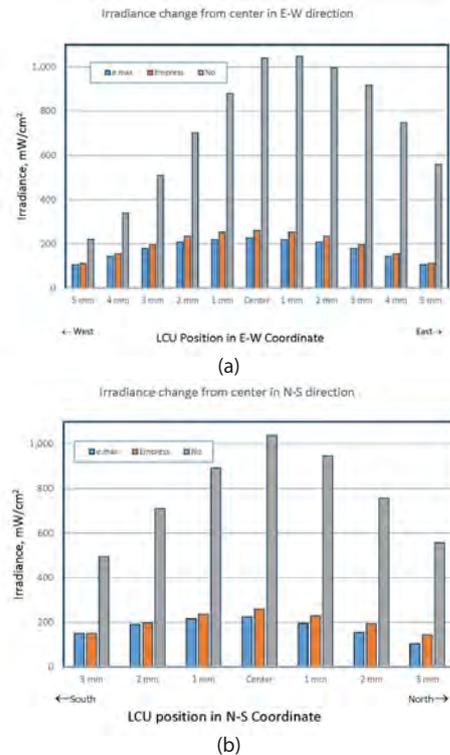


**Figure 2.** Effect of disk thickness on irradiance change in E-W direction (a) and N-S direction (b).

value which was identified in the present study when positioning the LCU directly and centered on the sensor. The percentage of irradiance loss was statistical analyzed by means of linear regression for each material, shade, thickness and direction. The effect of vertical position (distance between LCU and bottom of ceramic or sensor surface), horizontal position or off-set (X-Y plane), glass ceramic type, thickness and shade on the irradiance were analyzed using multiple ANOVA's (SAS 9.4, Cary, NC, USA).

### 3. Results

The numerical data show that there is a linear relationship between the irradiance measured by the MARC unit and the offset distance from the center, excluding the irradiance value at the center. A total of 144 linear regressions (SAS 9.4) were performed from a combination of two ceramic, four directions, three slab thicknesses and six translucency/shade of each ceramic. The degree of fit was in general greater than 90% with the majority in the 99% range. The value of intercept of linear regression is the calculated irradiance at the center and can influence the values of the slope. To normalize the irradiance at the center, each value of slope was divided by the respective value of intercept of the linear regression resulting



**Figure 3.** Irradiance change from center in E-W direction (a) and N-S direction (b).

normalized slope values with a unit of  $\text{mm}^{-1}$ . Although decreasing irradiance with offset distance yielded negative value of the slope; to avoid potential confusion of negative sign in the text absolute value of the normalized slope is used (Table 2).

Two three-way ANOVA's were performed. One examined the influence of ceramic slab, direction and translucency/shade. It shows only the direction of measurement exhibited significant influence ( $p < 0.0001$ ) on the mean normalized slope values. The other one examined the influence of ceramic slab, direction and slab thickness. It shows the mean normalized slope values are significantly influenced by the direction of measurement and the slab thickness ( $p < 0.0001$ ). The mean normalized slope value is in the decreasing order of 1.0, 1.5 and 2.5 mm. For the effect of direction of measurement, the mean normalized slope value is in the decreasing order of North, West, South and East. It means the inhomogeneity of the light curing depends on the device and the thickness of the ceramic slabs. The optical characteristic of the ceramic would have no influence on the inhomogeneity as determined by MARC. Figure 2 shows the values of irradiance with respect to the offset distance and direction of measurements for each thickness of the two ceramics.

The mean and standard deviation of normalized slope values by offset distance and slab thickness are pooled

together for each ceramic in Table 3 along with those when no ceramic slabs were present. The values of no ceramic slabs were means of taken from a previous study [28]. Figure 3 shows the mean irradiance values measured at each location. The values in the figure are means of all thickness and translucency/shade for both ceramics.

#### 4. Discussion

The LCU used in this study was selected on purpose because it is known to have a quite inhomogeneous beam profile as shown in a previous study [28]. The objective of this study was to show the effect of ceramics on the inhomogeneity of the beam profile.

Therefore, it makes sense to use an LCU, where this characteristic is to be expected. As shown in the previous study, the blue range the LCU used was so dominant (irradiance: blue 1088 mW/cm<sup>2</sup> vs violet 71 mW/cm<sup>2</sup>) [28], that the observed effects may be mainly for the blue light portion only. However, two factors need to be considered, that may influence the outcome. First, it is known that the violet light is scattered differently from the blue light by ceramic, which is seen by the different rate of attenuation [29]. Second, one should remember that the sensitivity of photo initiators sensible in the violet range is much higher than the one of camphorquinone for the blue light. Thus, despite the less amount of violet light reaching the resin-based composite, due to the better efficiency, the initiation of the polymerization is effectively enough to cure the RBC [30], which may influence the degree of conversion of an RBC at least under thin layers of the ceramic [29].

In the present study, the LCU was laterally moved in a controlled way in the X- and Y-direction of a coordinated system. This creates a decrease in the irradiance as a function of the offset from the center value, which can be determined as a slope, as seen in Figs 2 and 3, and Tab. 2, which is the expression of the inhomogeneity of the beam profile.

With the method used (controlled lateral movements), the inhomogeneity of the beam could be roughly reproduced. However, the cosine corrector light signal collector used has a diameter of 3.9 mm, which limits the precision. It is suggested for future measurements to use a smaller sensor diameter.

The ceramics used for the present study (Empress and IPS e.max) were chosen because they are sufficiently translucent for resin-bonded restorations (inlays, onlays, veneers and crowns) where light curing of the resin bonded luting material may be an option [31,32]. Therefore, the scattering behavior of the blue (and violet) light is important if the beam profile is inhomogeneous). It is known that the irradiance at the target surface received is a function of the exposure distance [21]. Therefore, the decrease in irradiance reported in Fig. 2 is not only due to the increased thickness of the ceramic but also to the increasing distance from the sensor to the light exciting window of the LCU. Figure 3 confirms the fact that interposing ceramics in the light beam attenuates a substantive amount of light irradiance [7,33].

The decrease in irradiance as the measuring point moves farther away from the center is due to the design of the LCU and representative for its beam profile. A steeper slope (higher value) means a greater rate of irradiance

reduction relative to the offset distance. A flatter slope determined from the same experimental configuration but with the presence of ceramic slabs would mean that increased scattering of the light has occurred. As seen in Fig. 3, the absolute irradiance values without ceramic were substantially higher than those with ceramic interposition. Therefore, for direct comparisons, the slopes must be normalized as described in Materials and Methods. The ANOVA's showed that there were no significant differences with respect to the ceramic materials and translucency/shade; however, highly significant differences for the position (design of LCU) and thickness of the ceramic. It is known to clinicians that the translucency and the shade have a high impact on the aesthetical outcome of a restoration. This is the reason why ceramics are not only produced in different shades, but also in different translucencies. Therefore, it is interesting to see that the shades/translucencies have little effect of scattering the light in the blue or purple range. This confirms that yellow colors are more important to reach good esthetics with restorations of teeth.

In Table 2 where the data of all ceramics tested are displayed, the slopes with thick slabs are always lower, which means that there is a light scattering effect by the thickness of the ceramic; the thicker the ceramic the more light scattering. The same is visible in Table 3, where the ceramic shades and translucencies were pooled.

Based on the outcome of the ANOVA's, the ceramic had no effect on the beam profile, which can also be seen in Tab. 3. Therefore, the first null hypothesis must be accepted. However, one must note that the ceramic had a strong effect when one looks at the attenuation of the light, which was not the topic of the present investigation. The second null hypothesis can be rejected, since thicker ceramic slabs showed more scattering of the light.

#### 5. Conclusion

The thicker the ceramic the fewer irradiance changes were found as a function of the position indicating that the ceramics were scattering the light and thus slightly alleviating the effect of the inhomogeneous beam profile.

#### Author contributions

JFR: Idea, experimental design, wrote the manuscript. CS: Performed data analysis, substantially contributed to writing manuscript. MMK: Performed spectrometer experiment.

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## CV

Jean-François Roulet, DDS, Dr med dent, PhD, is the former chair and current professor of the Department of Restorative Dental Sciences at the University of Florida. Professor Roulet is author/coauthor of more than 180 papers, edited/contributed to 27 textbooks and mentored more than 150 theses. He is a renowned international lecturer with over 800 appearances to date. Dr. Roulet is a member of many professional organizations, has won numerous awards, and holds four patents. He is editor of the Prophylaxe Impuls and Stomatology Edu Journal. His areas of interest include minimally invasive dentistry, dental materials (ie, composites and ceramics), adhesive dentistry, esthetic dentistry, and application concepts in preventive dentistry.

## Questions

### 1. Why are amine free resin-based composites preferred to bond veneers?

- a. They allow for a longer working time;
- b. Tertiary amines used in combination with campherquinone tend to discolor over time;
- c. Tertiary amines and campherquinone require a broadband light curing unit;
- d. Amine free resin-based composites provide a stronger bond.

### 2. Which ceramics were used for the experiment?

- a. Leucite reinforced ceramic and lithium disilicate ceramic;
- b. Translucent Zirconium oxide ceramic;
- c. Feldspathic ceramic;
- d. None of the above.

### 3. The results were analyzed with:

- a. ANOVA and Wilcoxon test;
- b. ANOVA and t-test;
- c. ANOVA and Kruskal Walls Test;
- d. ANOVA and linear regression.

### 4. Which was the main outcome of the experiment?

- a. Ceramic color, shade and type had a significant effect on the scattering of light;
- b. Ceramic did not alter the irradiance;
- c. All of the above;
- d. The thicker the ceramic, the more light-scattering occurred.

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