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ORIGINAL RESARCH

CURING EFFICIENCY OF DUAL-CURE RESIN CEMENT UNDER ZIRCONIA WITH TWO DIFFERENT LIGHT CURING UNITS

Dual-Cure Reçine Simanın Zirkonya Seramikleri Altındaki Polimerizasyon Etkinliğinin İki Farklı Işık Kaynağı ile İncelenmesi

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ABSTRACT

Purpose: *Adequate polymerization is a crucial factor in obtaining optimal physical properties and a satisfying clinical performance from composite resin materials. The aim of this study was to evaluate the polymerization efficiency of dual-cure resin cement cured with two different light curing units under zirconia structures having differing thicknesses.* ***Materials and Methods:*** *4 zirconia discs framework in 4 mm diameter and in 0.5 mm, 1 mm and 1.5 mm thickness were prepared using computer-aided design system. One of the 0.5 mm-thick substructures was left as mono-layered whereas others were layered with feldspathic porcelain of same thickness and ceramic samples with 4 different thicknesses (0.5, 1, 1.5 and 2.0 mm) were prepared. For each group ($n=12$) resin cement was light cured in polytetrafluoroethylene molds using Light Emitting Diode (LED) or Quartz-Tungsten Halogen (QHT) light curing units under each of 4 zirconia based discs ($n=96$). The values of depth of cure (in mm) and the Vickers Hardness Number values (VHN) were evaluated for each specimen.* ***Results:*** *The use of LED curing unit produced a greater depth of cure compared to QTH under ceramic discs with 0.5 and 1 mm thickness ($p<0.05$).At 100µm and 300 µm depth, the LED unit produced significantly greater VHN values compared to the QTH unit ($p<0.05$). At 500 µm depth, the difference between the VHN values of LED and QTH groups were not statistically significant.* ***Conclusion:*** *Light curing may not result in adequate resin cement polymerization under thick zirconia structures. LED light sources should be preferred over QTH for curing dual-cure resin cements, especially for those under thicker zirconia restorations.*

Keywords: *Polymerization; translucency; resin cement; hardness; zirconia*

ÖZ

Amaç: *Kompozit reçine esaslı malzemelerin ideal fiziksel özelliklerinin ve klinik performanslarının elde edilmesi; yeterli polimerizasyonun sağlanmasına bağlıdır. Bu çalışmanın amacı, farklı kalınlıklardaki zirkonya esaslı restorasyonların altında kullanılan dual-cure reçine simanın polimerizasyon etkinliğinin iki farklı ışık kaynağı ile değerlendirilmesidir.* ***Gereç ve Yöntem:*** *4 mm çapında disk şeklinde 4 adet zirkon alt yapı (2 adet 0.5 mm, 1 adet 1mm, 1 adet 1.5 mm kalınlığında) bilgisayar destekli tasarım sistemi kullanılarak hazırlandı. 0.5 mm lik disklerden biri alt yapı olarak bırakılırken diğer 3 diske aynı kalınlıkta üst yapı porseleni uygulanarak 4 farklı kalınlığa (0.5, 1, 1.5 ve 2.0 mm) sahip seramik örnek elde edildi. Politetrafloroetilen kalıp içine konulan reçine siman 4 farklı seramik disk üzerinde her bir grupta 12 adet örnek olacak şekilde Light Emitting Diode (LED) ya da Quartz-Tungsten Halogen (QTH) ışık kaynakları kullanılarak polimerize edildi ($n=96$). Polimerizasyon derinliği (mm) ve Vickers sertlik değerleri (VHN) her bir örnek için tespit edildi. Verilerin istatistiksel olarak analizinde tek yönlü varyans analizi, Tukey HSD ve Student t testi kullanıldı ($p<0.05$).* ***Bulgular:*** *LED ışık kaynağının kullanımı ile 0.5 ve 1 mm.lik örnek gruplarında QTH'a oranla daha yüksek polimerizasyon derinliği sağlamıştır ($p<0.05$). 100 µm ve 300 µm derinlikte LED ışık kaynağı QTH'a oranla istatistiksel olarak anlamlı derecede yüksek VHN değerleri göstermiştir ($p<0.05$). Simanda 500 µm derinlikte, iki ışık kaynağının polimerizasyon etkinliği arasında Vickers sertliği açısından anlamlı bir fark bulunmamıştır.* ***Sonuç:*** *Zirkon esaslı restorasyonların kalınlığı arttıkça reçine simanın polimerizasyonu yetersiz kalabilir. Özellikle kalın zirkon esaslı restorasyonların altında bulunan dual-cure reçine simanlarının ideal olarak polymerize edilebilmesi için LED ışık kaynağı QTH ışık kaynağına tercih edilmelidir.*

Anahtar kelimeler: *Polimerizasyon; translusentlik; reçine siman; sertlik; zirkon*

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Introduction

The success of adhesive bonding of a ceramic restoration depends on a number of factors including the ceramic system, luting agent, curing light characteristics, and curing protocol (1). Adequate polymerization is a crucial factor in obtaining optimal physical properties and a satisfying clinical performance from composite resin materials (2-4). Inadequate cement polymerization under ceramic restorations is related to insufficient amount of light radiation to activate monomers. The clinical performance of light-polymerized resins are determined by both the polymerizing unit output and the amount of light which is transmitted through the restoration to the resin-based adhesive (5). Light intensity decreases as the restoration thickness and shade increase. Ceramic material characteristics, such as optical translucency and refraction index, may determine the amount of transmitted light and, consequently, the degree of conversion of resin cements (2, 5-7). As the ceramic material becomes thicker, the effect of opacity increases, resulting in a greater influence on the resin cement polymerization (8, 9). Similarly, the shade effect seems to be associated with restoration thickness. Since the ceramic layer reflects and refracts the light, decreasing the total energy that reaches the deepest restorative regions, will result in inadequate polymerization of the setting material at the deepest restorative areas or at the adhesive interface (2).

The amount of light transmission through the ceramic restoration affects the potential for polymerization of the resin luting agent. Therefore, the total light intensity and the intensity of light at the proper wavelength are important (10-13). Halogen lamps, also known as quartz tungsten halogens (QTH), are the most frequently used light sources for the polymerization of resin-based dental materials. They emit a continuous spectrum only a small part of which is useful for curing.

Other wavelengths are filtered out to prevent undesirable side effects. However, the spectral impurities of halogen lights deliver several wavelengths that are highly absorbed by dental materials which, in turn, induces heating of the tooth and resin during the curing process (11, 12). Other drawbacks are the decline of irradiance over time, limited depth of cure and relatively long exposure time (10, 13). QTH light curing units (LCU) usually provide power densities between 400-800 mW/cm^2 and adequate curing is obtained within 40 seconds (14). The recently introduced light-emitting diode (LED) lights offer a much more narrow emission spectrum (around 470 nm, with a bandwidth of about 20 nm) that falls closely within the absorption range of camphoroquinone, which is the most frequently employed photo-initiator in resin composites (9, 15). In general, the LED light has the following advantages: extended lifetimes of over 10.000 hours, little degradation of light output over time, preventing overheating, and resistance to shock and vibration (14-16).

10-methacryloyloxydecyl dihydrogen phosphate (MDP) containing dual-cure resin cements are recommended for cementing zirconia-based restorations. As one of these luting agents, the manufacturer identifies Panavia F 2.0 (Kuraray Medical Inc., Osaka, Japan) as the material containing two photo-initiators which provide a wider curing band that can be used with both LED and QTH curing lights. The photo-initiator system in the luting agent is based on camphoroquinone, which absorbs energy when it is exposed to visible light in the 400 to 500 nm wavelength range and reacts with tertiary amine to form an excited state complex that breaks down into reactive free radicals (17).

Relatively few data is available on the polymerization efficiency of dual-cure resin cement used for the cementation of zirconia-based ceramic restorations. The aim of this study was therefore to evaluate the curing efficiency of dual-cure composite resin cement used under zirconia-based ceramic structures with two different LCUs. The null hypotheses tested in this study are: (1) LED LCUs have the same curing performance as QTH LCUs and (2) the curing efficiency of dual-cure resin cement is unrelated to the thickness of the zirconia substructures.

Materials and Methods

In order to evaluate the efficiency of LCUs under zirconia based restorations, four disc-shaped samples, each in 4 mm diameter but in different thicknesses (0.5 mm, 1 mm, 1.5 mm and 2 mm) and substructure layering combinations were prepared for each polymerization group (Table 1).

The zirconia substructures of the samples were prepared from non-hot isostatic pressing (non-HIP blocks (Everest BIO ZS-blanks; KaVo Dental GmbH, Biberach, Germany) by milling in 3 different thicknesses using computer assisted design and manufacturing (CAD/CAM) system (Everest; KaVo Dental GmbH) then immersed into coloring liquid (LL2 Vita Coloring Liquid, Vita Zahnfabrik, Bad Sackingen, Germany) in order to obtain A2 final color, and then sintered for 6 hours at 1450°C in a furnace (Everest Therm; KaVo Dental GmbH). One 0.5 mm thick disc sample (Z group) was left as only zirconia substructure, three remaining discs (Z_1, Z_2, and Z_3 groups) were prepared as bilayer structures by applying 0.5 mm feldspathic ceramic on zirconia substructure with different thicknesses (0.5 mm, 1 mm, and 1.5 mm) (Table 1).

Table 1. *Substructure and restoration thicknesses of the groups.*

Group (n=12)	**Zirconia thickness (in mm)**	**Feldpathic ceramic thickness (in mm)**
Z	0.5	-
Z_1	0.5	0.5
Z_2	1	0.5
Z_3	1.5	0.5

The feldspathic layering with A2 color (GC Initial Zr, GC Europe, Leuven, Belgium) were performed using a custom-made stainless steel mold in order to achieve standard porcelain dimensions. The ceramic layering was applied by condensing the material into stainless steel mold allowing the compensation amount of porcelain during dentin firing between 450ºC and 810ºC according to the manufacturer's recommendations.

The total thickness of ceramic discs were measured with a digital caliper and excess ceramic was abraded to obtain correct dimension after firing. The outer surfaces of the disc samples were then glazed at 820ºC according to the manufacturer's recommendations. Thus, four disc sample groups were prepared for photo-polymerization of resin cement samples using two different LCUs (Table 1).

In the next step, 96 resin samples were prepared by placing the dual-cure resin cement (Panavia F 2.0, Kuraray Medical, Inc., Osaka, Japan) in polytetraflouroethylene (PTFE) molds which were prepared in standard dimensions of 4 mm in diameter and 6 mm in height. For resin specimen preparation, a clear glass slab on top of a black background was used as supporting surface and to decrease the reflectivity of the underlying surface toward each specimen. The equal amounts of base and the catalyst of the resin cement was mixed according to the manufacturer's recommendations.

The PTFE mold was filled with resin cement, and a second transparent film strip was put on top, followed by a second microscope slide with finger pressure. The excess cement material was removed from the mold by pressing the film strips between the glass slides. Following the removal of the microscope slide covering the upper strip of film, one of the four ceramic discs was put on top and resin cement sample was light-irradiated by placing the LCU's tip onto the top of the zirconia disc so that light could pass through the disc over the material. Resin samples were randomly allocated to 8 groups yielding 12 samples per zirconia disc and LCU (n=12). Light curing was accomplished using two different LCUs (LED and QTH) under each ceramic disc. The LED LCU (Elipar S10, 3M ESPE, Seefeld, Germany) had a wavelength range of 430-480 nm and a power density of 1200 mW/cm2. Photopolymerization mode for the LED LCU was 20 s exposure time (5 seconds ramp, 15 seconds full cure).

The QTH LCU (Hilux 200, Benlioglu, Istanbul, Turkey) with 600 mW/cm^2 power density and 410-500 nm wavelength range was used for 40 s exposure time in continuous mode. Both LCUs were calibrated before polymerization of each sample group. The curing light was also monitored with the built-in light meter after polymerizing each resin specimen.

The resin specimens were then taken out of the mold, and the uncured material was removed using a plastic spatula according to ISO 4049 (18). To evaluate the depth of curing, the height of the cylinder of cured material was measured with a digital micrometer (Mitutoyo 150 mm series, Mitutoyo, Tokyo, Japan) which has an accuracy of 0.01 mm. Following the procedure, specimens were stored in dry, light-proof containers for 24 hours. Then, the degree of conversion was evaluated by measuring the Vickers hardness number (VHN) of the resin specimens according to ISO 4049 (18). The resin specimens were longitudinally embedded in cold-curing methylmethacrylate (Meliodent, Bayer Dental, Newburg, Germany) using cylindrical molds and, to obtain a smooth surface for hardness testing, longitudinally wet-flattened with 240-, 320-, 400-, 600-, and 1200-grit SiC papers. To measure the degree of conversion, three measuring points were evaluated on each specimen.

The Vickers hardness measurements were made using a micro-hardness tester (402 MVD, Wolpert Wilson Instruments, Aachen, Germany) with a 50-g load applied for 15 seconds in the cross-sectional area 100 µm, 300 µm, and 500 µm deep from the surface of each specimen (19). The measurement depths were set by using the positioning knobs on the tester machine.

Statistical analysis

Data were analyzed using One-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) tests (SPSS for Windows 15.0; SPSS Inc., Chicago, IL). Pairwise comparisons among groups were performed by Student's t test. The confidence interval was set to 95% and p values less than 0.05 were considered significant.

Results

Depth of Cure

Student's t test revealed that the use of LED LCU produced a greater depth of cure when compared to QTH LCU beneath Z and Z1 groups. However, there was no statistically significant difference between the depth of cure values produced by both LED and QTH LCUs beneath Z2 and Z3 groups (Table 2).

Oneway ANOVA test results showed that both LED and QTH light polymerization produced statistically significantly different depth of cure values for different ceramic thicknesses ($p<0.01$) (Table 3).

Degree of Conversion

One-way ANOVA test revealed that for all measurement depths and ceramic thicknesses, the LED LCU produced greater VHN values when compared to the VHN values produced by QTH LCU (Table 4). Test results showed that for all measurement depths and both LCUs, VHN value decreased as the ceramic thickness increased. Also for the same measurement depth and LCU, the VHN value difference was found to be statistically significant for differing thicknesses according to One-way ANOVA test (Table 4).

Table 2. *Mean depth of cure values of resin cement cured beneath different ceramic thickness groups with different LCUs.*

	Depth of cure (mm)		***p***
	QTH	**LED**	
	Mean±SD	**Mean±SD**	
Z	5.78±0.36	6.31±0,34	***0.001*****
Z_1	4.57±0.25	4.80±0,27	***0.048****
Z_2	4.38±0.43	4.42±0,73	***0.870***
Z_3	47±0.45	4.12±0,72	***0.837***

*Student's t test * $p<0.05$ ** $p<0.01$*

Table 3. *Mean depth of cure values of resin cement cured beneath different ceramic thickness groups with different LCUs.*

LCU	**Depth of cure (mm)**				***p***
	Z	**Z_1**	**Z_2**	**Z_3**	
	Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	
QTH	5.78±0.36	4.57±0.25	4.38±0.43	47±0.45	***0.001*****
LED	6.31±0.34	4.80±0.27	4.42±0.73	4.12±0.72	***0.001*****

*One-way ANOVA test ** $p<0.01$*

Table 4. *Mean Vickers hardness number and standard deviation (SD) values of groups at various measurement depths under different ceramic thicknesses with different LCUs.*

Measurement Depth (µm)	**Light Source**	**Thickness**				***P***
		Z	**Z_1**	**Z_2**	**Z_3**	
		Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	
100	QTH	66.78±4.36	58.85±41	52.77±2.50	49.37±2.26	*0.001***
	LED	69.95±5.35	65.26±2.55	62.80±2.83	52.10±3.47	*0.001***
300	QTH	60.52±45	54.35±5.89	48.29±1.80	46.20±1.25	*0.001***
	LED	62.67±4.70	58.00±4.14	54.15±2.73	49.33±4.82	*0.001***
500	QTH	48.71±2.68	44.15±1.79	41.34±3.44	37.88±2.54	*0.001***
	LED	53.15±7.64	49.00±3.89	43.64±2.52	39.41±3.37	*0.001***

*One-way ANOVA test ** $p<0.01$*

Table 5. *Mean Vickers hardness number and standard deviation (SD) values of groups at different measurement depths with different LCUs.*

Measurement Depth (µm)	**Thickness**	**VHN**		***p***
		QTH	**LED**	
		Mean±SD	**Mean±SD**	
100	**Z**	66.78±4.36	69.95±5.35	***0.127***
	Z_1	58.85±41	65.26±2.55	***0.001*****
	Z_2	52.77±2.50	62.80±2.83	***0.001*****
	Z_3	49.37±2.26	52.10±3.47	***0.032****
300	**Z**	60.52±45	62.67±4.70	***0.243***
	Z_1	54.35±5.89	58.00±4.14	***0.093***
	Z_2	48.29±1.80	54.15±2.73	***0.001*****
	Z_3	46.20±1.25	49.33±4.82	***0.050****
500	**Z**	48.71±2.68	53.15±7.64	***0.071***
	Z_1	44.15±1.79	49.00±3.89	***0.001*****
	Z_2	41.34±3.44	43.64±2.52	***0.075***
	Z_3	37.88±2.54	39.41±3.37	***0.222***

*Student's t test * $p<0.05$ ** $p<0.01$*

Student's t test analysis revealed that, in Z group for 100 µm measurement depth, the difference in VHN values between two LCUs was not significant, however in Z_1, Z_2, and Z_3 groups the samples cured with LED LCUs produced significantly higher VHN values than those cured with QTH LCU ($p<0.05$, $p<0.01$) (Table 5).

At 300 µm depth, Student's t test results showed that the LED LCU produced significantly greater VHN values compared to the VHN values produced by QTH LCU for all ceramic thicknesses (Table 5). But for Z and Z_1 groups the differences in VHN values were not significant for both LCUs, whereas the VHN value for Z_2 and Z_3 groups were found to be statistically significantly higher for LED group than QTH according to Student's t test analysis ($p<0.01$, $p<0.05$) (Table 5). At 500 µm depth, Student's t test showed that the differences between the VHN values for Z, Z_2 and Z_3 groups were not significant for two LCUs, however for Z_1 group, the difference in VHN values was significantly higher for LED LCU ($p<0.01$) (Table 5).

Pairwise comparison of ceramic thicknesses for the same LCU was determined by Tukey's HSD test and summarized in Table 6.

Table 6. *Tukey's HSD test results.*

Measurement Depth (µm)	LCU	Thickness	*p*
100	**QTH**	**Z / Z1**	*0,001***
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,001***
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,084*
	LED	**Z / Z1**	*0,018**
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,375*
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,001***
300	**QTH**	**Z / Z1**	*0,001***
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,001***
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,529*
	LED	**Z / Z1**	*0,043**
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,125*
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,034**
500	**QTH**	**Z / Z1**	*0,001***
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,063*
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,015**
	LED	**Z / Z1**	*0,047**
		Z / Z2	*0,001***
		Z / Z3	*0,001***
		Z1 / Z2	*0,041**
		Z1 / Z3	*0,001***
		Z2 / Z3	*0,149*

* $p<0.05$ ** $p<0.01$

Discussion

First null hypothesis of this study was partially rejected since using LED LCU resulted in better polymerization compared to using QTH LCU for thinner zirconia discs, however as the thickness of the zirconia structure increased, the difference between LCUs ceased to exist. Second null hypothesis was also rejected as thicker zirconia structures negatively affected the curing of dual-cure resin cement. There are several methods to investigate the performance of new curing technologies by measuring the physical and mechanical properties and the degree of conversion of composite materials (16). There are some direct methods such as infrared and laser raman spectroscopy for measuring the conversion values. However these techniques expensive and time consuming in spite of their high sensitivity (20). Universal hardness test is known as a sophisticated indirect method to evaluate the degree of conversion of composite materials and requires specific equipment. Vickers, Knoop or Rockwell methods are also known to be reliable and easy to perform indirect methods to investigate the degree of conversion of a composite material by measuring the hardness profiles (21). In this study, in order to evaluate the degree of polymerization of the resin-based luting material, the hardness of the material was used as a parameter.

Several authors (3, 22, 23) have reported that the dual-cure resin cements require adequate light polymerization in order to achieve optimal mechanical properties; chemical polymerization component of the dual-cure resin cement does not compensate for the lack of light polymerization. Adequate polymerization determines the mechanical properties of the dual-cure resin cement (19). Sufficient light transmission is crucial in obtaining effective polymerization of the material. However, the intensity of light transmitted through ceramic veneers is affected by the type and thickness of the ceramic. It has been reported that incident light is attenuated with increasing distance from the polymerized surface as a result of absorption and scattering effects promoted by fillers and resin components (23). At the same study, it was also reported that about only 25% of the light energy reaching the resin is available at 1 mm depth (23). Thus, the amount of light reaching the material produced by the light curing unit is attenuated and its polymerization effectiveness is reduced as the ceramic thickness increases (24). Several authors showed that light intensity was reduced after being transmitted through thicker ceramic. According to Meng *et al.* (25) a light intensity of 800 mW/cm^2 was reduced to 160 mW/cm^2 after being transmitted through 2 mm of a machined ceramic. Also El-Mowafy *et al.* (3) showed that the hardness of the underlying dual-cure resin cement decreased significantly when ceramic thickness is 2-3 mm or more. They also stated that the polymerization decreased by about 70% through a 1 mm thick ceramic. When VHN values are evaluated to assess the degree of polymerization, the findings in this study were in accordance with the results of the studies mentioned above (3, 23, 25). The VHN mean values obtained from this study indicated that VHN values under the 0.5 mm thick ceramic layer were always significantly higher compared to the VHN values under the 1, 1.5, and 2 mm thick ceramic layer and the values decreased as the ceramic thickness increased.

In this study, ceramic samples were prepared as bilayer zirconia structures except one group in order to mimic the clinical conditions. Z group was used monolayer with 0.5 mm zirconia thickness, whereas Z_1 bilayer group had the total thickness of 1 mm with 0.5-mm zirconia and 0.5-mm feldspathic porcelain. The Tukey's HSD test results have shown that for all measurement depths and for both LCUs, VHN values of resin cement polymerized under Z group samples were significantly higher than those of light-cured under Z_1 group ceramics. Thus, it can be assumed that using feldspathic porcelain on zirconia base dramatically decreases the curing efficiency of resin cement for both LCUs. These results are in accordance with other studies investigating the effect of ceramic thickness on resin cement polymerization (26, 27).

This study evaluated the depth of cure of a dual-cured resin cement under varying thickness' of zirconia layered with ceramic using two different LCUs. The thickness of the resin cement tested in this study might not be suitable for luting purposes clinically. However, the intensity of light transmitted through ceramic veneers is affected by the polymerization unit and the type and thickness of the ceramic. It is known that zirconia ceramics have high refractive indices, low absorption coefficients and high opacity. This increased opacity may be useful for masking colored teeth or metal abutments but it also compromises the photo-polymerization of dual-cured resin cements used under the restorations. Materials with higher potential for in-depth polymerization would be eligible under thicker ceramic materials when low light intensity is available especially for those with higher opacity like zirconia (22). In the present study, evaluation of the VHN values to obtain the degree of polymerization showed that high intensity LED LCU resulted in significantly higher VHN values compared to the VHN values of the low intensity QTH LCU. However, the inconsistency beneath the 1 mm ceramic can be attributed to the sudden decrease in the intensity of the low intensity QTH LCU at deeper parts. Only a small portion of the halogen emission spectrum actually is used to activate the photo-initiator components. Polydorou *et al.* (4) reported that blue light in different parts of the absorption spectrum of camphoroquinone (CQ) has a different effectiveness and, that light near to the absorption peak (468 nm) is more effective at curing. They also showed that QTH LCU produced higher micro-hardness values compared to LED LCU for a standard resin composite that contradicts with the findings of this study. However Uhl *et al*. (28) showed that LED LCU achieved greater depth of cure than the QTH LCU as some resin composites contain co-initiators in addition to CQ that absorb light at shorter wavelengths. In a study El-Mowafy *et al.* (29) demonstrated that the new LED LCUs were more effective in photopolymerization of resin composites than QTH based LCUs in terms of relative hardness. It was stated that, high power light sources produce more photons for absorption by photosensitizers and cause more CQ molecules to excite and react with amine, resulting in production of more free radicals for polymerization (30).

The depth of cure has been shown to increase proportionally to the logarithm of the product of light intensity and exposure duration (12)**.** In the present study, the use of LED LCU produced a greater depth of cure when compared to QTH LCU beneath ceramic discs with 0.5 and 1 mm thickness. However there were no statistically significant differences between the depths of cure produced by both LED and QTH light polymerization beneath ceramic discs with 1.5 and 2 mm thickness. According to these results, the shorter exposure duration of the LED LCU may not reach the sufficient light intensity at the relevant thickness. Therefore it can be speculated that higher energy density in a shorter period of time does not provide a higher depth of cure in the same period (31).

The findings of this study indicated that dual-cure resin cement extremely depends on photoactivation, and chemical polymerization alone leads incomplete polymerization of the material. In this study, variables were limited to different light sources and different ceramic thicknesses to better evaluate the polymerization potential beneath them. Only one cement is used in this study based on the method used. Within the limitations of this study, it can be speculated that zirconia thickness and different light sources affect the polymerization of the dual-cure resin cements used under these structures. Further studies are recommended in order to evaluate the critical threshold thickness values of zirconia structures where dual-cure resin cement use is adequate and in case self-cure resin cement usage is indicated.

Conclusion

For the polymerization of dual-cure resin cement under zirconia structures, LED LCU achieves better results compared to QTH LCU. Clinicians should consider using LED light sources for curing dual-cure resin cements especially under thicker zirconia restorations. Regardless of the light source, the thickness of the zirconia effects the light curing, and therefore polymerization of the dual-cure resin cements used under these structures. As the zirconia thickness increases the polymerization is affected negatively. Clinicians should be aware that under thick zirconia structures, the light curing may not result in desired polymerization of the dual-cure resin cement. Using self-cure resin cements should be considered under thick zirconia reconstructions.

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