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DEPTH OF CURE OF BULK-FILL RESIN COMPOSITES WITH DIFFERENT PHOTO-INITIATOR SYSTEMS CURED BY MONOWAVE AND POLYWAVE LIGHT CURING UNITS

Rahma Mohamed Elsharawy[*], Mohamed Elshirbeny Elawsya[**], Asmaa Mohamed AbdAllah[***] *and* Abeer ElSayed ElEmbaby[****]

ABSTRACT

Objective: To evaluate depth of cure (DOC) of bulk-fill resin-based composites (BFRBCs) with various photo-initiators cured by monowave and polywave light curing units (LCUs).

Methods: Two commercially available BFRBCs were used; Filtek One Bulk Fill Restorative (3M ESPE) (FOBF) which contains Camphorquinone (CQ) photo-initiator system only and Tetric N-Ceram Bulk Fill (Ivoclar Vivadent AG) (TNBF) which contain CQ and Ivocerin photo-initiator systems. LCUs utilized were two light-emitting diodes (LED) LCUs; a monowave LED LCU (BlueLEX LD-105, Monitex Industrial CO) and a polywave LED LCU (Twin Wave GT-2000, Monitex Industrial CO). Twenty cylindrical specimens (4 mm diameter and 10 mm thickness) were prepared from each BFRBC. Ten specimens light cured by monowave LCU and the other ten specimens cured by polywave LCU according to the manufacturer's recommendations (n=10). The International Organization for Standardization (ISO) 4049 method (Scraping test technique) was used to assess DOC. Statistical analysis was performed using two -way ANOVA and Tukey's post-hoc tests ($p < 0.05$).

Results: There were no statistically significant differences in DOC between LCUs within each BFRBC ($p > 0.05$). However, there was a statistically significant difference in DOC between composite types within each LCU ($p < 0.05$), and there was no interaction between them ($p > 0.05$). FOBF with CQ photo-initiator system only showed particularly high DOC mean values.

Conclusion: When a BFRBC has a variety of photo-initiators, the type of LCU has no effect on DOC. BFRBC with Ivocerin photo-initiator has lower DOC as ivocerin needs shorter violet wavelength which is scattered by filler particles.

KEY WORDS: Bulk-fill resin-based composites, Depth of cure, Light curing units, Photo-initiators.

* Clinical Demonstrator, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
** Lecturer, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
*** Assistant Professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
**** Professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.

INTRODUCTION

Resin-based Composites (RBCs) are currently the most used restorative material because of its good cosmetic qualities and potential for adhesion to teeth, which leads to less invasive cavity preparations.[50] Compared to the majority of other restorative materials, it is distinguished by having a high compressive strength.[7] The components of modern RBCs are: an organic resin matrix containing polymeric chains and cross-linking agents, inorganic fillers, a silane coupling agent, an initiator system for free radical polymerization, and stabilizers to increase storage stability.[7,20, 21]

Photo-polymerization is the term used to describe a process in which polymerization is initiated by a physical medium, such as light.[23] Camphorquinone (CQ) and its co-initiator tertiary amines have been the most widely used photo-initiator system in dental RBCs.[22,23] CQ is classified as a Norrish type II photo-initiator since it requires a reducing agent to react successfully in order to produce free radicals to start the polymerization process.[11,23]

CQ is cured by conventional light cure units, and the effective wavelength range to activate it has been observed to be between 410 nm and 500 nm, with a peak wavelength of 470 nm.[14,23] CQ has a chromatic group in its molecular structure that makes it photoactive but also gives the substance its intense yellow hue.[45] This yellow color affect the restoration's absolute beauty.[16]

In order to replace CQ or act synergistically with it CQ, researchers have explored a variety of photo-initiators in the organic matrix.[6] When enough energy at the right wavelength is provided, alternative photo-initiators like Lucirin TPO and benzoyl germanium decompose directly into one or more free radicals.[44] They initiate by cleaving, which eliminates the need for a co-initiator.[20]

These alternative initiators are typically sensitive to ultraviolet or violet light or light with a wavelength of 380 to 410 nm.[1] However, the common commercially available light emitting diode (LED) LCUs have an emission spectrum that matches for the CQ's peak absorption wavelength.[26] Due to the low spectrum sensitivity, the alternative initiators may not work with the widely used monowave LCUs.[14] There are several light curing units (LCUs) available based on various physical principles, including lasers, plasma arc lamps, quartz-tungsten-halogen (QTH) bulbs, and light emitting diodes (LEDs).[3,19] The development of LED LCUs with multiple diodes, which offer a wider range of output wavelengths necessary to coincide with the absorption of CQ and alternative photo-initiator systems, is an advantage of materials that use short wavelengths.[27]

The incremental application method is a widely used methodology for applying conventional light activated composites to lessen polymerization stress.[43] On the other hand, RBCs layering techniques and numerous curing steps take a lot of time.[12, 25] BFRBCs materials were created to make the application of RBCs simpler.[32] The improved depth of cure in BFRBCs was achieved by enhancing the materials' translucency, which is how it differs from typical RBCs.[18] This Enhancement is accomplished by utilizing novel photo-initiators, more photo-initiator content special resins, unique fillers, specific modulators and filler distribution.[15,52] CQ, phosphine oxide and a germanium-based photo-initiator as Ivocerin are used to create BFRBCs, which are designed for use in increments up to 4 mm.[20]

DOC has been described as the depth at which the resin matrix transforms from a glassy to a rubbery condition and is used to assess the extent to which RBCs of various thicknesses can be polymerized during light curing.[9] DOC are important parameter to evaluate the ultimate biological, mechanical, and physical characteristics of RBCs.[8, 36]

It is crucial to analyze the DOC of light-cured RBCs since a variety of factors hinder RBCs from achieving adequate photo-polymerization at depth,[10] such as a mismatch between the curing light emission spectrum and the requirements of the RBC's photo-initiators.[2, 39] LCUs are frequently ignored, however they can affect the depth of cure in RBCs.[1] The top and bottom hardness ratio, top and bottom degree of conversion ratio, removal of the uncured polymer from the sample with solvents, and manual scraping (SCR) (ISO 4049 standard) of the uncured material are several methods that have been suggested to measure the DOC.[5,9] A simple method has been described in the ISO 4049 [49] standard and is based on a measurement with micrometer of the RBC thickness that remains following removal of soft, unpolymerized material with a plastic spatula.[20,23]

According to several studies, there is no significant difference observed irrespective of the variations in photo-initiators inside the examined RBCs, that indicate the major effect of LCU was not significant.[26, 32, 48] However, according to other studies, the polywave LCU produced a higher monomer to polymer conversion than the monowave, particularly when resin composites with various photo-initiators were involved.[28, 34, 42, 46]

Studies on the effects of employing monowave and polywave LCUs on polymerization of BFRBCs with innovative photo-initiators was insufficient, so this study evaluated DOC of BFRBCs with different photo-initiator systems cured by monowave and polywave LCUs. The first null hypothesis tested was that the type of BFRBC had no significant effect on DOC values. The second null hypothesis tested was that the type of LCU had no significant effect on DOC values.

MATERIALS AND METHODS

Materials:

Detailed information about BFRBCs materials and light curing units used in this study is presented in Table 1 and Table 2 respectively.

TABLE (1) Bulk-fill resin-based composites used in the study.

BFRBC	Shade	Composition	Filler Load wt.% (vol%)	Recommended Curing Time and Light Intensity	Recommended Thickness	Manufacturer (Lot No.)
Filtek™ One Bulk Fill Restorative	A3	Resin: AUDMA, DDDMA, UDMA Fillers: silica filler, zirconia filler, zirconia/ silica Cluster filler and ytterbium trifluoride Photo-initiator: CQ/ amine system	76.5% (58.5%)	20 s >1000 mW/cm² —————— 40 s 550 -1000 mW/cm².	4 mm	3M ESPE, St. Paul, MN, USA (NE18435)
Tetric N-Ceram Bulk Fill	IVA	Resin: Dimethacrylates (19-21% weight), Bis-GMA, UDMA, Bis-EMA Fillers: barium glass, prepolymer, ytterbium trifluoride, and mixed oxide. Photo-initiator: CQ/ amine system, TPO and Ivocerin.	75-77% (53-55%)	10 s ≥1000 mW/cm² ———— 20 s ≥500 mW/cm²	4 mm	Ivoclar Vivadent AG, Schaan, Liechtenstein (Z02SV4)

TABLE (2) Light curing units used in the study.

LCU	Type	Wavelength (nm)	Irradiance (mW/cm^2)	Manufacturer
BlueLEX LD-105	Monowave	420-490 nm (peaks at 455 – 465 nm)	1200 mW/cm^2	Monitex Industrial CO. LTD, Taiwan
Twin Wave GT-2000	Polywave	420-490 nm (peaks at 455 – 465 nm) 360-420 nm (peaks at 400-410 nm)	1300 mW/cm^2	Monitex Industrial CO., LTD, Taiwan

Study design and specimen's preparation:

The study was submitted to and approved by the Dental Research Ethics Committee under protocol number A07061222 (Faculty of Dentistry, Mansoura University). Using G*power version (3.0.10) to calculate sample size based on effect size =1.64, 2-tailed test, α error =0.05 and power = 90% then total sample size were 9 per group. So, n = 10 specimens were prepared for each group.

Twenty specimens with a cylinder shape were prepared from each BFRBC material using a cylindrical stainless-steel mold with dimensions of 4 mm diameter and 10 mm thickness.[29] Vaseline was applied to the internal surface of the mold by a microbrush for the easy removal of the specimens after curing.[5]

A Mylar strip was placed over a 1 mm thick glass microscope slide and mold was placed on it. The material was packed in one increment into the mold, the top was covered by another Mylar strip and glass slide, and to ensure consistent packing of the specimens, a load of 0.5 Kg was applied to the glass slide for 60 seconds. When performing light curing, the tip of the light curing unit made direct touch with the glass slide only from the top surface.[40]

Ten samples were light cured using monowave LED LCU. The other ten specimens were light cured using polywave LED LCU. Light curing was done according to the manufacturer's guidelines for each BFRBC (10 seconds for TNBF and 20 seconds for FOBF). Power intensity was measured regularly after each specimen using a digital radiometer (Bluephase Meter II, Ivoclar Vivadent, Liechtenstein). The power intensity of the monowave LED LCU is 1200 mW/cm^2, while the power intensity of the polywave LED LCU is 1300 mW/cm^2.

After light curing, the cylindrical specimens were forced out of the stainless-steel mold by using a stainless steel "pin driver" whose diameter is the same as the mold hole.[29]

Depth of cure test:

DOC of the examined materials was measured according to ISO 4049 method[49].The uncured part of the samples was scraped with a plastic spatula.[5] After that, a digital caliper was used to measure the cylindrical specimen of hardened composite resin's absolute length in millimeters (Figure 1). Three measurements were recorded for each single specimen and the average was calculated. The length values were divided by two according to ISO 4049.[41]

Fig. (1) Measuring the length of the specimen with the digital caliper for depth of cure test.

Statistical analysis:

Data analysis was performed by SPSS software, version 25 (SPSS Inc., PASW statistics for windows version 25. Chicago: SPSS Inc.). After exploring the data distribution (Shapiro-Wilk test), DOC data showed parametric distribution and were analyzed using two-way ANOVA tests followed by Tukey's post-hoc test for multiple comparisons. The level of significance was set at $p < 0.05$ in all analyses.

RESULTS

There were no statistically significant differences in DOC between LCUs within each BFRBC ($p > 0.05$). However, there was a statistically significant difference in DOC between composite types within each LCU ($p < 0.05$), and there was no interaction between them ($p > 0.05$). The mean value SDs of DOC of all research groups are presented in Table 3. Also, the result of Tukey's post-hoc test is shown in Table 3.

TABLE (3) DOC mean values ± SDs of the tested BFRBCs with Tukey's post-hoc test results.

BFRBC \ LCU	Monowave	Polywave
Filtek™ One Bulk Fill Restorative	4.39±0.09 Aa	4.27±0.13 Aa
Tetric N-Ceram Bulk Fill	3. 63±0.07 Ba	3.71 ±0.10 Ba

-Different capital letters in the same column indicate statistically significant difference.

-Different lowercase letters in the same row indicate statistically significant difference.

FOBF cured by monowave LCU showed particularly high DOC mean values followed by FOBF cured by polywave LCU, TNBF cured by polywave LCU, and TNBF cured by monowave LCU respectively. There were no statistically significant differences between the used LCUs within each RBC material ($p > 0.05$), but there was statistically significant difference between the tested RBC materials regardless of the used LCU ($p < 0.05$).

DISCUSSION

Although monowave and polywave LED LCUs can generate comparable amounts of power for the restoration, variations in their spectral outputs can significantly affect the photo-initiator system.[4] In the current study, the effect of using polywave LCU was compared to the effect of using monowave LCU in curing of two BFRBCs with different photo-initiators. The comparison was done by the evaluation of DOC.

In the current study, two BFRBCs (FOBF and TNBF) were used. FOBF, is a nanofilled RBC, contains nanoparticles that cannot scatter or absorb visible light, which have a considerable impact on the curing, translucency, and esthetics.[40] Only CQ serves as a photo-initiator in FOBF.[13] TNBF, is a nanohybrid BFRBC, includes pre-polymerized resin fillers which are consisted of resin-encased fillers that have been polymerized and milled to a required particle size.[36] Other photo-initiators included in Tetric N- Ceram include Ivocerin (a derivative of dibenzoyl germanium) and TPO, which are stimulated by many wavelengths and are intended to promote photopolymerization.[13] Both photo-initiators require wavelength irradiated by a polywave LCU.[26] The wavelength of light at which ivocerin is most reactive is 408 nm, however it is also still quite sensitive to light between 400 and 430 nm.[44]

DOC and the composition of RBC itself are the two most significant variables impacting the mechanical properties of RBC.[47] The depth of polymerization is crucial to ensure that clinical issues are not caused by partially polymerized material in the cavity's base.[52] To measure DOC of RBCs, a number of techniques have been suggested, such as measuring the bottom and top surfaces' microhardness or degree of conversion at various depths until an 80% bottom/top ratio is reached, removing the uncured material from the specimen with solvents, and manually scraping (SCR) the uncured material.[9,5]

In the current study, DOC was evaluated by ISO scraping test technique. The ISO 4049 standard outlines a basic technique for measuring DOC.[24] This ISO scraping test method was employed to determine DOC because it requires less instrumentation and can be carried out anywhere.[17] In this study, the non-polymerized part of the specimen was dismissed by manual scraping technique as described in ISO 4049 test. Although it was simple to use the alternative solvent-dissolution procedure to remove uncured RBC,[38] the solvent-immersion approach has not been subjected to a standardized application protocol.[9] Comparing the solvent dissolving no-touch approach to the "scraping" method, it lessens the operator's effect, but it is not covered by ISO 4049 standard.[41] Also, the scraping technique is a validated research tool to directly compare different materials, LCUs, and curing times.[35, 31]

In the current study, FOBF had significantly higher DOC than TNBF regardless of the used LCU. This might be attributed to the fact that BFRBCs have less light penetrating into their depth because to light reflection from BFRBCs, light deflection from filler particles, and light absorption by photo-initiators.[37] Although FOBF does not identify any alterations to the initiator, it does state that the matrix is made up of a combination of high molecular weight monomers.[29] TNBF's filler loading (79-81 wt%) and pre-polymerized fillers may significantly affect the incident light's intensity and reducing DOC.[43] Maghaireh et al.[30] observed that the additional photo-initiator (Ivocerin) in TNBF is unable to entirely compensate for the reduced translucency of this product since DOC of CQ-based materials can be larger than that of TPO-based materials. These observations agreed with the current study results.

Shorter wavelengths of light will be more likely to be scattered by filler particles, according to the Rayleigh effect. The majority of the radian exposure at the specimen's depth came from the blue light spectrum due to the composite's considerable attenuation of the polywave LCU's violet spectrum.[33] This might explain why this study showed that both LCUs had the same effect within each BFRBC material on DOC by ISO method.

The current study results showed that TNBF had the lowest DOC by ISO method and did not achieve the manufacturer's recommended thickness (4 mm) evenly with polywave LCU. The mold's material might have an effect on DOC, the specimens in ISO method were prepared using opaque stainless-steel mold to prevent light penetration.[51] Stainless steel does not transmit light, in contrast to ceramic or polymeric materials. Teflon molds cause DOC values to be overestimated, as light is transmitted through the Teflon unlike stainless steel.[33]

Based on the findings of this study, The first null hypothesis was rejected as the results showed statistically significant difference between the tested RBC materials regardless of the used LCU. The second null hypothesis was accepted as the results showed that there were no statistically significant differences between the used LCUs within each RBC material.

In this study, the in vitro study's limitations were noted such as this study was conducted using fabricated molds instead of natural teeth, which might have affected the results. Another limitation is that this study tested only two materials with dark shade. Lighter shades or other products of RBCs may provide different results; therefore, the conclusions cannot be generalized. In addition, further studies should evaluate the use of polywave LCUs with higher power densities or longer exposure times that may enable enough light from reaching a 4-mm thickness of BFRBCs with combination of photo-initiators (CQ, TPO, and Ivocerin).

CONCLUSIONS

The use of a polywave LCU is not obligatory to achieve optimal DOC of a BFRBC with combination of photo-initiators (CQ, TPO, and Ivocerin).

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