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Research Article

LIGHT-CURING DISTANCE AND RESIN THICKNESS EFFECTS ON THE SHORT FIBER–REINFORCED RESIN COMPOSITES' DEPTH OF CURE

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ABSTRACT

Objective: This study evaluated the light-curing distance and resin thickness effects on the depth of cure of short fiber–reinforced resin composites (SFRCs).

Methods: Fifteen SFRC specimens with a diameter of 6 mm and thickness of 4 mm were divided into groups (n=5) with light-curing distances of 0, 2, and 4 mm. Another 15 specimens with a diameter of 6 mm and thicknesses of 3, 4, and 5 mm (n=5) were subjected to a 0-mm light-curing distance. Microhardness tests were conducted using a Vickers hardness tester (load: 200 g; dwell time: 15 s), and the depth of cure was assessed by calculating the hardness ratio of the bottom to the top surface (%). Statistical tests included one-way analysis of variance (ANOVA) followed by *post hoc* Fisher's LSD tests.

Results: The depths of cure with 0-, 2-, and 4-mm light-curing distances were 79.0±0.7%, 77.0±0.6%, and 75.0±0.8%, while those with thicknesses of 3, 4, and 5 mm were 81.0±1.0%, 78.2±1.0%, and 34.4±2.0%, respectively. Significant differences (p<0.05) in the depth of cure were found in all groups.

Conclusion: A depth of cure >80% was only attained with a 3-mm resin thickness and 0-mm light-curing distance.

Keywords: Depth of cure, Short fiber–reinforced resin composite, Light-curing distance, Resin thickness.

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INTRODUCTION

Resin composites have been used as restorative materials in dentistry [1,2]. One of the advancements related to resin composites is the fiber-reinforced resin composite that is more widely used nowadays [3-6]. Recently, a short fiber–reinforced resin composite (SFRC) was introduced for use in restorative dentistry. This type of resin composite exhibits high fracture resistance, which is the same as that of dentin and almost twice as strong as those of other types of resin composite; therefore, it can be used as a replacement for dentin or substructure combined with particulate resin composite on the restoration of posterior teeth [7,8]. The resin matrix in this product is made of bisphenol A–glycidyl methacrylate, triethylene glycol dimethacrylate, and linear polymer polymethyl methacrylate, which form the matrix structure of the semi-interpenetrating polymer network, thereby providing a higher bonding strength and improving the quality of the resin composite [7,9].

The success of light-cured resin composite materials corresponds directly with the polymerization process. It has been shown that insufficient polymerization may lead to a decrease in the physical/mechanical and biological properties of resin composites. The thickness of resin composite successfully polymerized by changing monomers to polymers using a certain light is termed the depth of cure [10-12]. The light source should be in contact with the surface of the resin composite materials to attain the deepest layer of polymerization and the greatest depth of cure [13,14]. However, in the restoration of a tooth, especially in the posterior area, contact between the light source and resin composite surface is often a problem due to the position of the tooth and the inaccessibility of light-curing unit (LCU) tip in reaching the resin composite surface because of the size of the cusps [15].

According to the SFRC manufacturer (EverXPosterior™, GC Corp., Tokyo, Japan), this SFRC can be applied as a substructure in posterior teeth restoration in bulks of up to 4 mm in thickness [8]. SFRCs polymerized with an irradiance of 600m W/cm^2 for 30 s have been reported to attain a depth of cure of 4.02 mm, measured using the ISO 4049 method [16]. Another study found that bulk fill materials produce a depth of cure that is overestimated with the ISO 4049 method [13]. The research was done on bulk fill particulate resin composite, whether inserted with an incremental technique or bulk, shows that it produces a high depth of cure, using the measuring method of the Vickers hardness ratio [17]. However, little research has been conducted to measure the depth of cure of SFRCs, especially using methods other than ISO 4049.

There are several methods for measuring the depth of cure *in vitro*. One is the Vickers hardness test [11]. Measuring the hardness of the top and bottom surfaces of the resin composite can be a good indicator in determining the depth of cure. An adequate depth of cure is attained if the ratio of hardness of the bottom to the top surface is a minimum of 0.80 (80%) [17,18].

Clinically, an SFRC is applied as a substructure, replacing dentin on a posterior restoration; the top surface will be layered with particulate resin composite with a thickness of 1–2 mm [8]. Therefore, the distance of the LCU tip cannot obtain an optimally intact contact with the resin surface. Furthermore, the manufacturer's claim that the bulk insertion of an SFRC with a thickness of 4 mm also raises the question of whether it can really attain a depth of cure of 4 mm. Hence, this research has been carried out to evaluate the effects of variation of the light-curing distance on the depth of cure of 4 mm in the SFRC inserted using the bulk technique. In addition, the effect of varied resin thicknesses was assessed to measure the depth of cure when curing is done at a distance of 0 mm. The depth of cure of the SFRC was evaluated by calculating the hardness ratio of the bottom to the top surface of the resin composite.

METHODS

Thirty SFRC specimens were randomly divided into six groups (n=5/group). Three groups were treated with different light-curing distances of 0, 2, and 4 mm, and three groups were treated with different resin thicknesses of 3, 4, and 5 mm. The SFRC for the dentin replacement/substructure used was EverXPosterior™ (GC Corp.). A description of the resin composite used in this research can be seen in Table 1.

The specimens for treatment with different light-curing distances had a diameter of 6 mm and thickness of 4 mm, whereas the specimens treated with varied resin thicknesses of 3, 4, and 5 mm had the same diameter of 6 mm [19]. The specimens were created using a stainless-steel split mold. The SFRC was filled and condensed into the mold using a plastic filling instrument and then polymerized according to the manufacturer's directions using an LED LCU (Litex™ 695, Dentamerica, USA) for 20 s, with an irradiance of 800 mW/cm^2. The polymerization was carried out by positioning the tip of LCU directly on top of the Mylar strip at 0, 2, and 4mm from the surface of the specimen [20]. For the group treated with varied thicknesses, the LCU tip position was positioned on top of the Mylar strip at 0 mm.

After polymerization was complete, specimens were released from the mold, inserted into a pot filled with distilled water and stored at 37°C for 24 h before testing [19,21]. Microhardness testing was conducted on both the top and bottom surfaces using a Vickers hardness tester (Zwick Roell (Zhμ)® Microhardness tester, Germany). Eight random indentations were made with a 200-g load and a dwell time of 15 s [21].

The depth of cure was assessed by calculating the hardness ratio of the bottom to the top surface (%) [22]. Statistical data tests were conducted using one-way ANOVA followed by *post hoc* Fisher's LSD with a significance value of $p<0.05$ for light-curing distance treatment and resin thickness treatment.

RESULTS

Surface hardness with various light-curing distances

The mean values and standard deviations (SDs) of the SFRC surface hardness with a light-curing distance of 0 (directly on top of the Mylar strip), 2, and 4 mm can be seen in Table 2.

There was no significant difference ($p>0.05$) in the top surface's mean hardness value between the groups treated with 0-mm and 2-mm light-curing distances. However, there was a significant difference ($p<0.05$) between the groups treated with 0- and 2-mm and the group treated with 4-mm light-curing distances.

Apart from that, the mean value of the bottom surface hardness showed a significant difference between the groups treated with 0-, 2-, and 4-mm light-curing distances.

The depths of cure with various light-curing distances

The mean values and SDs of the depth of cure of SFRCs with light-curing distances of 0, 2, and 4 mm can be seen in Table 2. The depths of cure with the different light-curing distances were 79.0±0.7%, 77.0±0.6%, and 75.0±0.8%, respectively. The highest value of the depth of cure of the SFRCs was shown in the group with a 0-mm light-curing distance, and the lowest value was observed in the group with a 4-mm light-curing distance. The mean depths of cure values of the SFRCs in all treatment groups were significantly different, with all $p<0.05$ (Table 2).

Surface hardness with varying resin composite thicknesses

The results of the top and bottom surface hardness tests with varying SFRC thicknesses of 3, 4, and 5 mm can be seen in Table 3. There was a significant difference in hardness between the 3-mm and 4-mm thickness treatment groups on the top and bottom surfaces of the SFRCs, as well as between the 3-mm and 5-mm thickness treatment groups. There was no significant difference in hardness between the 4-mm and 5-mm thickness treatment groups in the top surface of specimens, whereas the bottom surface of the specimens showed a significant difference.

SFRC depth of cure with varying thicknesses

The mean values and SDs of the depth of cure of the SFRCs with varying thicknesses of 3, 4, and 5 mm are presented in Table 3. The depths of cure with the different thicknesses were 81.0±1.0%, 78.2±1.0%, and 34.4±2.0%, respectively. The depths of cure of the SFRCs in all treatment groups were significantly different with all $p<0.05$.

DISCUSSION

In this study, the results showed that the mean value of surface hardness of an SFRC as a substructure decreased with the increase of light-curing distance both on the top and bottom surfaces. The distance between the LCU's light tip and the resin composite surface may affect the light intensity that reaches the material surface, and 1 mm of air reduced the light intensity by approximately 10%, thereby interfering with the polymerization depth [23]. The total energy that reaches the surface of the SFRC during polymerization may affect the mechanical properties of the resin composite; one such property is surface hardness [24].

The decrease of the top surface hardness of the SFRCs is consistent with D'Souza's claim that a decrease in light intensity during polymerization occurred when the light-curing distance exceeded 2 mm [25]. In this study, an increase in light-curing distance from 0 to 4 mm caused a decrease in the top surface hardness of 14.6%, whereas there was a 19.7% decrease in the bottom surface hardness.

The surface hardness of SFRCs is related to the number of crosslinks or networks that are formed during the propagation stage. The top surface of the SFRC receives less-optimal energy due to an increase in the light-curing distance. A light-curing distance exceeding 2 mm could decrease the crosslinks that are formed, resulting in the decrease of the top surface hardness of the SFRC.

The bottom surface hardness value was lower than the top surface hardness, resulting from differences in the light-curing distance. The SFRC, which comprises heterogeneous structures of combined resin matrices and fillers, caused the light intensity that passed through the resin composite to be propagated at the confluence of the resin matrices with the filler due to the differences in the refractive indices of each component. This caused a decrease in the intensity of light required during the process of the fiber resin composite's deepest polymerization [26,27].

Adequate depths of cure are obtained if the ratio of the bottom surface hardness to the top surface is at least 0.80 (80%) [18]. The results of this study indicated that the highest depth of cure was only 79.0±0.7% at a light-curing distance of 0 mm. A depth of cure of 80% could not be achieved with the 4-mm resin thickness at varying light-curing distances of 0, 2, and 4 mm, although the top surface hardness

Table 1: Material, description, composition, and manufacturer

Material	Description	Composition	Manufacturer
EverXPosterior™	SFRC substructure	Bis-GMA, PMMA, TEGDMA, short E-glass fiber filler, barium glass 74.2 wt.%, 53.6 vol.%	GC Corp, Tokyo, Japan

SFRC: Short fiber–reinforced resin composite, Bis-GMA: Bisphenol A–glycidyl methacrylate, PMMA: Polymer poly methyl methacrylate, TEGDMA: Triethylene glycol dimethacrylate

Table 2: Mean hardness value, depth of cure (%) and SD of the SFRC

Light-curing distance (mm)	Mean hardness value±SD VHN		Depth of cure±SD %
	Top surface	Bottom surface	
0	59.6±2.0[A]	47.3±1.3[A]	79.0±0.7[A]
2	57.8±1.2[A]	44.2±0.9[B]	77.0±0.6[B]
4	50.9±1.1[B]	38.0±0.8[C]	75.0±0.8[C]

*Value with different superscript letters shows a significant difference at p<0.05. SD: Standard deviation, SFRC: Short fiber–reinforced resin composite

Table 3: Mean hardness value, depth of cure (%), and SD of the SFRC

Specimen thickness (mm)	Mean hardness value±SD VHN		Depth of cure±SD (%)
	Top surface	Bottom surface	
3	63.8±2.1[A]	51.9±1.6[A]	81.0±1.0[A]
4	59.1±1.3[B]	46.1±1.0[B]	78.2±1.0[B]
5	58.2±0.7[B]	19.9±0.9[C]	34.4±2.0[C]

*Value with different superscript letters shows a significant difference at p<0.05. SD: Standard deviation, SFRC: Short fiber–reinforced resin composite

in the light-curing distances of 0 and 2 mm showed no significant difference.

In clinical use, as a substructure of the posterior tooth restoration, the SFRC must be coated with an overlying resin composite particulate. As a result, in clinical terms, a light-curing distance of 1–2 mm from the SFRC is required. In addition, the presence of large cusps and a more posterior tooth position affect the direction of curing, as it is relatively hard to position the light perpendicularly (90°) to the surface of the SFRC [24]. A direction of curing that is less perpendicular to the SFRC may cause the light beam to spread.

This study indicated that the depth of cure with a light-curing distance of 2 mm was only 77.0±0.6%, meaning that it failed to reach the minimum depth of cure value 0.80 (80%).

This study also showed an increased polymerized resin thickness caused the bottom surface hardness to decrease as the light passing through the bulk of the resin composite decreased in intensity. The intensity of the light was reduced due to the scattered beam caused by the filler and resin matrices. In general, if the beam does not reach the bottom of the specimen, it will be poorly polymerized. The poorly polymerized parts tend to be softer than the well-polymerized ones.

An increase in polymerized resin thickness from 3 to 5 mm (2 mm increase) resulted in a decrease in top surface hardness of 8.8%, whereas the bottom surface hardness fell to 61.6%. An increase of 2 mm in the light-curing distance only caused the top surface hardness to fall to 3% whereas the bottom surface to 6.6%. This result indicated that the polymerized resin thickness considered more carefully than the light-curing distance [21].

The ratio of the bottom surface hardness value to that of the top surface will affect the depth of cure value of the fiber resin composite [13]. The results showed that the depth of cure of the SFRC with a 3-mm thickness achieved a value of 81.0±1.0% with an irradiance of 800 mW/cm^2 using an LED LCU, a curing duration of 20 s, and the distance of the light-curing tip of 0 mm (directly above the Mylar strip). In another study, polymerization of SFRCs with 600 mW/cm^2 for 30 s was reported to produce a 4.02-mm depth of cure, as measured by the scraping method (ISO 4049) [16].

The manufacturer stated that, as a substructure, SFRC can be polymerized up to 4 mm in thickness, and depth of cure measurements were also performed using scraping method (ISO 4049) [8]. Nevertheless, the scraping method is only able to show the estimated crude value of the depth of cure due to the difficulty of standardizing the pressure during resin composite scraping, which tends to cause an overestimated result [13].

CONCLUSION

Given the limitations in the present study, the SFRCs used in this research could be placed and cured properly only in the case of 3-mm thickness and 0-mm light-curing distance, resulting in a depth of cure of 0.81 (81.0%).

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