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Comparing the Curing Quality of Bulk-fill and Conventional Composites at Various Irradiation Times and Depths

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Abstract
Background: Bulk-fill composites are a new class of materials introduced to speed up the clinical process of posterior restorations. This study compared the curing quality of bulk-fill and conventional composites at different irradiation times and depths.
Methods: In this in-vitro study, 40 specimens from a bulk-fill composite, Tetric N-Ceram bulk-fill (TNB), and a conventional composite, Tetric N-Ceram (TN), were fabricated using a metal mold (6 mm × 4 mm) (n = 10). The composites were placed and cured in bulk for each composite. For each composite, half of the samples were cured for 20 seconds (s) using a light-emitting diode (LED) curing unit, and the irradiation time for the other half was 40. After 24 hours of storage in distilled water, the hardness of the samples was measured using a microhardness tester at different depths (0.1, 1, 2, 3, and 4 mm). Statistical analysis was done using multivariate ANOVA and independent *t* test ($P < 0.05$).
Results: Both composites presented a significant reduction in hardness value with increasing depth. TNB showed significantly higher hardness values at all depths in both irradiation times than conventional composite. TNB composite did not achieve a depth of cure (DOC) of 4 mm at any of the two curing times. Irradiation time significantly affects hardness values in both composites.
Conclusion: Given that neither bulk-fill nor conventional composite was cured at depths greater than 3 mm, it is suggested that prolonged curing cycles be used to improve the DOC of composites.
Keywords: Composite, Bulk fill, Hardness, Irradiation time, Depth of cure

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Introduction

Depth of cure (DOC) and limitation of light penetration are essential issues in light-cured dental composites (1). Adequate polymerization is a critical factor in achieving appropriate mechanical properties (2). Several clinical strategies have been proposed to reduce the problems of direct posterior composite restorations, including incremental placement of composite, use of stress breaker liners, and changes in the photoinitiation mechanism. Incremental placement of composite is the standard technique of placing composite in thicknesses no more than 2 mm (3,4). Two logical reasons for using this technique are to reduce polymerization shrinkage stress and to provide a sufficient degree of cure (5). As a result, a smaller volume of the composite is placed, the C-factor decreases, and the contact surface of the composite with the cavity wall decreases. This method has some disadvantages. It is a time-consuming technique, especially in deep cavities, and there is a risk of increased contamination and trapped void, leading to weakened bonds between layers. The increased potential of suboptimal curing at the base of restoration may tarnish marginal integrity and cause postoperative sensitivity (4-7).

Clinicians are still looking for simpler and faster methods for composite restorations. In this regard, bulk-fill composites have been introduced recently and have become popular. These composites have better cure depth, controlled shrinkage stress, and less cuspal deflection than conventional composites (1,8,9). The number of layers required to fill a cavity has been reduced compared to conventional techniques using these materials. In contrast to the maximum of 2 mm thickness recommended for conventional composites, according to the manufacturer's claims, bulk-fill composites can be applied in layers 4–5 mm thick (1, 5). Using bulk-fill materials will simplify restoration and save clinical time in large posterior cavities. The possibility of applying greater thicknesses for bulk-fill composites is due to modifications in photoinitiator systems and increased translucency (changes in filler size/content) (3,10-12).

Ivoclar Vivadent has introduced the Tetric N-Ceram bulk-fill (TNB) composite. It is claimed to achieve a DOC of 4 mm due to its unique composition. Using a new photoinitiator along with filler modifications for more effective polymerization and minimizing shrinkage stress allows for a deeper cure compared to conventional composites (13).

The quality and extent of effective polymerization can be evaluated by direct methods such as Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy, which measure the degree of conversion. Hardness measurement is a common, simple, and precise indirect technique recommended to evaluate the DOC of resin composites. A bottom-to-top hardness ratio above 0.8 indicates adequate DOC (14). Considering the curing quality of composites has a great effect on physical and mechanical properties, and there are controversial data regarding the curing performance of bulk-composites, the present study aimed to investigate the microhardness profile and DOC of bulk-fill and conventional composites in different irradiation times. The null hypotheses were: 1) There would be no differences in the DOC of the two tested composites, and 2) There would be no differences in the DOC of the composites between two irradiation times.

Methods

In this experimental study, a bulk-fill composite, Tetric N-Ceram bulk-fill (Ivoclar Vivadent, Schaan, Liechtenstein), and a conventional composite, Tetric N-Ceram (TN) (Ivoclar Vivadent, Schaan, Liechtenstein) were used (Table 1). Twenty samples of each composite (40 samples in total) were fabricated using a two-piece semi-cylindrical metal mold (height 6 mm and radius 4 mm).

Composites were placed into the mold using their respective method to mimic the clinical process (layering technique for TN and bulk technique for TNB). The layering technique included placing the composite in increments ≤ 2 mm and curing each layer for either 20 or 40 s from above. In the bulk method, a single composite layer was applied to fill the mold and cured for 20 or 40 seconds from the top surface. Before every curing round, a glass slide was placed on the mold. The curing process was done using a light-emitting diode (Demi Ultra, Kerr, USA-1200 mw/cm^2) curing unit; the output of the light curing unit was checked periodically. The tip of the curing unit was kept in contact with the glass slide to ensure a constant distance from the composite surface.

After 24 hours of storage in distilled water at room temperature, the hardness profile of the samples was measured using a microhardness tester (Duramin 20, Struers, Denmark) with 100 g load for 15 s from top to bottom at every one millimeter to the depth of 5 mm. In each depth, the hardness was measured from three indentations, and then, the mean of the three values was reported as the hardness at that depth. The following formula was used to calculate the microhardness:

$$HV = 1.8544 \times F / d2$$

Where d is the diagonal of the indentation, and F is the predetermined load applied on the sample.

Statistical analysis was performed using SPSS 26. First, the microhardness level was calculated using descriptive indices (mean and standard deviation) for each composite type in terms of time and depth. Then, the Kolmogorov-Smirnov test was used to determine the normality of microhardness at different depths. The distribution of Vickers hardness in both composites at different depths was analyzed using multivariate ANOVA and independent *t* test. A significance level of 0.05 was considered.

Results

The hardness values of TNB and TN composite are presented at different depths based on curing time in Tables 2 and 3, respectively. The results showed that the VHN values at 40 seconds were significantly higher than at 20 seconds at all depths ($P = 0.0001$).

Comparison of two composites

Bulk-fill composite showed significantly higher hardness value in all depths than conventional composite (Table 4). Based on the repeated measures test, the trend of changes with increasing depth in both composites and times significantly decreased ($P = 0.0001$) (Figures 1 and 2).

Discussion

A significant challenge in the clinical application of

Table 1. Material specifications

Composite	Type	Manufacture	Batch No./shade	Composition
Tetric N-Ceram	Conventional	Ivoclar Vivadent Schaan Liechtenstein	RO 8354 A_2	Resin: Bis-GMA, UDMA Filler: Ba Glass, Yb3f, mix Oxide (80-81Wt%)
Tetric N-Ceram bulk-fill	High-viscosity bulk-fill	Ivoclar Vivadent Schaan Liechtenstein	S2 8518 IVA	Resin: Bis-GMA, UDMA Filler: BA-AL-Si Glass Prepolymerized filler (monomer, glass filler, Ybf) Mixed oxide (75–77 wt%)

Table 2. Mean and standard deviations of hardness values for the TNB composite at different depths and times

	Time	Mean	Standard deviation	*P* value
0.1 mm	20	67.5889	1.28607	0.0001
	40	79.1444	2.25473	
1 mm	20	66.1500	1.34087	0.0001
	40	78.3556	2.85888	
2 mm	20	60.1111	1.25224	0.0001
	40	73.0944	3.14651	
3 mm	20	55.8722	1.55556	0.0001
	40	68.4111	2.16738	
4 mm	20	50.6056	1.45944	0.0001
	40	62.5611	2.09401	
5 mm	20	46.7278	1.09319	0.0001
	40	55.8611	2.11275	

Table 3. Mean and standard deviations of hardness values for the TN composite at different depths and times

	Time	Mean	Standard deviation	*P* value
0.1 mm	20	53.2500	1.69124	0.0001
	40	63.3167	1.61619	
1 mm	20	52.3444	2.00065	0.0001
	40	62.3500	2.20247	
2 mm	20	46.4111	2.21755	0.0001
	40	57.1222	2.08371	
3 mm	20	43.7444	1.35048	0.0001
	40	54.0333	3.41605	
4 mm	20	39.9667	1.59115	0.0001
	40	48.0889	1.69702	
5 mm	20	37.9111	2.96130	0.0001
	40	43.1111	1.55597	

Table 4. Comparison of the two studied composites at different depths

	Composite	Mean	Standard deviation	*P* value
0.1mm	Tetric N-Ceram Bulk Fill	73.3667	6.13263	0.0001
	Tetric N-Ceram	58.2833	5.35876	
1 mm	Tetric N-Ceram Bulk Fill	72.2528	6.56895	0.0001
	Tetric N-Ceram	57.3472	5.48116	
2 mm	Tetric N-Ceram Bulk Fill	66.6028	6.99402	0.0001
	Tetric N-Ceram	51.7667	5.83085	
3 mm	Tetric N-Ceram Bulk Fill	62.1417	6.62456	0.0001
	Tetric N-Ceram	48.8889	5.81165	
4 mm	Tetric N-Ceram Bulk Fill	56.5833	6.31816	0.0001
	Tetric N-Ceram	44.0278	4.42632	
5 mm	Tetric N-Ceram Bulk Fill	51.2944	4.91923	0.0001
	Tetric N-Ceram	40.5111	3.51972	

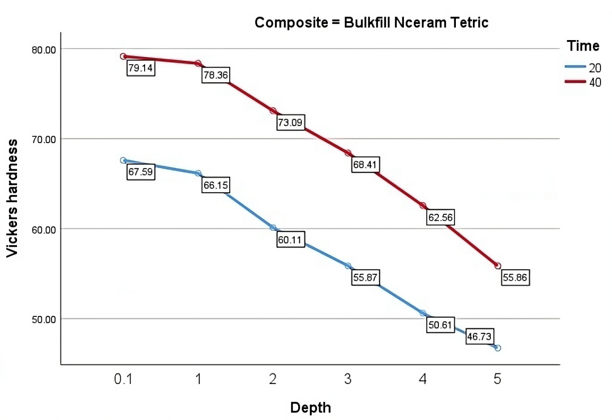

Figure 1. Trend of changes with increasing depth in TNB

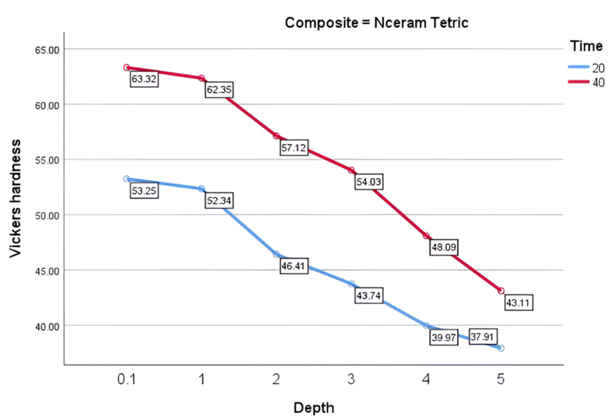

Figure 2. Trend of changes with increasing depth in TN

composite is the DOC and polymerization shrinkage (4). DOC refers to the thickness of a composite that light can cure adequately (bottom-to-top hardness ratio of 0.8) (1,14). DOC of dental composites is influenced by filler (size/load), shade, and translucency, light irradiance, exposure time, monomer composition, and initiator type and concentration (5,10). The first null hypothesis of this study was accepted. TN and TNB composites achieved 80% surface hardness in both 20 and 40 s of irradiation at a depth of 3 mm. TNB could not achieve the DOC of 4 mm. This result is consistent with the studies of Aggarwal et al and Jang et al, who reported that TNB composite was not sufficiently cured in the 4 mm depth (15,16).

In the current study, the hardness number decreased with increasing thickness and depth, consistent with previous studies (17-19). There is much evidence of a gradual decrease in the degree of conversion at deeper parts of the restoration in the literature (20). Previous studies have reported a strong correlation between degree of conversion (DC) and hardness values (21-23). Since composites are heterogenous materials (resin and filler), during light transmission, the light intensity is reduced with increasing thickness due to absorption and scattering phenomena (4,10), where the light is scattered at the resin/filler interface due to the difference in the refractive index of two components. As the light intensity decreases through the bulk of the composite, the degree of conversion of the composite decreases. According to the logarithmic decrease in light transmission at depth (only 7% overall transmittance at 3 mm), light attenuation while passing through the resin composites is high and increases exponentially with thickness (14,24).

In the present study, TNB composite achieved higher hardness values at both irradiation times in all depths (20 s/40 s), which confirmed the manufacturer's claim (22). Kubo et al revealed that with increasing depth in bulk-fill composites, the degree of conversion is higher compared to conventional composites (25). TNB composite showed higher hardness values than TN composite, which is related to characteristics of bulk-fill composites and their compositional difference from conventional ones. It is claimed that the increased DOC of bulk-fill composites is related to modifications in their filler content/size, higher translucency, and the use of additional photoinitiators (3). Despite the similarity in shape and size of fillers, the higher translucency due to different filler composition and lower filler content of TNB (75–77 wt%) compared to TN (80–81 wt%) can justify this result that is supported by previous studies (26-28). Also, the presence of pre-polymerized fillers (containing barium glass and silica materials) in TNB leads to achieving high filler load while containing a low specific surface between the filler and matrix, which may result in more light transmittance to deeper parts of the composite and higher conversion (27-29). This result is contrary to the findings of the study by Kelić et al, who reported lower microhardness for bulk-fill composites containing pre-polymerized fillers (30). The new photoinitiator available in Ivoclar Vivadent bulk-fill composites is a germanium derivative called Ivocerin, which is added along with camphorquinone/amine initiator systems for faster polymerization and greater DOC. Ivocerin has a superior photo-curing activity to camphorquinone. Although the number of photons that reach the bottom of the cavity is significantly less than the amount that hits the surface, it is enough to activate Ivocerin to stimulate polymerization in deeper parts (8,25).

As a result of using the layering method, the bottom-to-top surface hardness ratio reached 80% at a depth of 3 mm in the TN composite. Due to the lower hardness value in the TN composite, a layering technique is required to ensure adequate polymerization of the composite in deeper areas (17,31). The incremental technique has the cumulative effect of light on deeper parts of the material. The deep layers receive extra light and experience greater polymerization (32-34).

The second hypothesis was rejected, and 40 s irradiation had significantly higher hardness values than 20 s irradiation. This agrees with previous studies that showed a higher degree of conversion with longer irradiation time (25,35). Increasing curing time and, therefore, higher energy density leads to higher conversion at deeper parts of composite bulk (31).

Conclusion

The parameters of depth, irradiation time, and composite type significantly affected the hardness values of the studied composites. Despite the manufacturer's claim, TNB could not achieve the DOC of 4 mm in this study. Therefore, increasing the irradiation time and limiting the increment thickness of composites in clinical performance is suggested.

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Authors' Contribution

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Methodology: Nafiseh Elmamooz.
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Visualization: Nafiseh Elmamooz, Ali Eskandarizadeh, Maryam Bagherinasab, Mehdi Rezaei, Mehrnaz Karimi Afshar.
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Writing-review & editing: Nafiseh Elmamooz.

Competing Interests

None.

Ethical Approval

This study was approved by the Ethics Committee at Kerman

University of Medical Sciences (ethical code: IR.KMU.REC.1393.476)

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