Odovtos-International Journal of Dental Sciences (Odovtos-Int. J. Dent. Sc.) 28 (3), 2026 (September-December): 197-210. ISSN: 2215-3411
https://doi.org/10.15517/z21whs73

ODOVTOS
International Journal of Dental Sciences

UNIVERSIDAD DE COSTA RICA
FOd Facultad de Odontología

https://revistas.ucr.ac.cr/index.php/rOdontos

BASIC RESEARCH:

Effect of High-Power Curing on Polymerization Shrinkage and Microhardness of Composite Resins

Efecto del curado a alta potencia sobre la contracción de polimerización y la microdureza de las resinas compuestas

Nur Selen Öztürk[1] https://orcid.org/0000-0002-8451-6519
Mustafa Demirci[2] https://orcid.org/0000-0002-9297-6945
Safa Tuncer[3] https://orcid.org/0000-0003-2101-3225
Neslihan Tekçe[4] https://orcid.org/0000-0002-5447-3159
Özge Duman Özbilgi[5] https://orcid.org/0000-0003-0521-4318

[1]Postgraduate student, University of Istanbul Institute for Health Sciences, Istanbul, Turkey.
[2]Professor & Head, Department of Restorative Dentistry. University of Istanbul, Turkey.
[3]Professor Department of Restorative Dentistry. University of Istanbul, Turkey.
[4]Professor Department of Restorative Dentistry. University of Kocaeli, Turkey.
[5]Postgraduate student Department of Restorative Dentistry. University of Istanbul, Turkey.

Correspondence to: Nur Selen Öztürk - n-selen@hotmail.com

Received: 21-VIII-2025 Accepted: 20-XI-2025

ABSTRACT: The polymerization shrinkage (PS) and microhardness of dental composite resins, are known to be significantly influenced by the intensity of the curing light and the thickness of the material. However, the specific effect of high-power curing mode on composite resins has not been fully clarified. This study investigated the effect of the curing mode using high-power curing unit (VALO) on the volumetric shrinkage and microhardness of nanohybrid composites. SonicFill 3 and OptiShade were polymerized using standard and high-power curing modes with the VALO Cordless. A total of 60 specimens were prepared using Teflon molds with a diameter of 8 mm and a thicknesses of 2 mm and 4 mm. The microhardness values were measured using a Vickers hardness tester (Innovatest,Maastricht,Holland). Forty specimens were prepared for volumetric shrinkage ratios. PS was measured using a video imaging device (Acuvol Volumetric Shrinkage Analyzer; Bisco Inc., Schaumburg, IL, USA). The curing mode affected the microhardness of each composite material. Pertaining to microhardness of the nanohybrid composite materials, there were significant differences between thicknesses and light-curing modes ($p<0.05$). For the volumetric shrinkage, differences were measured between the materials based on the curing mode. High-power curing of a bulk-fill composite resulted in the lowest PS value. Increasing the layer thickness negatively affected the hardness of the composite resins.

Copyright (c) 2026 Nur Selen Öztürk, Mustafa Demirci, Safa Tuncer, Neslihan Tekçe, Özge Duman Özbilgi.

Odovtos -Int J Dent Sc endorses to CC-BY-NC-SA 4.0.

KEYWORDS: Composite resins; Dental curing lights; Dental materials; Hardness tests; Polymerization; Mechanical stress.

RESUMEN: Se sabe que la contracción por polimerización y la microdureza de las resinas compuestas dentales están significativamente influenciadas por el grosorde aplicación y la intensidad lumínica de la unidad de fotocurado. Sin embargo, el efecto específico del modo de fotopolimerización de alta potencia sobre las resinas compuestas no ha sido complemente esclarecido. Este estudio in investigó el efecto del modo de curado utilizando una unidad LED de alta potencia (VALO) en términos de contracción volumétrica y microdureza de resinas compuestas nanohíbridos. SonicFill 3 y OptiShade fueron polimerizadas empleando modos de curado estándar y de alta potencá con el disposivito VALO Cordless. Se prepararon un total de 60 especímenes utilizando moldes de teflón con un diámetro de 8 mm y un grosor de 2 mm y 4 mm. Los valores de microdureza fueron determinados mediante un durómetro Vickers (Innovatest, Maastricht, Holanda). Para la medición de la contracción volumétrica, se prepararon 40 especímenes adicionales de los composites SonicFill 3 y OptiShade, evaluados con un analizador de contracción volumétrica (Acuvol Schaumburg, IL, EE. UU.). Se ha observado que cada uno de los modos de curado afecta a la microdureza de cada material compuesto. En cuanto a la microdureza de los materiales compuestos nanohíbridos, se observaron diferencias signficatives entre los espesores y los mododa de curado con luz ($p<0,05$). En cuanto a la contracción volumétrica, se midieron diferencias entre los materiales según el modo de curado. El curado de alta potencia para el compuesto de relleno masivo mostró el valor más bajo de contracción por polimerización- El aumento del espesor de la capa tuvo un efecto negativo en la dureza de las resinas compuestas.

PALABRAS CLAVE: Resinas compuestas; Lámparas de fotocurado dental; Materiales dentales; Ensayos de dureza; Polimerización; Estrés mecánico.

INTRODUCTION

Resin-based materials are important place in restorative dentistry. Dental composites meet the esthetic and strength requirements demanded by clinicians and patients; however, some shortcomings remain. During the polymerization process, volumetric shrinkage of the composite material leads to the formation of a gap between the restoration and the bonded tooth surface. This shrinkage is a significant clinical concern, as it can result in marginal leakage, cuspal flexure, discoloration, secondary caries and postoperative sensitivity (1). Consequently, the mechanical integrity and longevity of the restoration can be compromised (2). One of the primary strategies to address this issue is to minimize the volumetric shrinkage of the material.

PS of composite resins can be measured either linearly or volumetrically (3). In addition to the direct measurement of PS, surface hardness measurement is widely employed, as it offers a simple, accurate, and reliable indication of the degree of polymerization. This is because it is closely related to the monomer-to-polymer conversion rate, which reflects the efficiency and success of the polymerization process (4, 5). Resin-based composites are generally considered to be sufficiently cured when the bottom/top hardness ratio is 80% (6). The efficiency of the polymerization process plays a crucial role in ensuring sufficient curing and is influenced by several factors, including the type of composite, layer thickness, light intensity, and curing time (7). These parameters directly affect the mechanical performance and long-term clinical success of the restoration.

In clinical practice, ensuring adequate polymerization is essential for shrinkage. Stepwise layering techniques are recommended to reduce the configuration factor (C-factor) by applying the composite in thin increments, thereby increasing the polymerization efficiency and minimizing polymerization-induced stress (1). However, owing to the technical sensitivity of the layered technique and the risk of gap formation between layers, alternative placement methods and a new category of resin-based materials known as bulk-fill composites have been developed and made introduced into clinical practice (1, 8).

Bulk-fill materials, which allow placement in increments of up to 4-5 mm, simplify and accelerate clinical procedures while reducing the risk of technical errors by eliminating interlayer gaps (9). Studies have shown that bulk-fill composite resins enable better control of the polymerization process, provide a greater depth of cure, and increase surface hardness (10-12). However, advanced monomer technologies have been developed to overcome the increased PS related to the placement of large volumes of composite fillings (13).

In this context, conventional monomers, such as high-viscosity bisphenol A-glycidyl methacrylate (Bis-GMA), are either removed or partially replaced with lower viscosity alternatives, such as triethylene glycol dimethacrylate (TEGDMA), ethoxylated bisphenol A dimethacrylate, (EBPDMA) and urethane dimethacrylate (UDMA) to facilitate deeper curing and reduce polymerization stress (14). Moreover, the addition of anti-stress fillers to the structure allows control of the PS process (15).

SonicFill 3 (Kerr Corp., Orange, CA), produced as a high-viscosity bulk-fill material applied at a depth of 4-5 mm with the sonic activation technique, is one of them. A filler rate uses sonic vibration to decrease the viscosity during insertion when applied the material flows into the cavity. This allows the material to better conform to the cavity walls and mitigate marginal microleakage. SonicFill 3 contains a higher concentration of the resin matrix and nanofillers than conventional composites. This formulation reduces PS and gap formation, thereby enhancing the material's mechanical properties and wear resistance of the material (16).

Used for 20 years in both anterior and posterior restorations, these composites are classified as universal composites and have good polishing properties owing to the ultrafine filler in their structures. Recently, a universal nanohybrid composite resin known as OptiShade (Kerr, Corp., Orange, CA, USA) has been introduced, featuring a high filler load and a matrix enhanced with nanosized particles (17). When producing universal composite resins, light-absorbing pigments are either reduced/removed or modified in type, resulting in a more translucent material (18). Additionally, the incorporation of fine micro- and nano-scale structures into the resin matrix enhances light reflection. Adequate curing of universal composites ensures optimal restorative performance, whereas insufficient polymerization may lead to restoration failure and can adversely affect both the physical and mechanical properties (19).

Some light-related factors, such as the curing method, radiant exposure, curing time, and light output, affect the polymerization process and hence the mechanical properties of composite resins. First, the increase in mechanical properties reaches a saturation point, and the threshold of radiant exposure at which saturation occurs varies depending on the material. Second, it has been shown that different combinations of curing time and irradiance can lead to significant differences in material properties, even at a given radiant exposure, although the degree of conversion and

mechanical properties, such as hardness are also affected (20). This can be explained by the possible loss of radical growth centers through bimolecular termination in the during the early stages of polymerization, when the monomer mobility is high (21).

This loss (referred to as premature termination) is more pronounced under high irradiance conditions, as the reaction tends to terminate at lower degrees of conversion (21, 22).

To reduce the volumetric shrinkage of the composite resins and the associated stresses, modifications to the curing protocols have also been introduced. It was hypothesized that slowing down the initial polymerization phase (e.g., soft-start and pulse-delay protocols) would allow greater viscous flow before the majority of the shrinkage stress began to accumulate (23). However, as soft-start and pulse-delay polymerization protocols have failed to reduce associated stresses to a clinically desirable level (23), high-intensity light curing with a short curing time has gained prominence , contributing to the overall simplification of restorative procedures.

New-generation light-emitting diode (LED) light devices provide polymerization in a short time with high light power (VALO, Ultradent, Bluephase Powercure, Ivoclar, Vivadent), and the increased light tip diameter provides more homogeneous irradiation, thereby improving polymerization efficiency (24).

This study aimed evaluate the effects of high-power curing light on the microhardness and PS of nanohybrid universal and bulk-fill composite resins. The following null hypotheses were tested: (1) High-power curing light has no effect on the PS and microhardness of bulk-fill and universal composite resins (2). The type of composite material does not affect the microhardness and PS in terms of high-power light curing.

MATERIALS AND METHODS

Two resin-based composites were selected: a bulk-fill (SonicFill 3, Kerr Corp., USA, [SF3]) and a nanohybrid universal composite (OptiShade, Kerr Corp., USA, [OS]). Detailed information about these products is presented in Table 1.

PREPARATION OF SPECIMENS

For the microhardness tests, the composite materials were divided into groups. Disc-shaped specimens were fabricated for each resin type, yielding a total of 60 specimens (n=10 per group). The specimens were prepared using cylindrical stainless-steel molds with dimensions of 8.0 mm in diameter and 2.0 mm in height for conventional and bulk-fill composites and 8.0 mm in diameter and 4.0 mm in height specifically for bulk-fill composite. The composites were placed in the molds, which were then clamped between two microscope glass slides to remove excess material.

For each composite group, half of the specimens were polymerized using the standard mode of the light-curing unit (LCU) for 10 s, and while the remaining half were polymerized using the high-power mode for 8 s. Following curing, both the top surfaces of all the specimens were prepolished for 20 s using 600 grit silicon carbide (SiC) paper under running water. Final polishing was carried out with Shofu Super Snap Finishing and Polishing Discs (L506, L508, L501, and L502) at a low speed for 15 s.

For the PS measurement test, the specimens were prepared in a hemispherical shape at the time of measurement. Specimens were not

polished. For each composite, half of the specimens were cured with the standard mode of the LCU for 10 s and the other half were cured with the high-power mode for 8 s.

LIGHT-CURING UNIT CHARACTERISTICS

The VALO Cordless 3rd. generation light device has a multiwave light emission with a wavelength range of 385-515 nm and short curing times (Table 1). This device can also be used for for photoinitiators produced in addition to camphorquinone (CQ).

Depending on the selected curing mode, the device can deliver irradiance levels of up to 3200 mW/cm^2. In accordance with the to the manufacturer's recommendation, the curing time was doubled for every 2 mm increase in the material thickness. The intensity of the light unit was measured using a radiometer (Woodpecker Curing Light Meter, Genç Dental, Istanbul, Turkey).

Table 1. Information of composite materials and light-curing unit tested in this study.

Brand Name	Filler Type	Composition	Shade	Lot	Manufacturer
SonicFill	Nanohybrid bulk-fill	BisGMA,TEGDMA, Bis-EMA,Silica particles,barium glass particles,ytterbium trifluoride, 20-500 nm particles 81.3%(w) 65.5%(v)	A1	8986216	Kerr Orange, CA, USA
OptiShade	Nanohybrid universal	Bis-GMA, TEGDMA,Bis-EMA, 400 nm Ba-glass silica Nanoparticles 5-400 nm nanoparticles, 81%(w) 64.5%(v)	Medium	9319996	Kerr Orange, CA, USA
Light-Curing Unit	**Type**	**Irradiance/Recommended Curing Time**			**Manufacturer**
VALO	LED third-generation	Standard mode (1200 mW/cm^2) 10s High-power mode (1800 mW/cm^2) 8s			Ultradent Products Inc, South Jordan, UT, USA

Bis-GMA,Bisphenol-A glycidyl methacrylate; TEGDMA, Triethylene glycol dimethacrylate; UDMA, Urethane dimethacrylate; Bis-EMA,Ethoxylated bisphenol A dimethacrylate

MEASUREMENT OF POLYMERIZATION SHRINKAGE

A video imaging device (Acuvol Volumetric Shrinkage Analyzer; Bisco Inc., Schaumburg, IL, USA) was used to test PS (n=10). Each composite specimen was shaped into a hemisphere and placed on a 4.2 mm-diameter polytetrafluoroethylene (PTFE) pedestal positioned in front of the device's CCD camera. The specimen size was verified according to the guide line on the computer screen used for measurement. If any material extended beyond the intended boundaries, it was carefully removed before polymerization to ensure precise shape conformity. Once the final geometry was obtained, the device lid was closed and the specimens were kept for 5 min and the initial volume was recorded as V_1. Then, a curing unit (VALO™ Cordless Light Emitting Diode, Ultradent) with the tip close to the surface of the specimen was activated for irradiation. The post curing volume after 5 min was recorded as V_2. The resulting volumetric changes were observed and recorded using a computer program.

PS was calculated as follows:

$$PS = (V_1 - V_2) / V_1 \times 100$$

MEASUREMENTS OF MICROHARDNESS

All prepared specimens were stored in distilled water at 37 º C for 24 h before testing. The composite specimens were placed on the device table and the diamond tip of a Vickers microhardness tester (Innovatest,Maastricht, Netherlands) was applied to the top and bottom surfaces of the specimens with at a constant load of 500 g for 15 s. Three indentations were made at a distance of 1 mm apart on each surface to be measured. The specimens were observed at ×40 magnification and the Vickers hardness number (VHN) was recorded,and the impression formed after the measurement was examined at ×10 magnification. The mean of three values obtained for each surface was calculated.

In this study, the bottom/top ratio (%) for different layer thicknesses was calculated as the depth of cure of the materials under different curing protocols. In addition, the tested materials were compared for their bottom/upper ratio, and a threshold of 80% indicated adequate polymerization efficacy.

STATISTICAL ANALYSIS

The Number Cruncher Statistical System (NCSS) 2007 Statistical Software (Utah, USA) package program was used for the statistical analyses. In addition to descriptive statistical methods, such as mean and standard deviation, the distribution of variables was examined using the Shapiro–Wilk normality test. One-way ANOVA analysis of variance was used to compare normally distributed variables, Tukey's post hoc multiple comparison test was used for subgroup comparisons, and the independent t-test was used for pairwise group comparisons. The coefficient and 95% confidence interval were used. Statistical significance was set at $p<0.05$.

RESULTS

POLYMERIZATION SHRINKAGE RESULTS

The PS results are listed in Table 2. The mean PS of ranged from 1.72% to 1.85%. No statistically significant differences were observed between the SonicFill and OptiShade materials after standard light curing .

The average PS of the SonicFill 3 resin-based composite under high- power light curing was statistically significantly lower than that of the OptiShade universal composite.

Table 2. Polymerization shrinkage ratio (%).

Material Group	Standard	High-Power
SonicFill 3	1.77±0.08	1.72±0.08
OptiShade	1.74±0.16	1.85±0.16
p*	0.656	0.008

*Independent t test

SURFACE MICROHARDNESS RESULTS

The VHN values for the resin composites tested using different light-curing protocols are shown in Table 3 and Table 4. As presented in Table 5, both material and surface type demonstrated statistically significant main effects on microhardness (p=0.0001 for each), and significant two-way effects were observed between material and light-curing mode (p=0.0001), between material and surface type (p=0.0001), and between light-curing mode (p=0.083); nor the three-way effects among material, light-curing mode, and surface type (p=0.0721) were not statistically significant.

Table 3. Vickers microhardness values of the same composite material at different thicknesses.

Material	Standard			High-Power		
	Upper surface	Bottom surface	p*	Upper surface	Bottom surface	p*
SonicFill 3 (2mm)	78.59±5.29 (AaA^1)	70.06±7.43 (AbA^1)	0.008	63.19±7.03 (AaB^1)	59.64±4.38 (AaB^1)	0.192
SonicFill 3 (4mm)	64.46±6.08 (BaA^1)	44.25±5.78 (BbA^1)	0.0001	66.54±3.79 (AaA^1)	48.9±6.21 (BbA^1)	0.0001
p*	0.0001	0.0001		0.371	0.001	

‡ One-way variance analysis *Independent test. Different lowercase letters within each row and different capital letters within each column represent statistically significant differences. Different superscript letters (A^1, B^1) within the same row indicate statistically significant differences between light-curing modes for the same surface and the material ($p<0.05$).

Table 4. Vickers microhardness values of different composite materials with the same thickness.

Material	Standard			High-Power		
	Upper surface	Bottom surface	p*	Upper surface	Bottom surface	p*
SonicFill 3 (2mm)	78.59±5.29 (AaA^1)	70.06±7.43 (AbA^1)	0.008	63.19±7.03 (AaB^1)	59.64±4.38 (AaB^1)	0.192
OptiShade (2mm)	71.35±6.53 (BaA^1)	55.57±5.52 (BbA^1)	0.0001	71.45±5.12 (BaA^1)	62.93±6.30 (AbB^1)	0.001
p*	0.027	0.0001		0.006	0.399	

‡ One-way variance analysis *Independent test. Different lowercase letters per line and different capital letters per column represent statistically significant differences. Different superscript letters (A^1, B^1) within the same row indicate statistically significant differences between light-curing modes for the same surface and the material ($p<0.05$).

Table 5. Tukey's post hoc test comparing for the effects of material type, curing mode, and surface on microhardness values.

Source	Type III Sum of Square	df	Mean Squa-re	F	p
Material	3148.44	2	1574.22	45.56	0.0001
Light-Curing	105.95	1	105.95	3.07	0.083
Surface	4804.55	1	4804.55	139.05	0.0001
Material * Light-Curing	1868.67	2	934.34	27.04	0.0001
Material * Surface	830.40	2	415.20	12.02	0.0001
Light-Curing * Surface	175.17	1	175.17	5.07	0.026
Material * Light-Curing * Surface	22.66	2	11.33	0.33	0.721

df: degrees of freedom.

For standard light curing, both the SonicFill 3 and OptiShade materials showed significant differences at the top and bottom surfaces for the same thickness.

When the materials used for standard curing were compared, a statistically significant difference was found between them in different thickness applications for both the bottom and upper surfaces.

When the microhardness values on the upper surface of materials applied at different thicknesses were compared, a difference was detected.

For the bottom surfaces, a significant difference was observed between SonicFill 3 and OptiShade material applied at a thickness of 2 mm.

For the SonicFill 3 material, the microhardness values of both the top and bottom surfaces in the standard light-curing group were statistically significantly higher than those in the high-power light curing group.

For the OptiShade material, the microhardness values of the bottom surface in the standard light-curing group were statistically significantly lower than those in the high-power light curing group.

No statistically significant differences were observed between the microhardness value averages of the standard and high-power light-curing groups (p=0.083).

According to the bottom/upper ratio (Table 6-7), the 2 mm thickness of the SonicFill 3 for standard curing was significantly higher than the 4 mm thickness (Tables 6 and 7). The 2 mm-thick SonicFill 3 for high curing was significantly higher than the 4 mm-thick SonicFill 3 high curing. The 2 mm thickness of the OptiShade for standard curing was significantly lower than the 2 mm thickness of the OptiShade for high curing. The 2 mm thickness of SonicFill 3 for standard curing was significantly higher than the 2 mm thickness OptiShade standard curing.

Table 6. Bottom/top ratio values of the materials according to light-curing modes and layer thickness (mean±SD).

Material/LED LCU	Mean±SD	Median (Min–Max)
SonicFill 3 2mm-Standard	89.32±10	85.51 (81.03–114.91)
SonicFill 3 4mm-Standard	69.58±13.39	70.22 (48.52–87.21)
OptiShade 2mm-Standard	78.41±9.58	79.03 (60.52–92)
SonicFill 3 2mm-High-power	89.1±10.04	88.36 (72.7–106.25)
SonicFill 3 4mm-High-power	73.79±11.15	70.06 (59.85–98.07)
OptiShade 2mm-High-power	87.93±11.66	88.72 (65.7–109.63)

Table 7. Significance (p-values) for pairwise comparisons between different thicknesses of the tested materials.

Material/ LED LCU Modes	Material/ LED LCU Modes	p
SonicFill 3	SonicFill 3	0.002
2mm-Standard	4mm-Standard	
SonicFill	OptiShade	0.029
2mm-Standard	2mm-Standard	
SonicFill	SonicFill 3	0.650
2mm-Standard	2mm-High-power	
SonicFill	SonicFill 3	0.450
4mm-Standard	4mm-High-power	
OptiShade	OptiShade	0.039
2mm-Standard	2mm-High-power	
SonicFill	SonicFill 3	0.007
2mm-High-power	4mm-High-power	
SonicFill	OptiShade	0.833
2mm-High-power	2mm-High-power	

DISCUSSION

In this study, the first null hypothesis that high-power curing light had no effect on PS and microhardness of bulk-fill and universal composite resins was rejected. The second hypothesis, that the type of composite material had no effect on microhardness and PS in terms of high-power light curing, was also rejected.

Various methods have been employed to measure PS, including the water/mercury, the bonded disc method, cuspal deflection, specific gravity analysis, electrical strain gauges, micro-CT, and optical methods (8, 25, 26).

The Acuvol device utilized for the evaluation of volumetric shrinkage is a simpler and more extensively tested method than other dilatometer-based methods. The Acuvol video imaging device was used to ascertain PS. Video imaging systems offer an expeditious and repeatable method for measuring volumetric shrinkage (13, 27). The device facilitates three-dimensional evaluation of volumetric shrinkage using a digital imaging system. Furthermore, the integration of a PTFE base into the device, in conjunction with the implementation of computerized visualization of excess material, has been demonstrated to facilitate the standardized adjustment of sample dimensions and yield more accurate results (28).

In the present study, PS for standard light curing was ranged from 1.74% to 1.77%, whereas for high-power light curing, this ratio ranged from 1.72% to 1.85%. A recent study concluded that different curing modes do not significantly affect volumetric shrinkage (29). In the same study, because materials with similar filler ratios were used, the filler volume was not an effective factor and different particles may have restricted molecular mobility by affecting light scattering (30). Contrary to our findings, a study using bulk-fill composite resins found that the PS rates range from 1.48% to 4.26%. This difference was attributed to the filler ratio of the resin-based

composites. Notably, flowable giomers with their lower filler and higher resin content are expected to exhibit greater shrinkgae than their higher filler restorative counterparts (13). Furthermore, increased volumetric shrinkage has been observed as a consequence of reduced filler content, which increases the resin matrix ratio. A significant correlation exists between the filler ratio and volumetric shrinkage of giomer composites, with the filler ratio identified as the primary factor influencing volumetric shrinkage (28). In the referenced study, the Bluephase light device (Ivoclar, Vivadent) utilized a curing tip diameter of 8 mm. In the present study, a curing tip diameter of 10 mm was employed with the VALO Cordless light. An increased light tip diameter has been shown to provide more homogeneous irradiation and enhance the polymerization efficiency (24). This likely contributed to the lower shrinkage values observed.

Rizzante *et al*. determined that the shrinkage rates of high-viscosity bulk-filled composite resins range from 0.84% to 3.07%. In the same study, low-viscosity bulk-fill composite resins exhibited higher shrinkage rates, ranging from 3.11% to 3.84% (11). In the present study, sonic activation of the bulk-fill composite resin may have resulted in a lower shrinkage rate compared to the high-viscosity bulk-fill resins. On the other hand, Rizzante *et al*. used μ-CT for three-dimensional volumetric shrinkage assessment. The μ-CT device measures changes on the surface rather than the changes in the internal volume of the material (25). Therefore, lower PS values were obtained. In addition, the use of a third-generation light-curing device, which allowed for standardized specimen sizes and high light intensity (1800 mW/cm²), was effective in reducing PS.

In this study, the top surfaces of both the conventional and bulk-fill composite materials exhibited higher microhardness than the bottom surfaces. This result can be explained by the universally accepted phenomenon of the direct exposure of the top surface to light (31). SonicFill 3 exhibited higher VH values than OptiShade at a thickness of 2 mm under the standard mode of the LCU. SonicFill 3 maintains the polymerization depth as a high-fill composite resin that requires sonic activation when applied with a special handpiece (32). Another reason could be the high photoinitiator content of SonicFill 3, as stated by the manufacturer. Moreover, the differences in microhardness values between the A1 shade SonicFill 3 and the medium-shade OptiShade composite materials can be explained by the color differences. Consistent with our results, Jeong *et al*. reported that dark- and medium-shade composites exhibited lower microhardness values than light-shade composites (33).

SonicFill 3 exhibited a statistically significant decrease for both curing modes at a thickness of 4 mm. In a study with bulk-fill composite materials, the surface hardness values decreased as the thickness increased (12). Bulk-fill resin composites are more translucent for blue light than conventional composite materials because of their high filler content and irregularly shaped particles, which cause light scattering, thus reducing light transmittance (34). Light scattering increases in materials with a large filler-matrix interface area owing to differences in the refractive indices between the filler particles and the resin matrix (14, 34, 35). Another possible reason may be the lack of light penetration through the composite at increasing depths, as a high percentage of the wavelengths are absorbed near the top surface and are not available to activate the co-initiators at greater depths (36).

Torres *et al*. measured lower microhardness values than those obtained in this study when applying light curing for 10 s and 20 s to SonicFill 3 composite resins with a thicknesses of 2 mm and 4 mm (37). This difference is believed to be caused by the LCU we used. Tores *et al*. employed a LCU with a single wavelength and a power of

1000 mW/cm^2 in their study. Our research utilized a LCU capable of applying power in standard mode with multiple wavelengths and a power output of 1200 mW/cm^2. It has been stated that light devices with more than multiple wavelengths increase the hardness of materials (38, 39).

In the current study, there was no significant difference between the microhardness values of the specimens polymerized with the same LCU using the standard and high-power modes. Consistent with our findings, Gonulol *et al*. (40) determined that there was no significant difference between the microhardness values of composite specimens polymerized with the same LCU using standard and high-power modes. In agreement with our study, Jakupović *et al*. (10) reported that the curing protocol did not cause a significant difference in the microhardness of resin-based composites. They explained that the material composition, including the organic matrix content and photoinitiator type as well as the amount, size, and distribution of fillers, was more influential than the curing protocol. In contrast, Ilie et al. reported that there was no significant difference between the microhardness values of composite materials using different LCUs, and suggested that this finding was due to the material itself and not the LCU used (41).

CONCLUSIONS

Considering the limitations of the present study, the following conclusions can be reached:

Surface microhardness varied among the tested resin composites. The bulk-fill composite did not achieve the same surface microhardness as conventional composite. The bulk-fill resin composite exhibited lower volumetric shrinkage than the conventional resin composite.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: N.S.Ö., M.D., S.T., N.T.; Literature deview: N.S.Ö.; Methodology: N.S.Ö., M.D., S.T., N.T., Ö.D.Ö.; Validation: N.S.Ö., M.D., S.T.; Formal analysis: N.S.Ö., M.D., S.T.; Investigation and data collection: N.S.Ö., M.D., S.T.; Resources: N.S.Ö., M.D., S.F.; Data analysis and interpretation: M.D., S.T., N.T.; Writing-original draft preparation: N.S.Ö. M.D.; Writing-review & editing: N.S.Ö., M.D., S.T., N.T.; Supervision: M.D., S.F., N.T.; and Project administration: M.D. and S.T.

ETHICS COMMITTEE APPROVAL: Ethics committee approval was not required because this study used only inanimate materials.

INFORMED CONSENT: Written informed consent was not obtained because no individuals participated in this study.

DISCLOSURE STATEMENT: The authors declare no conflict of interest.

FUNDING: This research received no external funding.

REFERENCES

1. Meereis C.T.W., Münchow E.A., de Oliveira da Rosa W.L., da Silva A.F., Piva E. Polymerization shrinkage stress of resin-based dental materials: A systematic review and meta-analyses of composition strategies. J Mech Behav Biomed Mater. 2018; 82: 268-81.
2. Shah P.K., Stansbury J.W. Photopolymerization shrinkage-stress reduction in polymer-based dental restoratives by surface modification of fillers. Dent Mater. 2021; 37 (4): 578-87.
3. Watts D.C., Cash A. Determination of polymerization shrinkage kinetics in visible-light-cured materials: methods development. Dental Materials. 1991; 7 (4): 281-7.

4. Fanfoni L., De Biasi M., Antollovich G., Di Lenarda R., Angerame D. Evaluation of degree of conversion, rate of cure, microhardness, depth of cure, and contraction stress of new nanohybrid composites containing pre-polymerized spherical filler. J Mater Sci Mater Med. 2020; 31 (12): 127.
5. Aung S.Z., Takagaki T., Ikeda M., Nozaki K., Burrow M.F., Abdou A., et al. The effect of different light curing units on Vickers microhardness and degree of conversion of flowable resin composites. Dent Mater J. 2021; 40 (1): 44-51.
6. Ilie N., Stark K. Curing behaviour of high-viscosity bulk-fill composites. J Dent. 2014; 42 (8): 977-85.
7. Ferracane J.L. Resin composite-state of the art. Dental materials. 2011; 27 (1): 29-38.
8. Yu P., Xu Y.X., Liu Y.S. Polymerization shrinkage and shrinkage stress of bulk-fill and non-bulk-fill resin-based composites. J Dent Sci. 2022; 17 (3): 1212-6.
9. Lima R.B.W., Troconis C.C.M., Moreno M.B.P., Murillo-Gómez F., De Goes M.F. Depth of cure of bulk fill resin composites: A systematic review. J Esthet Restor Dent. 2018; 30 (6): 492-501.
10. Jakupović S., Pervan N., Mešić E., Gavranović-Glamoč A., Bajsman A., Muratović E., et al. Assessment of Microhardness of Conventional and Bulk-Fill Resin Composites Using Different Light-Curing Intensity. Polymers (Basel). 2023; 15 (10).
11. Rizzante F.A.P., Duque J.A., Duarte M.A.H., Mondelli R.F.L., Mendonça G., Ishikiriama S.K. Polymerization shrinkage, microhardness and depth of cure of bulk fill resin composites. Dent Mater J. 2019; 38 (3): 403-10.
12. Karacolak G., Turkun L.S., Boyacioglu H., Ferracane J.L. Influence of increment thickness on radiant energy and microhardness of bulk-fill resin composites. Dent Mater J. 2018; 37 (2): 206-13.
13. Yu P., Yap A., Wang X.Y. Degree of Conversion and Polymerization Shrinkage of Bulk-Fill Resin-Based Composites. Oper Dent. 2017; 42 (1): 82-9.
14. Czasch P., Ilie N. In vitro comparison of mechanical properties and degree of cure of bulk fill composites. Clin Oral Investig. 2013; 17 (1): 227-35.
15. Jang J.H., Park S.H., Hwang I.N. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent. 2015; 40 (2): 172-80.
16. Yang Y., Lei H., Liu Y., Xia B. Clinical evaluation of SonicFill bulk resin technique in the restoration of proximal deep caries of primary molars: a two-year randomized controlled trial. BMC Oral Health. 2024; 24 (1): 1461.
17. Kerr Dental. Optishade™ Technical Bulletin. Kerr Corporation; Orange, CA, USA; 2023.
18. Ilie N., Moldovan M., Ionescu A.C. Microstructure and Mechanical Behavior of Modern Universal-Chromatic and Bulk-Fill Resin-Based Composites Developed to Simplify Dental Restorative Procedures. J Funct Biomater. 2022;13 (4).
19. van Dijken J.W. Durability of resin composite restorations in high C-factor cavities: a 12-year follow-up. J Dent. 2010; 38 (6): 469-74.
20. Peutzfeldt A., Asmussen E. Resin composite properties and energy density of light cure. J Dent Res. 2005; 84 (7): 659-62.
21. Leprince J.G., Palin W.M., Hadis M.A., Devaux J., Leloup G. Progress in dimethacrylate-based dental composite technology and curing efficiency. Dent Mater. 2013; 29 (2): 139-56.
22. Leprince J.G., Lamblin G., Devaux J., Dewaele M., Mestdagh M., Palin W.M., et al. Irradiation modes' impact on radical entrapment in photoactive resins. J Dent Res. 2010; 89 (12): 1494-8.

23. Par M., Marovic D., Attin T., Tarle Z., Tauböck T.T. The effect of rapid high-intensity light-curing on micromechanical properties of bulk-fill and conventional resin composites. Sci Rep. 2020;10 (1):10560.
24. Price R.B., Ferracane J.L., Hickel R., Sullivan B. The light-curing unit: An essential piece of dental equipment. Int Dent J. 2020; 70 (6): 407-17.
25. Ersen K.A., Gürbüz Ö., Özcan M. Evaluation of polymerization shrinkage of bulk-fill resin composites using microcomputed tomography. Clin Oral Investig. 2020; 24 (5): 1687-93.
26. Marx P., Wiesbrock F. Expanding Monomers as Anti-Shrinkage Additives. Polymers (Basel). 2021; 13 (5).
27. Tiba A., Charlton D.G., Vandewalle K.S., Ragain J.C., Jr. Comparison of two video-imaging instruments for measuring volumetric shrinkage of dental resin composites. J Dent. 2005; 33 (9): 757-63.
28. Nie J., Yap A.U., Wang X.Y. Influence of Shrinkage and Viscosity of Flowable Composite Liners on Cervical Microleakage of Class II Restorations: A Micro-CT Analysis. Oper Dent. 2018; 43 (6): 656-64.
29. Atria P.J., Sampaio C.S., Cáceres E., Fernández J., Reis A.F., Giannini M., et al. Micro-computed tomography evaluation of volumetric polymerization shrinkage and degree of conversion of composites cured by various light power outputs. Dent Mater J. 2018; 37 (1): 33-9.
30. Papadogiannis D., Tolidis K., Gerasimou P., Lakes R., Papadogiannis Y. Viscoelastic properties, creep behavior and degree of conversion of bulk fill composite resins. Dent Mater. 2015; 31 (12): 1533-41.
31. Ilie N., Stark K. Curing behaviour of high-viscosity bulk-fill composites. Journal of dentistry. 2014; 42 (8): 977-85.
32. Alsahafi T.A., Walter R., Nunes M., Sulaiman T.A. Wear of Bulk-fill Composite Resins After Thermo-mechanical Loading. Oper Dent. 2023; 48 (4): 416-24.
33. Jeong T.S., Kang H.S., Kim S.K., Kim S., Kim H.I., Kwon Y.H. The effect of resin shades on microhardness, polymerization shrinkage, and color change of dental composite resins. Dent Mater J. 2009; 28 (4): 438-45.
34. Tarle Z., Attin T., Marovic D., Andermatt L., Ristic M., Tauböck T.T. Influence of irradiation time on subsurface degree of conversion and microhardness of high-viscosity bulk-fill resin composites. Clin Oral Investig. 2015; 19 (4): 831-40.
35. Bucuta S., Ilie N. Light transmittance and micro-mechanical properties of bulk fill vs. conventional resin based composites. Clin Oral Investig. 2014; 18 (8): 1991-2000.
36. Garcia D., Yaman P., Dennison J., Neiva G. Polymerization shrinkage and depth of cure of bulk fill flowable composite resins. Oper Dent. 2014; 39 (4): 441-8.
37. Torres C.R.G., Prado T.P., Ávila D., Pucci C.R., Borges A.B. Influence of Light-Curing Time and Increment Thickness on the Properties of Bulk Fill Composite Resins With Distinct Application Systems. Int J Dent. 2024; 2024: 2123406.
38. Santini A., Miletic V., Swift M.D., Bradley M. Degree of conversion and microhardness of TPO-containing resin-based composites cured by polywave and monowave LED units. J Dent. 2012; 40 (7): 577-84.
39. Varshney I., Jha P., Nikhil V. Effect of monowave and polywave light curing on the

degree of conversion and microhardness of composites with different photoinitiators: An in vitro study. J Conserv Dent. 2022; 25 (6): 661-5.
40. Gonulol N., Ozer S., Tunc E.S. Effect of a third-generation LED LCU on microhardness of tooth-colored restorative materials. Int J Paediatr Dent. 2016; 26 (5): 376-82.
41. Ilie N., Stark K. Effect of different curing protocols on the mechanical properties of low-viscosity bulk-fill composites. Clin Oral Investig. 2015; 19 (2): 271-9.