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Effect of Layer Thickness on Conversion Degree and Microhardness of Bulk-Fill Composites

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Abstract

Background: This study aimed to evaluate the effect of layer thickness on the conversion degree and microhardness of low- and high-viscosity bulk-fill composite resins.

Methods: Six different bulk-fill composite resins, SDR (Dentsply), Sonic Fill (Kerr), X-tra Fil (Voco), Beautifil Bulk Restorative (Shofu), Beautifil Bulk Flowable (Shofu), and Filtek Bulk Fill Flowable (3M ESPE) were tested. Disc-shaped samples (7 mm diameter, 2 and 4 mm thickness, n = 4 per group) were prepared and polymerized using an LED (Light-Emitting Diode) curing unit (Elipar S10, 3M ESPE). After 24 hours at 37°C, the degree of conversion was analyzed using Fourier Transform Infrared Spectroscopy (FTIR)- Attenuated Total Reflectance (ATR) (Perkin Elmer Spectrum Two), and microhardness was measured using a Knoop hardness tester (Buehler MMT-3 Digital Microhardness Tester). Data were analyzed using Shapiro-Wilk, ANOVA, Tukey's HSD, and Pearson correlation with SPSS 26.0V (IBM SPSS Corp.; Armonk, NY, USA).

Results: No significant difference in bottom/top surface hardness ratio was observed in 2 mm samples ($P > .05$). However, at 4 mm, a statistically significant difference was found among the composite groups ($P = .003$). SDR had the highest hardness ratio (0.87 ± 0.04), while Beautifil Bulk Restorative (BBR) had the lowest (0.68 ± 0.08). The highest degree of conversion at both thicknesses was in SDR (65.13 ± 2.00 at 2 mm, 62.90 ± 2.30 at 4 mm), whereas X-tra Fil had the lowest (41.25 ± 13.57 at 2 mm, 39.25 ± 6.75 at 4 mm). In BBR, conversion at 2 mm was significantly higher than at 4 mm ($P = .004$).

Conclusion: The filler content and matrix structure significantly influence the conversion degree and mechanical properties of bulk-fill resins. Low-viscosity composites should be combined with high-viscosity materials for improved clinical outcomes in posterior restorations.

Keywords: Bulk fill, composite resin, conversion degree, microhardness

What is already known on this topic?

- *Conversion degree and microhardness are critical parameters for assessing the clinical performance and longevity of resin composites, especially in deep cavities.*
- *Conversion degree and microhardness are critical parameters for assessing the clinical performance and longevity of resin composites, especially in deep cavities.*
- *While low-viscosity and high-viscosity bulk-fill composites are designed to allow increased curing depth, their mechanical and chemical behavior under different thicknesses remains variable.*

What this study adds on this topic?

- *This study provides a comparative evaluation of six bulk-fill composites with varying viscosities, analyzing how 2 mm and 4 mm layer thicknesses affect their conversion degree and Knoop microhardness.*
- *The results demonstrate that filler content and resin matrix structure significantly influence polymerization and surface*

INTRODUCTION

Bulk-fill resin-based composites (BFRCs) have been developed to simplify the restorative process. These materials allow direct placement in increments of up to 4-5 mm while still ensuring proper depth of cure and mechanical properties. Bulk-fill composites

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hardness, particularly at greater thicknesses.

- *Clinically, the findings suggest that combining low- and high-viscosity composites may optimize both adaptation and mechanical performance in posterior bulk restorations.*

offer advantages such as reduced chairside time, simplified application, and improved efficiency, particularly in posterior restorations where access and patient compliance may be challenging.[1]

It has been shown that BFRCs can also reduce the specific difficulties of conversion degree and polymerization shrinkage exhibited by conventional resin composites when used under the same conditions.[2,3] Manufacturers have implemented several strategies to enhance the depth of cure and conversion degree of BFRCs. These include increasing translucency, incorporating more efficient photoinitiators, and optimizing filler content and resin matrix composition.[1,4] Enhancing translucency allows better light penetration, while alternative photoinitiators improve polymerization efficiency. Adjusting filler size and distribution also influences the material's mechanical strength and wear resistance.[5,6]

Most dental resin-based composite materials are derived from methacrylate resins and require visible light activation for polymerization. One key measure of polymerization efficiency is the degree of conversion, which calculates the proportion of carbon-carbon double bonds (C=C) that convert into carbon-carbon single bonds (C-C) to form the polymer structure.[6]

Achieving a high degree of conversion is essential for enhancing the mechanical properties, chemical stability, and longevity of restorations.[7] Incomplete monomer conversion can lead to restoration failure, secondary caries,[8] and the release of residual monomers, which have been linked to cytotoxicity and pulp tissue inflammation.[6,9]

This study aims to compare the conversion degree of high and low-viscosity bulk-fill composite resins at different thicknesses. The null hypotheses of this study are as follows:

1. The thickness of bulk-fill composite resins would not affect their degree of conversion.
2. The thickness of bulk-fill composite resins would not affect their microhardness ratio values.
3. There would be no correlation between the degree of conversion and the microhardness ratio values of bulk-fill composite resins.

MATERIALS AND METHODS

A comprehensive power analysis was conducted using G*Power 3.1 software (Heinrich Heine University, Dusseldorf, Germany), drawing upon insights from a comparable study.[10] This analysis established a minimum required sample size of 4 specimens for each experimental group in this investigation (covering 6 resin composites, 2 thickness totalling 12 combinations). The statistical parameters employed were an alpha probability of error set at 0.05 and a statistical power of 0.80. Since this study was conducted under in vitro conditions using composite resins, obtaining ethics committee approval and informed consent was not required. In the present study, 6 different low- and high-viscosity bulk-fill composite resins were used: SDR (Dentsply Caulk, Milford, DE, USA), SonicFill (Kerr, Orange, CA, USA), X-tra Fil (Voco, Cuxhaven, Germany), Beautifil Bulk Restorative (Shofu Inc., Kyoto, Japan), Beautifil Bulk Flowable (Shofu Inc., Kyoto, Japan), and Filtek Bulk Fill Flowable (3M ESPE, St. Paul, MN, USA). The materials that were used in the study and the composition of these materials are listed in Table 1.

Specimen Preparation

Stainless steel molds with a diameter of 6 mm and a thickness of 2-4 mm were used in the preparation of composite disc samples (n=4) on which conversion degree and microhardness tests would be applied.

Table 1. Materials Used in the Study and Their Characteristics

Composite Resin	Composite Resin Type	Manufacturer and Serial Number	Resin Matrix	Filler	Filler Rate (wt%/vol%)
SDR	Base material	Dentsply Caulk, Milford, DE, USA 1409000738	Modified UDMA, EBPDMA, TEGDMA	Barium borosilicate glass, strontium alumino fluorosilicate glass	68/45
Sonicfill (SF)	Bulk-fill restorative	Kerr Orange, CA, USA 6383676	Bis-GMA, TEGDMA, Bis-EMA	Barium, aluminum, boron, silicate	83.5/66
X-tra Fil (XF)	Base material	Voco,Cuxhaven, Germany 1729431	Bis-GMA, UDMA, TEGDMA	Barium boroaluminosilicate	86/70.1
Beautifil Bulk Restorative (BBR)	Bulk-fill restorative	Shofu Inc, Kyoto, Japan 081617	Bis-GMA, UDMA, Bis-MPEPP, TEGDMA	Floroboroaluminosilicate glass with S-PRG filler	87/74.5
Beautifil Bulk flowable (BBF)	Base material	Shofu Inc, Kyoto, Japan 101615	Bis-GMA, UDMA, Bis-MPEPP, TEGDMA	Floroboroaluminosilicate glass with S-PRG filler	72.5/-
Filtek Bulk Fill Flowable (FBF)	Bulk-fill restorative	3M ESPE, St Paul, MN, USA N900884	Bis-GMA, TEGDMA, UDMA, Bis-EMA, Bis-PMA	Ceramic filler including silane, silica filler including silane	64.5/42.5

Bis-EMA: Bis-ethylene glycol dimethacrylate Bis-GMA: Bisphenol-A-Glycidyl-Methacrylate Bis-PMA: 2,2-Bis [4-(3-methacryloxypropoxy)phenyl]propane EBPDMA: Ethoxylated Bisphenol A Dimethacrylate MPEPP: Methacryloyloxypropyl-terminated Polyethylene Polyamine S-PRG: Surface Pre-Reacted Glass-ionomer TEGDMA: Triethylene Glycol Dimethacrylate UDMA: Urethane Dimethacrylate

Clear tape (Hawe Stopstrip, Kerr, Switzerland) was put on glass lamella and stainless steel molds were placed. A second clear tape and the other lamella were placed on these and the extra material was removed. During the polymerization of composite discs, the tip of the light source was directly brought into contact on the glass lamella to ensure minimum light application distance. The polymerization process was performed using the Elipar S10 LED curing light (3M, St. Paul, MN, USA), which emits a light intensity of 1200 mW/cm². The device's integrated light intensity meter was utilized to verify the power output before each polymerization procedure. All composite resins were polymerized according to the manufacturer-recommended curing time (Table 2). Each specimen was marked on its lateral surface with arrows indicating the bottom surface to ensure proper identification without affecting the measurements. After polymerization, the specimens were stored in a dark environment at 37°C for 24 hours to ensure complete polymerization before testing.

Microhardness

Knoop microhardness tester (Buehler MMT-3 Digital microhardness tester, Lake Bluff, IL, USA) was used to measure the top and bottom surfaces of the specimens for 15 s under 100 gr force. Knoop hardness number (KHN) was automatically calculated using the digital calculator on the device. Three measurements were taken from each sample and KHN was recorded by averaging these values. The hardness ratio (bottom/top) was calculated by dividing the average KHN of the bottom surface by the average KHN of the top surface for each specimen.

Table 2. Curing Times for Resin Composites Used in the Study

Composite Resin	Curing Time (s)
SDR (SDR)	20 s
Sonicfill (SF)	20 s
X-tra fil (XF)	10 s
Beautifil Bulk Restorative (BBR)	10 s
Beautifil Bulk flowable (BBF)	10 s
Filtek Bulk Fill Flowable (FBF)	20 s

s, seconds.

Conversion Degree

Samples were stored at 37°C for 24 hours before the conversion degree was determined. The FTIR-ATR analysis was conducted using a spectrophotometer (Perkin Elmer Spectrum Two, PerkinElmer Inc. Waltham, MA, USA) with a spectral resolution of 4 cm^{-1}, scanning a wavenumber range of 4000-600 cm^{-1}.

FTIR-ATR spectrums of the samples which were kept at 37°C for 24 hours were obtained with SpectrumTwo FTIR spectrophotometer (Perkin Elmer) that can measure between 4000 and 600 cm^{-1} intervals. First, pre-polymerization spectral measurements of composite resins were made. In the present study, C=C bonds were found to give the peak value at 1717 cm^{-1}. Peak values of C-C bonds were found by taking the peak value at 1509 cm^{-1}.

The values obtained as a result of measurement were put in the formula below and percentage (%DC) values of conversion degrees were calculated (1).[10]

$$\%DC = 1 - \frac{\left(A_{C=C} / A_{C-C}\right)\text{Polymer}}{\left(A_{C=C} / A_{C-C}\right)\text{Monomer}} \times 100 \quad (1)$$

Statistical Analysis

In the present study, error terms were found to be distributed normally according to Shapiro–Wilk and Skewness–Kurtosis normality tests ($P < .05$). Independent t-test and one-way ANOVA were used for comparison, and Tukey's HSD test was applied as a post-hoc analysis for multiple comparisons

following ANOVA. Pearson correlation coefficients were calculated to determine the relationship between the bottom/top surface hardness ratio and the conversion degree. The results were presented as mean and SD, and differences between groups at the significance level of $P < .05$ were considered significant. All statistical analyses were performed using SPSS 26.0V (IBM SPSS Corp.; Armonk, NY, USA).

RESULTS

Microhardness Test

The mean and SD values for the top and bottom surface hardness, along with the bottom/top surface hardness ratio for 2 mm and 4 mm thicknesses, are presented in Tables 3 and 4 and Figure 1.

In 2 mm thickness samples, there was no statistically significant difference between the bottom/top surface hardness ratio ($P > .05$). In the 4 mm thick samples, a statistically significant difference was found between the bottom/top surface hardness ratio according to the composite groups ($P = .003$). The highest ratio was in the SDR group (0.87 ± 0.04), and there was no difference between SF (0.86 ± 0.03) and BBF (0.81 ± 0.05). The lowest rate was in the BBR group (0.68 ± 0.08), which was statistically different from all other groups. There was no difference between the XF (0.80 ± 0.09) and FBF (0.75 ± 0.03) groups in the ratio of bottom/top surface hardness. In the SF, XF, BBF, and FBF composite groups, the bottom/top surface hardness ratio of the samples prepared at 2 mm thickness was significantly higher than that of the samples prepared at 4 mm thickness ($P = .012$, $P = .034$, $P = .001$, $P = .001$, respectively).

Table 3. Comparison of Top and Bottom Surface Hardness Values According to Composite Groups and Thickness

		Thickness		
		2 mm	4 mm	
	Composites	Mean ± SD	Mean ± SD	*P
Bottom surface hardness	SF	52.36[a] ± 8.28	45.65[a] ± 2.48	.172
	XF	60.46[a] ± 2.55	47.60[a] ± 3.69	**.001**
	SDR	35.57[b] ± 7.11	28.09[b] ± 0.68	.081
	BBF	34.82[b] ± 9.49	35.71[b] ± 1.68	.859
	BBR	36.70[b] ± 5.96	32.70[b] ± 5.24	.353
	FBF	26.17[b] ± 1.84	19.49[c] ± 0.59	**.001**
Top surface hardness	SF	56.14[a] ± 8.19	53.07[a] ± 3.66	.518
	XF	65.07[a] ± 2.85	59.88[a] ± 4.91	.117
	SDR	39.31[c] ± 7.96	32.12[b] ± 1.76	.128
	BBF	35.57[c] ± 9.54	43.99[a] ± 3.33	.146
	BBR	43.60[b] ± 4.44	48.16[a] ± 3.15	.145
	FBF	27.40[c] ± 2.72	25.92[c] ± 1.45	.376
	**P	.001	.001	

$P < .05$, no statistically significant difference was observed among the groups indicated by the same letters within the same column.
*Independent Samples t-test results.
**One-way ANOVA results.
[a, b, c]Indicate differences between groups (Tukey HSD post-hoc test).
Mean±SD: Mean±Standard deviation.

Table 4. Bottom/Top Surface Hardness Ratio According to Composite Groups

		Thickness		
		2 mm	4 mm	
	Composites	Mean ± SD	Mean ± SD	*P
Bottom/Top hardness ratio	SF	0.93 ± 0.02	0.86[a] ± 0.03	**.012**
	XF	0.92 ± 0.02	0.80[b] ± 0.09	**.034**
	SDR	0.91 ± 0.04	0.87[a] ± 0.04	.413
	BBF	0.97 ± 0.02	0.81[a] ± 0.05	**.001**
	BBR	0.84 ± 0.13	0.68[c] ± 0.08	.075
	FBF	0.96 ± 0.04	0.75[b] ± 0.03	**.001**
	**P	.063	**.003**	

$P < .05$, no statistically significant difference was observed among the groups indicated by the same letters within the same column.
*Independent Samples t-test results.
**One-way ANOVA results.
[a, b, c]Indicate differences between groups (Tukey HSD post-hoc test).
Mean±SD: Mean±Standard deviation.

Conversion Degree

The mean and SD values for the conversion degree at 2 mm and 4 mm thicknesses are presented in Table 5 and Figure 2.

At 2 mm and 4 mm thickness, there was a statistically significant difference in the degree of conversion of the samples prepared according to the composite groups ($P = .001$). At 2 mm thickness, the highest conversion degree was observed in the SDR group (65.13 ± 2.00), and no difference was observed between the SF (63.35 ± 2.24) and BBR (62.00 ± 0.52) groups. The lowest degree of conversion was observed in the XF (41.25 ± 13.57) group, and it was statistically different from all other groups. The results of the BBF and FBF groups were similar.

At 4 mm thickness, the highest conversion degree was SDR (62.90 ± 2.30), followed by SF (62.63 ± 0.15), BBR (54.93 ± 3.03), FBF (51.78 ± 0.10), BBF (50.75 ± 1.60), and XF (39.25 ± 6.75). While the conversion degrees of SDR and SF composite groups and BBR, BBF, FBF composite groups

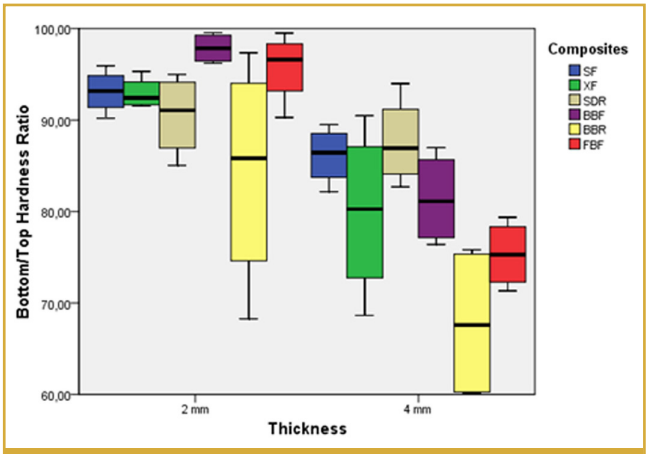

Figure 1. Comparison of bottom/top surface hardness ratios according to thickness.

Table 5. Conversion Degrees According to Composite Groups

		Thickness		
		2 mm	4 mm	
	Composites	Mean ± SD	Mean ± SD	*P
Conversion Degree	SF	63.35[a] ± 2.24	62.63[a] ± 0.15	.542
	XF	41.25[c] ± 13.57	39.25[c] ± 6.75	.801
	SDR	65.13[a] ± 2.00	62.90[a] ± 2.30	.194
	BBF	52.35[b] ± 0.31	50.75[b] ± 1.60	.097
	BBR	62.00[a] ± 0.52	54.93[b] ± 3.03	**.004**
	FBF	52.90[b] ± 1.08	51.78[b] ± 0.10	.083
	**P	.001	.001	

P < .05, no statistically significant difference was observed among the groups indicated by the same letters within the same column.
*Independent samples t-test results.
**one-way ANOVA results.
[a, b, c]Indicate differences between groups (Tukey HSD post-hoc test).
Mean±SD: Mean±Standard deviation.

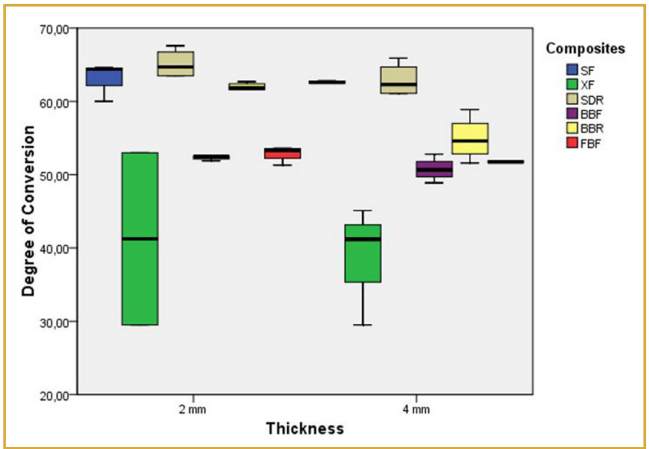

Figure 2. Comparison of the conversion degree of composite groups according to thickness.

were similar, XF had the statistically lowest value among the groups. When compared according to thickness, the degree of conversion obtained in 2 mm thickness is statistically significantly higher than that in 4 mm thickness only in the BBR composite group (*P* = .004).

When composite groups and thicknesses are considered, the correlation relationship between the bottom/top surface hardness ratio and the degree of conversion is shown in Table 6. According to the findings, there is no significant correlation relationship between the 2 parameters (*P* > .05).

Table 6. Bottom/Top Surface Hardness Ratio—Degree of Conversion Correlation Analysis

		Bottom/Top Hardness Ratio	
		2 mm r (*P*)	4 mm r (*P*)
Degree of conversion	**SF**	0.780 (.220)	0.914 (.086)
	XF	0.338 (.662)	−0.575 (.425)
	SDR	0.528 (.472)	−0.256 (.744)
	BBF	0.490 (.510)	0.794 (.206)
	BBR	−0.591 (.409)	0.566 (.434)
	FBF	−0.325 (.675)	0.573 (.427)

r (*P*), Correlation Coefficient (*P* value).

DISCUSSION

The first null hypothesis, which stated that the thickness of bulk-fill composite resins would not affect their conversion degree, was partially rejected. A significant difference was observed between the 2 mm and 4 mm samples in the BBR composite group, whereas no such difference was found in the other groups. When the top surface microhardness values were compared, no significant difference was observed between the composite groups at 2 mm and 4 mm thicknesses. However, a difference was found in the bottom surface microhardness values between the XF and FBF groups. Additionally, when the bottom/top surface hardness ratios of the samples prepared at 2 mm and 4 mm thicknesses were compared, a statistically significant difference between the 2 thicknesses was observed in the SF, XF, BBF, and FBF groups. Based on these findings, the second null hypothesis stating that the thickness of bulk-fill composite resins would not affect their microhardness ratio values was also partially rejected. Based on the findings, no correlation was found between the conversion degree and the microhardness ratio values of bulk-fill composite resins. Therefore, the third null hypothesis stating that there would be no correlation between these 2 parameters was accepted.

Conversion degree should be high for composite resins to show an optimum level of success. The conversion degree (DC) determines the material's biocompatibility and mechanical performance. When the conversion degree is low, undesired situations such as a decrease in endurance, an increase in permeability and solubility, a decrease in the retention of restoration, microleakage, and pulpal reactions can occur.[11,12] Furthermore, the conversion degree is commonly assessed to determine the efficiency of photopolymerization using spectroscopic techniques that measure the amount of double bonds remaining, including Fourier Transform Infrared (FTIR) spectroscopy,[13] Raman spectroscopy[14] and Fourier Transform Near Infrared (FT-NIR) spectroscopy.[15]

Studies have shown a correlation between surface microhardness and the degree of conversion on composite specimens from top to bottom, depending on the type of Resin based composite (RBC).[16] Microhardness gradually decreases along the surface hardness profile. This indicates a decrease in the conversion degree of resin-based composites with light penetration and distance from the irradiated surface. Microhardness analysis has been shown to be a valuable indirect method of assessing the conversion degree of the polymer matrix.[17,18] Through the hardness method, conversion degrees of composite resins are found with the rate of bottom surface microhardness value to top surface microhardness value. For clinically acceptable polymerization, the

bottom/top surface hardness ratio should be between 0.80 and 0.90.[19]

Hardness tests are also used with methods such as FTIR, Laser Raman Spectroscopy, Electron Spin Resonance, and Infrared Spectroscopy in finding out the conversion degrees of monomers in the composition of composite resins into polymers.[20] In this research, FTIR and microhardness tests were used to determine conversion degree.

In FTIR analysis studies, peak values at 1638 cm^{-1} and 1608 cm^{-1} wavelengths are generally used.[10,21-23] Borges et al[20] examined the spectra of C=C double bonds of different composite resins and reported that there were differences in the spectra. They stated that the reason for this difference might be related to the variation in the structure and/or geometry of composite resins and that the conversion fraction of the material is directly proportional to the peak intensity or area. In the present study, C=C double bonds were found to peak at 1717 cm^{-1} and C-C bonds at 1509 cm^{01} and absorption values at these wavelengths were used.

Cross-links in the structure of composites make the polymerization of dimethacrylate-containing resins more complex. At the point where dimethacrylate-containing resins show full gelation, a conversion degree between 20% and 80% is mentioned.[22] The DC of the C=C double bond for RBC is generally between 55% and 65% for restorative dental materials.[24]

Yokesh et al[20] prepared 4 mm thick samples by using SDR and Filtek Bulk Fill Flowable composite resins and found conversion degrees with FTIR analysis. According to the results of the study, SDR showed significantly higher conversion degree ($P = .0203$) in measurements from coronal surface when compared with Filtek Bulk Fill Flowable. Similarly, in the present study, SDR showed a higher degree of conversion than Filtek Bulk Fill Flowable. It was concluded that the conversion degree of Filtek Bulk Fill Flowable composite resin in 2 and 4 mm thicknesses were above 50% and there was no statistical difference between these values (respectively, 52.90 ± 1.08, 51.78 ± 0.10). When the microhardness levels of the same composite resin are compared; the bottom/top surface hardness ratio of the samples prepared at 4 mm is below 0.8. In addition, the hardness values had the lowest values among all groups. While the acceptable level of conversion percentages can be explained by the addition of Bis-GMA-like procrylate resin in the structure; the low hardness values can be explained by the weakening of the mechanical properties of bulk fill composite resins due to the change of filler ratios to increase the translucency.

Yu et al[10] calculated the conversion degree by FTIR-ATR and compared the polymerization shrinkage of composite samples prepared in thicknesses of 2, 4, and 6 mm using Tetric-N-Ceram, Beautifil Flow Plus (BF), Beautifil II (BT), SDR, Tetric-N-Ceram Bulk-fill, Beautifil Bulk Flowable (BBF), and Beautifil Bulk Restorative (BBR). SDR showed the highest conversion percentage in all thicknesses. The fact that SDR showed the highest conversion degree at all thicknesses was explained by the resin matrix containing UDMA and large fillers. In the same study, BBR (46.03%-45.94%) showed the lowest conversion percentage at 2 and 4 mm thickness and BF (30.65%) at 6 mm thickness. In the present study, similar to the results of these studies, SDR composite resin containing modified UDMA monomer in its structure showed the highest conversion value in both thicknesses. In dimethacrylate-containing composite resins, the conversion degree was found to be influenced by their chemical components. Sideridou et al[25] reported that the conversion degree decreased in the order of TEGDMA > UDMA > Bis-EMA > Bis-GMA. The mobility of the radical sites within the network increases as a result of chain transfer events that, in conjunction with the amino groups in the urethane structure of the UDMA monomer, create another alternative pathway for ongoing polymerization, thereby facilitating polymerization and improving monomer conversion. The modified UDMA monomer in the structure of the SDR composite is considered to enhance the degree of conversion. In the 2 mm and 4 mm thick samples, there was no significant difference between the conversion degrees in the other groups except for the BBR composite group. In addition, it was observed that the conversion percentages of BBF and BBR groups were lower than SDR and SF groups in 4 mm prepared samples. This difference can be explained by the fact that the chemical contents of BBR and BBF are the same, the filler properties differ compared to other composite resins, which may decrease the conversion percentages, and may prevent the penetration of light depending on the filler type, size, and shape. BBR composite group exhibited the lowest bottom/top surface hardness ratio, with statistically significant differences compared to other groups, which may be attributed to its filler characteristics and polymerization behavior.[26,27] It is thought that S-PRG fillers in the structure of BBR and BBF bulk fill composite resins, which are based on giomer, may also affect the polymerization properties.

Ilie et al[1] used TetricEvoCeram, Sonic Fill, Filtek Bulk Fill, SDR, Venus, X-tra Fil and X-tra Base bulk fill composite resins, polymerized the samples with Elipar Freelight 2 (3M ESPE) and compared the micromechanical properties of these composite resins. In the study, X-tra Fil (133.5 HV) has the highest Vickers hardness value and Venus Bulk Fill (38.1 HV) the lowest. Sonic Fill showed values of 82.0 HV and SDR 54.2 HV. Leprince et al[27] compared Venus Bulk Fill, TetricEvoCeram Bulk Fill, SDR, Sonic Fill, Filtek Bulk Fill, X-tra Base, X-tra Fil and Xenius composite resins with Grandio and Grandio Flow as reference materials in terms of conversion degree and physico-mechanical properties. According to the data obtained from the present study, it was observed that the SF composite group had a conversion degree of 63.35% at 2 mm and 62.63% at 4 mm, and there was no

difference between it and the SDR group ($P > .05$). It can be concluded that during the application of SonicFill composite resin to the cavity, changing its viscosity with sonic vibrations may enhance the polymerization process. Sonic vibration may promote polymerization by increasing free radical mobility directly. When molecules vibrate, they bump into each other, transferring kinetic energy to other molecules, which sometimes radiate this energy as heat, and indirectly as a consequence of decreased viscosity. This thermal effect and enhanced mobility of free radicals could positively influence the polymerization, ultimately increasing the conversion degree of the SF group.[28]

Since the filler size in X-tra Base, X-tra Fil, Sonic Fill and SDR composite resins is 20 nm and more, the light scattering at the interface between the filler and the matrix decreases and affects the mechanical properties positively. In the present study, X-tra Fill bulk fil composite resin had the highest microhardness values on the top and bottom surfaces, while the conversion degree was lower than the other groups with 41.25% at 2 mm thickness and 39.25% at 4 mm thickness. While the increase in filler sizes positively affects the microhardness levels of X-tra Fil composite resin as in other studies, it is thought that the high filler ratio and size difference during FTIR measurements may affect the measurements of the ATR tip and accordingly may cause a difference between the conversion percentages.

Nascimento et al[29] investigated the physicomechanical properties of composite samples prepared in different thicknesses using 9 different bulk fill resins and their effects on biological tissues. According to the results of the study, they showed that the degree of transformation and hardness values decreased as the thickness of the composite resin increased. Marigo et al[30] also showed that 2 mm and 4 mm thickness affected the microhardness level. Bulk fill composite resins showed lower values compared to conventional composites, but there was no statistical difference, similar results were shown in the studies of Flury et al[17] and Garoushi et al[18] according to the results obtained in the present study, high-viscosity bulk fill composite resins were shown to have higher hardness values compared to low-viscosity bulk fill composite resins. Therefore, in line with the recommendations of the manufacturers, low-viscosity bulk fill composite resins should be completed with conventional or high-viscosity bulk fill composite resins in order to ensure longevity in the oral cavity.

When the conversion degree and microhardness values were compared in the studies, different results obtained when the correlation between the 2 parameters was evaluated.[18,31] While some studies report a positive correlation between these 2 parameters, there are also studies that report no significant relationship.[31,32] These studies indicate that the relationship between microhardness and degree of conversion is influenced by various factors, including the type of material, filler content, polymerization method, and other related parameters.[32] Based on the results of this study, there was no correlation between microhardness and conversion degree. It is thought that the difference in the material structure of composite resins, filler size, amount, and content may cause this result.

The findings indicate that the selection of bulk-fill composites for posterior restorations should be informed by their viscosity-dependent characteristics. High-viscosity composites demonstrate adequate mechanical properties for independent use, whereas low-viscosity composites require the application of an additional capping layer to ensure optimal mechanical performance.

The physicomechanical properties of bulk-fill composite resins, designed to reduce treatment duration and enhance procedural efficiency in the posterior region, should be comprehensively evaluated through various in vivo and in vitro assessments. These investigations should include the fatigue resistance of bulk-fill composites under cyclic loading and the effectiveness of dual-cure systems in deep restorations to support their clinical applicability in routine practice.

Within the results of this study;

1. The degree of conversion of bulk-fill composite resins is influenced by their filler content and matrix composition.
2. The thickness of bulk-fill composite resins affects their conversion degree, with significant differences observed between 2 mm and 4 mm samples in certain composite groups.
3. The thickness of bulk-fill composite resins influences their microhardness values, particularly in the bottom surface microhardness and bottom/top surface hardness ratios among different composite groups.
4. No direct correlation was found between the conversion degree and the microhardness ratio values of bulk-fill composite resins.
5. Low-viscosity bulk-fill composite resins have lower microhardness values compared to high-viscosity bulk-fill composite resins.

Clinically, combining low-viscosity bulk-fill composites with materials that exhibit higher hardness levels may enhance the mechanical properties of restorations. Bulk fill composites can be preferred in recommended thicknesses in deep cavities when there is an appropriate indication.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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