Silorane-Based Composite: Depth of Cure, Surface Hardness, Degree of Conversion, and Cervical Microleakage in Class II Cavities

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ABSTRACT

Objective: The purpose of this study was to determine the depth of cure, degree of conversion (DC), hardness, and cervical sealing ability of silorane-based composite (Filtek Silorane [FS; 3M, Seefeld, Germany]) and to compare with methacrylate-based composites (MBCs = Filtek Supreme XT [FSXT] and Filtek P60 [FP60]).

Materials and Methods: The DC and hardness of every material were evaluated after 1, 7, and 30 days. The depth of cure was determined using the ISO 4049:2000 standard. Microleakage was evaluated by measuring dye penetration across the gingival wall in cross-sectioned specimens.

Results: FS showed lower depth of cure than FSXT and FP60. The DC of FS was significantly lower when compared to FP60 and FSXT. FS exhibited lower hardness than both FSXT and FP60 after 1 day of storage. The hardness of FS remained unchanged during the storage period. FS showed reduced microleakage scores compared to FSXT and showed similar microleakage scores compared to FP60.

Conclusions: In conclusion, the DC and cure depth of FS are lower than those of MBCs. However, FS revealed stable hardness in water that is comparable to MBCs. The sealing ability of FS is similar or even better than that of MBCs.

CLINICAL SIGNIFICANCE

Filtek Silorane can be used as an alternative to methacrylate-based composites because of its good sealing ability and stable hardness results. However, Filtek Silorane showed the lowest depth of cure, therefore clinicians should avoid thicker increments when working with Filtek Silorane.

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INTRODUCTION

Resin-based composites (RBCs) have been successfully used in dentistry for many years. Most RBCs used in dentistry are based on methacrylate chemistry. The methacrylate-based hybrid composites undergo a volume reduction upon curing from 1.9% to 3.5%.[1] The polymerization shrinkage of RBCs and its

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accompanying stress is a serious problem. In order to reduce polymerization shrinkage, researchers have focused on changing the structure of the monomer, the ratio and shape of the filler, or the surface treatment.[2]

Recently, researchers made several attempts to reduce the shrinkage by changing the nature of the resin.[1] The novel resin chemistry has been synthesized from the reaction of oxiranes and siloxane molecules and termed "silorane."[3] Siloranes have been suggested as alternatives to methacrylates as matrix resin components for dental composites because of the hydrophobicity and lower polymerization shrinkage.[4] Concerning the material properties of siloranes, the cyclosiloxane backbone imparts hydrophobicity[5,6] while the cycloaliphatic oxirane sites have high reactivity and less shrinkage (<1%) than methacrylates.[2,7,8] New silorane-based composites can exhibit lower polymerization shrinkage, which should be investigated to compare with methacrylate-based composites (MBCs). Polymerization shrinkage is one of the composite's basic properties. To date, only a few studies have been published in the literature determining the sealing ability of low shrink silorane-based composites.[9–11] Sealing ability of a restorative material can be assessed by microleakage test. Microleakage is a phenomenon of diffusion of oral microorganisms, fluids, and chemical substances through the interface between the tooth structure and the restorative material. Microleakage complications include postoperative sensitivity, marginal discoloration, recurrent caries, and pulpal inflammation.[12,13]

Although many methods are known to compare the properties of dental composites, it is important to compare, particularly, the conversation degree, cure depth, and hardness of different types of composites.[14,15] Until now, some characteristic properties of experimental siloranes have been reported by a few investigators.[2,3,16] However, the basic properties of Filtek Silorane (3M, Seefeld, Germany), the first commercially available silorane-based composite, have not been reported in the literature.

On the other hand, a light-curing unit (LCU) plays a more influential role in the basic properties of RBCs. Quartz-tungsten-halogen (QTH) units have been widely used for polymerizing resin-based dental materials for decades. QTH units exhibit several shortcomings, so, as an alternative, a light-emitting diode (LED) LCU was introduced for the polymerizing of RBCs. However, conflicting results have often been observed in the literature as related to the effects of both LCUs. Some of the research claimed that the curing performance of second-generation LED LCUs was similar to[14,17] or better than[18] that of the QTH LCU. In contrast, others reported that the curing performance of QTH LCUs was better than that of the LED LCU.[19,20] Therefore, the results of tests that include evaluations of a new composite could be affected by the quality of the selected LCUs.

The objectives of this study were as follows: (1) to determine the depth of cure, degree of conversion (DC), surface microhardness, and cervical sealing ability of silorane-based composite (Filtek Silorane) and to compare with MBCs; and (2) to investigate the effect of different LCUs (QTH and LED) on the depth of cure, DC, surface microhardness, and microleakage of silorane and MBCs. The null hypothesis was that there is no difference in depth of cure, DC, surface microhardness, and microleakage between the silorane-based composite and MBCs.

MATERIALS AND METHODS

Three commercially available composites were used in this study. Two composites, Filtek P60 and Filtek Supreme XT (3M, Seefeld, Germany), are based on aromatic and aliphatic dimethacrylates. The third composite, Filtek Silorane, is based on a new compound material called silorane. The A3 shade was selected for each composite resin; the materials, manufacturers, and composition are shown in Table 1.

A QTH LCU (Astralis 3, Ivoclar Vivadent, Schaan, Liechtenstein) with an output irradiance of 530 mW/cm^2 and a LED LCU (Elipar FreeLight 2, 3M ESPE, St. Paul, MN, USA) with an output irradiance of 1,000 mW/cm^2 were used for curing. Technical details of the QTH and LED LCUs used in this study are shown in Table 2. During specimen preparation,

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TABLE 1. Composition of the dental composites used in this study

Materials	Organic matrix	Inorganic filler	(% by vol.)	Size
Filtek Silorane (A3 shade) 3M, Seefeld, Germany	Bis-3,4-Epoxycyclohexylethyl-Phenyl-Methylsilane 3,4-Epoxycyclohexylcyclopolymethylsiloxane	Silanized Quartz Yttrium fluoride	55%	0.1–2 μm
Filtek Supreme XT (A3B shade) 3M, Seefeld, Germany	Bis-GMA, UDMA, TEGDMA, bis-EMA	Zirconia/silica	59.5%	Particle size = 20–75 nm Cluster size = 0.6–1.4 μm
Filtek P60 (A3 shade) 3M, Seefeld, Germany	Bis-GMA, UDMA, TEGDMA, bis-EMA	Zirconia/silica	61%	0.01–3.5 μm Average = 0.6 μm

TABLE 2. Technical details of the QTH and LED LCU used in this study

Lamp and manufacturer	Wavelength	Power density	Irradiated diameter
Elipar FreeLight 2 3M ESPE, St. Paul, MN, USA	430–480 nm	1,000 mW/cm^2	8 mm
Astralis 3 Ivoclar Vivadent, Liechtenstein	300–500 nm	530 mW/cm^2	8 mm

irradiance was periodically checked with a dental radiometer (Curing Radiometer, HILUX/Benlioglu Corp., Ankara, Turkey).

Depth of Cure

Seven samples for each composite and each LCU were prepared in a brass mold with a diameter of 4 mm and a depth of 8 mm. The top and bottom of the composite were covered by a glass slide. During the polymerization process, the mold was placed on a nonreflective surface. The resin was then cured using one of the LCUs. Both LCUs were used at a standard mode. The tip of the light guide was positioned in a way to contact the thin glass slide (thickness 150 μm; Saaringia, Saarlouis, Germany). According to the manufacturers' recommendations, the exposure time was arranged for QTH (40 seconds) and LED LCU (20 seconds). The cure depth of the resins was determined using a standardized technique (ISO 4049:2000).[21] Immediately after irradiation, uncured material was scraped away with a spatula. The height of the cylinder of set resin was measured with a digital micrometer to an accuracy of ±0.01 mm (Mitutoyo, Shanghai, China). Each sample was measured three times, and the mean value of these three readings was recorded as the depth of cure.

Degree of Conversion (DC)

To measure the DC, the uncured paste of each composite was placed between two polyethylene films and then pressed to form a very thin film. The absorbance peaks were obtained by the transmission mode of the Fourier transform infrared spectrometer (FTIR, Perkin Elmer 100 Series, Norwalk, CT, USA). Five samples for each composite and each LCU were cured in a brass mold with a diameter of 5 mm and a depth of 2 mm. The top and bottom of the mold were covered by a glass slide, and the mold was placed on a dark nonreflective surface during polymerization. After photoactivation, the specimens were stored at 37°C for 1 day, 7 days, and 30 days. The specimen was pulverized into fine powder using a mortar and pestle. Fifty micrograms of the ground powder was mixed with 5 mg of potassium bromide powder, and the absorbance peaks were recorded using the diffuse-reflection mode of FTIR.

Calculation of the Conversion Degree

Spectra in the region 4,000–400 cm^{-1} were recorded (10 scans) at a resolution of 4 cm^{-1}. Monomer conversion was calculated based on the changes in the

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ratios of aliphatic (1,636 cm^{-1}) to aromatic (1,609 cm^{-1}) carbon double bonds absorption peaks in the uncured and cured states. The DC was calculated by using the standard baseline technique.[22] By using the change in the ratio of the aliphatic C=C before and after curing, the DC of aliphatic C=C
into C–C could be calculated using the following formula[23]:

$$(\%C{=}C) = 1 - \frac{\left(aliphatic[C{=}C]/aromatic[C{=}C]\right)_{polymer}}{\left(aliphatic[C{=}C]/aromatic[C{=}C]\right)_{monomer}} \times 100$$

The monomer chemistry of the silorane-based composite does not contain aliphatic C=C groups. Consequently, the DC cannot be calculated from the equation.[23] The mean DC of the Filtek Silorane specimens was identified through regions of the FTIR spectra between 730 and 950 cm,$^{-1}$ which corresponded with the oxirane ring-opening regions. On irradiation, the oxirane peaks at 882 cm^{-1} for the silorane resin specimens decreased. A common internal standard was identified in which the absorption of aromatic C=C at 1,608 cm^{-1} remained constant during the polymerization, where the DC of the silorane resin specimens was calculated according to the equation[24]

$$(\%{-}C{-}O{-}C{-}) = \frac{\left(oxirane[{-}C{-}O{-}C]/aromatic[C{=}C]\right)_{polymer}}{\left(oxirane[{-}C{-}O{-}C{-}]/aromatic[C{=}C]\right)_{monomer}} \times 100$$

Knoop Hardness (KHN)

Eight samples for each composite and each LCU were prepared in a brass mold with a diameter of 6 mm and depth of 2 mm. The top and bottom of the mold was covered by a glass slide. In addition, the mold was placed on a dark nonreflective surface during polymerization. The cured eight specimens for each group were stored in distilled water at 37°C for 1 day, 7 days, and 30 days before testing. Then, the top and bottom surfaces of the specimens were analyzed for the microhardness test using the Micromet Microhardness Tester (Buehler MMT-3 digital microhardness tester, Waukagan Lake Bluff, IL, USA). A 100 gf load was applied through the indenter with a dwell time of 15 seconds. Three test indentations of each sample were made at randomly selected areas on the composite resins.

Microleakage Evaluation

Sixty sound human third molars extracted for clinical reasons were selected for this study. After extraction, they were hand scaled to remove tissue remnants and stored in distilled water at room temperature for no longer than 3 months. Only intact teeth free of defects were selected.

Standardized conservative Class II slots were prepared on the proximal surfaces of each tooth, with a #835-010-4 ML cylindrical diamond bur (Diatech-Dental, Mt. Pleasant, SC, USA) 245 in an air/water-cooled high-speed turbine. The dimensions of the preparations were 3 mm in width, 4 to 5 mm high, and 2 mm in depth. A new bur was used after four preparations. The cervical margins of the cavities were located 1 mm occlusal to the cementoenamel junction. The teeth were randomly assigned to 6 groups of 10 teeth each (20 cavities) according to the type of LCU (LED or QTH) and the type of composite resin (Filtek Silorane, Filtek Supreme XT, and Filtek P60).

Bonding and restorative procedures were carried out as recommended by the manufacturer. The cavities were restored with the following bonding agents and resin composites: Adper Single Bond (3M, ESPE, St. Paul, MN, USA)—Filtek Supreme XT; Adper Single Bond—Filtek P60; Silorane system adhesive (3M ESPE, St. Paul, MN, USA)—Filtek Silorane (Table 1). Composite resins were applied to the cavity in 2-mm increments. Each increment was polymerized for 20 seconds with LED LCU and 40 seconds with QTH LCU from occlusal surface. After storage in distilled water at 37°C for 24 hours, the restorations were finished with fine-grit finishing diamond burs (Diatech-Dental) and polished with a graded series

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of flexible discs (Sof-Lex, 3M ESPE, St. Paul, MN, USA).

The specimens were then thermocycled in a thermal cycling machine (1,000 thermocycling [Nova, Konya, Turkey] was performed at 5–55°C [±2°C]; dwell time: 30 seconds). The root apexes were sealed with epoxy resin, and the entire tooth surface was covered with two coats of nail varnish, except for 1 mm around the gingival tooth-restoration interface. Then, the teeth were immersed in a 0.5% basic fuscin solution for 24 hours at room temperature. Once the dye immersion was completed, the teeth were rinsed under running water for 5 minutes to remove excess dye. The teeth were sectioned longitudinally through the middle of the restorations using a diamond saw (Isomet-Buehler, Lake Bluff, IL, USA) under water lubrication. Dye penetration at the gingival margin was evaluated under a stereomicroscope (SZ-TP, Olympus, Tokyo, Japan) at 40× and blindly scored by two examiners on a 0 to 3 scale as below:

0 = No dye penetration
1 = Dye penetration less than half the length of the cervical floor
2 = Dye penetration up to full length of the cervical floor
3 = Dye penetration through the pulp

If examiners disagreed, a forced consensus was reached, and the consensus score recorded. Inter-examiner agreement was analyzed using the Kappa test.

Statistical Analyses

The values of depth of cure, DC, and Knoop hardness were recorded and then they were subjected to statistical analyses separately using a parametric one-way analysis of variance followed by Tamhane's T2 test and Student's *t*-test. Tamhane's post hoc test was adopted to compare storage periods (1 day, 7 days, 30 days) and to compare resin materials (Filtek P60, Filtek Silorane, Filtek Supreme XT). Student's *t*-test was adopted to compare QTH and LED LCUs. Microleakage data were analyzed with Kruskal–Wallis and Bonferroni-adjusted Mann–Whitney U tests. The significance level was $p < 0.003$ (Bonferroni correction: 0.05/15 (no. of test groups) = 0.003).

RESULTS

Depth of Cure

The results for the depth of cure for each resin and each LCU are shown in Table 3. When cured by QTH or LED LCUs, Filtek P60 showed the greatest cure depth followed by Filtek Supreme XT and then Filtek Silorane ($p < 0.001$).

The QTH LCU cured deeper than the LED LCU for each resin material. This difference was statistically meaningful for Filtek Silorane ($p < 0.001$) and Filtek P60 ($p < 0.05$).

TABLE 3. Depth of cure and standard deviation of three composites polymerized with the LED LCU and QTH LCU (mm)

	Light-curing unit	Composite materials			*p*
		Filtek Supreme XT	Filtek P60	Filtek Silorane	
Depth of cure	QTH	4.9 ± 0.1	6.0 ± 0.3*	4.7 ± 0.1*†	<0.001
	LED	4.8 ± 0.2	5.7 ± 0.1*	4.4 ± 0.1*†	<0.001
	p	>0.05	<0.05	<0.001	

LED = light-emitting diode; QTH = quartz-tungsten-halogen.

*$p < 0.05$ compared to the Filtek Supreme XT.

†$p < 0.05$ compared to the Filtek P60.

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Degree of Conversion (DC)

The DC values for materials tested in the current investigation are presented in Table 4. After the same storage periods for each LCU, there were significant differences among the DC of the three RBCs ($p < 0.001$; Filtek P60>Filtek Supreme XT>Filtek Silorane). Statistical analysis showed a significant increase in the DC of each cured material with the storage period ($p < 0.001$; 30 days > 7 days > 1 day).

Generally, curing with LED LCU produced statistically higher DC values compared with QTH LCU ($p < 0.05$); but for Filtek Silorane, after 1 day of storage, there were no meaningful differences between LED and QTH LCU ($p > 0.05$).

Knoop Hardness

For each resin and each light source, the Knoop hardness values obtained from top surfaces are shown in Table 5 and the Knoop hardness values obtained from bottom surfaces are shown in Table 6. After 1 and 30 days of storage, there was a significant difference between the microhardness values of each material ($p < 0.001$; Filtek P60>Filtek Supreme XT>Filtek Silorane). After 7 days of storage, there were no significant differences between the hardness of Filtek Silorane and Filtek Supreme XT ($p > 0.05$), but the hardness of Filtek P60 was different from that of both Filtek Silorane and Filtek Supreme XT ($p < 0.05$; Filtek P60>Filtek Silorane = Filtek Supreme XT). The microhardness of the MBCs (Filtek P60 and Filtek Supreme XT) decreased after 7 days and 30 days of storage compared to 1 day of storage, but the microhardness of the silorane remained unchanged.

Generally, there was no meaningful difference between the performances of the LED and QTH LCUs on the Knoop hardness of the three resin materials ($p > 0.05$); but after 1 day and 7 days storage period, samples of Filtek Supreme XT cured with QTH LCU showed higher Knoop hardness values compared with samples of Filtek Supreme XT cured with LED LCU ($p < 0.05$).

TABLE 4. The degree of conversion (%) of each material for each light-curing unit after 1, 7, and 30 days (mean ± SD)

	Light-curing unit	Time	Composite material			*p*
			Filtek Supreme XT	Filtek P60	Filtek Silorane	
Degree of conversion	QTH	1 day	60.8 ± 0.6	62.9 ± 0.8‡	43.3 ± 0.3‡,§	<0.001
		7 days	66.9 ± 0.3*	73.7 ± 0.7*,‡	48.2 ± 0.2*,‡,§	<0.001
		30 days	70.7 ± 0.3*,†	80.3 ± 0.8*,†,‡	55.2 ± 0.2*,†,‡,§	<0.001
		p	<0.001	<0.001	<0.001	
	LED	1 day	63.5 ± 0.6¶	67.5 ± 0.7‡,¶	43.5 ± 0.4‡,§	<0.001
		7 days	68.3 ± 0.5*,¶	75.1 ± 0.6*,‡,¶	52.3 ± 0.3*,‡,§,¶	<0.001
		30 days	72.7 ± 0.3*,†,¶	82.6 ± 0.6*,†,‡,¶	56.4 ± 0.3*,†,‡,§,¶	<0.001
		p	<0.001	<0.001	<0.001	

LED = light-emitting diode; QTH = quartz-tungsten-halogen.

*$p < 0.05$ compared to 1 day.

†$p < 0.05$ compared to 7 days.

‡$p < 0.05$ compared to the Filtek Supreme XT.

§$p < 0.05$ compared to the Filtek P60.

¶$p < 0.05$ compared to QTH.

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TABLE 5. Knoop hardness and standard deviation of top surface of three composites polymerized with the LED LCU and the QTH LCU

	Light-curing unit	Time	Composite material			*p*
			Filtek Supreme XT	Filtek P60	Filtek Silorane	
Knoop microhardness of top surface (kg/mm^2)	QTH	1 day	57.7 ± 2.4	68.7 ± 1.6‡	49.8 ± 1.7‡,§	<0.001
		7 days	49.8 ± 2.4*	57.4 ± 1.2*,‡	50.0 ± 1.5§	<0.001
		30 days	47.0 ± 2.0*,†	54.3 ± 1.6*,†,‡	49.9 ± 1.9‡,§	<0.001
		p	<0.001	<0.001	>0.05	
	LED	1 day	54.9 ± 2.4¶	68.7 ± 2.1‡	50.5 ± 2.2‡,§	<0.001
		7 days	46.1 ± 2.3*,¶	56.9 ± 1.7*,‡	50.0 ± 1.5‡,§	<0.001
		30 days	45.7 ± 1.6*	55.0 ± 1.4*,‡	49.4 ± 2.1‡,§	<0.001
		p	<0.001	<0.001	>0.05	

LED = light-emitting diode; QTH = quartz-tungsten-halogen.

*$p < 0.05$ compared to 1 day.

†$p < 0.05$ compared to 7 days.

‡$p < 0.05$ compared to the Filtek Supreme XT.

§$p < 0.05$ compared to the Filtek P60.

¶$p < 0.05$ compared to QTH.

Microleakage

The microleakage data are summarized in Table 7. The Kappa inter-examiner agreement was 0.75. For the Filtek P60, Filtek Supreme XT, and Filtek Silorane specimens, there was no statistically significant difference in microleakage scores related to LCU ($p = 0.445$, $p = 0.968$, and $p = 0.583$, respectively). After being cured with both LED and QTH LCUs, the Filtek Silorane specimens had significantly less microleakage than the Filtek Supreme XT specimens ($p < 0.003$). However, there was no statistically significant difference in the microleakage scores of the Filtek Silorane and Filtek P60 specimens. There was also no statistically significant difference in the microleakage scores of the Filtek Supreme XT specimens and the Filtek P60 specimens.

DISCUSSION

Post hoc power analysis is conducted after the study has been completed to determine what the power is in this study. The power of this study for each parameter (depth of cure, DC, Knoop hardness) is between 0.88 and 0.96 to detect a difference of 10% so the sample size for each parameter can be considered as enough. Therefore, parametric methods were chosen to analyze the data of depth of cure, DC, and Knoop hardness.

The conversion degree, depth of cure, hardness, and cervical sealing ability of composites were evaluated in this study because these properties represent important clinical parameters of composite restorations. A single shade (A3) was used to minimize the effects of shade on light polymerization, and 2-mm thick composite increments were used to promote uniform and maximum polymerization.[25] The FTIR methodology utilized in the current study has provided a useful tool in the quantitative analysis of both silorane- and methacrylate-based monomer conversion. There are many different techniques for assessing microleakage around

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TABLE 6. Knoop hardness and standard deviation of bottom surface of three composites polymerized with the LED LCU and the QTH LCU

	Light-curing unit	Time	Composite material			*p*
			Filtek Supreme XT	Filtek P60	Filtek Silorane	
Knoop microhardness of bottom surface (kg/mm^2)	QTH	1 day	56.9 ± 2.3	67.3 ± 2.8‡	49.8 ± 2.0‡§	<0.001
		7 days	49.8 ± 2.6*	57.2 ± 1.5*‡	49.9 ± 1.9§	<0.001
		30 days	47.0 ± 2.4*†	54.3 ± 1.6*†‡	49.9 ± 1.6‡§	<0.001
		p	<0.001	<0.001	>0.05	
	LED	1 day	54.2 ± 2.3¶	68.3 ± 1.7‡	50.1 ± 1.3‡§	<0.001
		7 days	46.0 ± 2.2*¶	56.7 ± 1.4*‡	49.7 ± 1.1‡§	<0.001
		30 days	45.2 ± 1.2*	55.0 ± 2.0*‡	49.2 ± 1.6‡§	<0.001
		p	<0.001	<0.001	>0.05	

LED = light-emitting diode; QTH = quartz-tungsten-halogen.

*$p < 0.05$ compared to 1 day.

†$p < 0.05$ compared to 7 days.

‡$p < 0.05$ compared to the Filtek Supreme XT.

§$p < 0.05$ compared to the Filtek P60.

¶$p < 0.05$ compared to QTH.

TABLE 7. Distribution of microleakage scores at gingival margins of three composites polymerized with the LED LCU and the QTH LCU

Groups	LED					QTH				
	0	1	2	3		0	1	2	3	
Filtek Silorane	19	1	—	—	(a)	17	2	1	—	(a)
Filtek Supreme XT	2	15	2	1	(b)	3	13	2	2	(b)
Filtek P60	11	9	—	—	(a,b)	9	9	2	—	(a,b)

LED = light-emitting diode; QTH = quartz-tungsten-halogen.

Same letters indicate no statistically significant differences ($p > 0.05$).

dental restorations. The easiest and most commonly used methodology involves exposure of the samples to a dye solution and then viewing cross sections under a light microscope.[13] Dye penetration was chosen for this study because it provided a simple, relatively cheap quantitative and comparable method of evaluating the performance of the various restoration techniques.[13,26]

Adequate polymerization is a crucial factor in obtaining optimal physical properties and clinical performance of resin composite materials. However, for a composite restoration to be considered clinically successful, a minimum DC has not yet been precisely established. Previous investigations reported that the DC of hybrid RBCs ranged from approximately 55% to 75% using conventional curing procedures.[14,27,28] This study, as reported in the previous investigation, found that the

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DC of MBCs had a range of approximately 63.5% to 67.5% when the LED LCU was used, and 60.8% to 62.9% when the QTH LCU was used, after 1 day of storage.

The DC of MBCs is measured via the conversion of aliphatic C = C double bonds. However, the monomer chemistry of the silorane RBCs do not contain aliphatic C = C groups. Silorane RBC polymerization degree is calculated by the conversation percentage of epoxy circle to the C-O-C- cord.[3] That is, the polymerization process of silorane occurs via a cationic ring-opening reaction, and the MBCs polymerize via a radical addition reaction of their double bonds.[1] The DC of Filtek Silorane has not been previously reported. However, in a previous study, Palin and colleagues[3] reported that the DC of experimental Silorane H1 averaged 50.2% after 24 hours. This study determined that the DC of Filtek Silorane ranged from 43.5% to 56.4% when the LED LCU was used and from 43.3% to 55.2% when the QTH LCU was used following storage periods. The DC of Filtek Silorane was significantly less compared with Filtek P60 and Supreme XT following storage periods. The decrease in the DC of Filtek Silorane compared with Filtek P60 and Supreme XT could be related to the difference in monomer chemistry. Additionally, variety in the filler size, filler volume, and filler type of the methacrylate and silorane RBCs could explain the difference.

The most efficient wavelength for the DC of the resin when CQ is used as the initiator has been reported to be 470 nm.[29] The LED LCU has a higher irradiance in the region of the peak absorption for CQ (i.e., 468 nm). After 1 day of storage, the performance of LED LCU on the DC of Filtek Silorane was similar to that of QTH LCU. However, the performances of LED LCU on the DC of both methacrylate RBCs were better than that of QTH LCU.

In general, a high DC yields greater hardness and strength.[30,31] However, previous studies have shown that the DC is not sufficient for characterizing the three-dimensional structure of dental composites, and that areas with different concentrations of C=C bonds, present as either pendant groups or residual monomer, coexist in the same polymer.[32,33] Thus, an absolute hardness number cannot be used to predict the degree of monomer conversion in comparisons of different resin materials.[31] In this study, after 1 day of storage, the highest overall mean KHN value was observed for the Filtek P60, intermediate values for the Filtek Supreme, and the lowest values for the Filtek Silorane. Except for the different monomer composition of Filtek Silorane, these results could be explained by its low filler content. Since the filler phase is almost always harder than the polymer phase, they therefore yielded lower surfaces hardness.

As is known, RBCs stored in an aqueous environment are often softened and show a lower hardness.[34] This reduction in hardness is related predominantly to the uptake of water by the softening of the polymer resin component by swelling the network and reducing the frictional forces between polymer chains.[35] As expected, the KHN values of Filtek P60 and Filtek Supreme decreased throughout the periods of storage in water. On the other hand, as shown in Tables 5 and 6, the hardness of Filtek Silorane did not significantly change throughout the storage periods due to the presence of the siloxane species in structure. Furthermore, this may be due to decreased water sorption, solubility of the siloranes compared to conventional MBCs.[36]

For clinical acceptance, there is no absolute minimum value for resin-based composite hardness, but it seems prudent to expect that new technologies should be able at least to match existing material properties and their clinical performance.[19] The hardness value of Filtek Silorane, 30 days later, was similar to that of the MBCs. Filtek Silorane, revealing stable hardness in aqueous media, could provide superiority in vivo circumstances (in terms of wear resistance), when compared to MBCs.

The depth of cure depends upon the monomer composition and type, the light permeability of the filler, and the concentration of the initiator, inhibitor, and accelerator in the resin materials.[37] Filtek Silorane showed the least cure depth, followed by Filtek Supreme XT (nanofilled composite) and then Filtek P60 (microhybrid composites) when cured by each LCU. The nanofilled RBCs are more difficult to cure because

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their small filler particles cause light to scatter.[38] The ratio of filler relative to resin is also important. The higher the proportion of filler, the more difficult it is for the light to penetrate the composite.[39] Thus, Filtek Supreme XT showed less polymerization depth than Filtek P60. In contrast to what might be expected, although Filtek Silorane had larger filler particles and a smaller filler ratio, this composite showed less polymerization depth than that of the MBCs. This study preferred the "scraping" test, during which the soft, unpolymerized resin is scraped from the bottom of a polymerized sample to measure the depth of the remaining (cured) material. Applying the scraping process immediately after the light application for the process of assessing the cure depth may have led Filtek Silorane to show, unexpectedly, less polymerization.

In this study, the mean depths of cure data showed that the QTH LCU achieved greater depth of cure than the LED LCU for all composites. It is known that performance of LCUs is related to the intensity of light and time of exposure.[40] The QTH LCU perhaps had a better depth of cure due to the increased energy density (irradiance × exposure time) applied to the respective resins. According to manufacturers' recommendations, the exposure time was arranged for QTH (40 seconds) and LED LCU (20 seconds). The irradiances of QTH and LED LCUs are 530 mW/cm^2 and 1,000 mW/cm^2, respectively.

However, the effect of LCUs on the depth of cure was statistically meaningful for Filtek Silorane (Table 3). The initiating system of silorane is different than that for MBC systems. Silorane has a triad initiating system composed of camphorquinone, an iodonium salt, and an electron donor.[1] Different polymerization depth may be linked to the different initiator system. However, both LCUs cured these resin composites deeper than required by the current ISO 4049 (lower limit 2 mm). Without a doubt, more data need to be taken into consideration before a complete evaluation is made of the overall performance of a dental restorative composite.[1] However, the results of this study may be significant in terms of providing an idea related to the basic features of a composite containing a new monomer.

The purpose of the microleakage test was to get information about the sealing ability of the restorative material. Failure of the restoration to seal the tooth may contribute to marginal staining, adverse pulpal response, postoperative sensitivity, and recurrent caries.[9,12,13] In the current study, none of the composites showed complete prevention of dye penetration (Table 7). The nonsignificant differences in microleakage of cavities restored with either Filtek P60 or Filtek Supreme XT may be associated with the similarities in the methacrylate chemistry (Table 1) and the utilization of the Adper Single Bond adhesive for Filtek P60 and Filtek Supreme XT. In addition, the manufacturers of Filtek P60 and Filtek Supreme report similar zirconia/silica filler loading (61 and 59.5 vol.%, respectively; Table 1). These results are in agreement with the findings of Cara and colleagues[10] who reported that no significant differences were identified in microleakage between the teeth restored with Filtek P60 or Filtek Supreme when an intermediary flowable was employed or not. However, Sadeghi and Lynch[41] observed less microleakage under Filtek P60 when compared with Filtek Supreme.

Promising microleakage results with Filtek Silorane were obtained in this study. The Filtek Silorane resin composite restorations showed similar microleakage results with Filtek P60 and showed better results than Filtek Supreme XT, regardless of the LCU used. In general, authors reported lower or similar microleakage scores for silorane-based composites compared to methacrylate-based ones similar to our results.[3,9,11] Bagis and colleagues[9] investigated the microleakage of Filtek Silorane composite in wide Class II mesio occlusal distal (MOD) cavities and stated that there was no microleakage found in specimens restored with Filtek Silorane, and this was significantly different from specimens restored with MBC. Thalacker and colleagues[11] also reported that the Silorane system showed a better marginal integrity on both enamel and dentin than the methacrylate system. Additionally, Palin and colleagues[3] used experimental silorane (H1) and an experimental silorane-bonding system in their study. All tested MOD restorations exhibited microleakage in the Palin study; but a significant or a non-significant decrease in the microleakage of MOD cavities restored

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with experimental silorane (H1) was identified compared with commercial MBC restorations. They attributed the significant decrease in the microleakage to the significant decrease in cuspal deflection manifested as a reduction in polymerization shrinkage stress at the tooth/restoration interface. However, in the current study, we did not determine polymerization shrinkage stresses generated by tested composites. We consider that lower microleakage scores obtained with Filtek Silorane in the current study could be partly attributed to the ring opening chemistry of the silorane system and the different nature of the silorane system adhesive.[9] Adhesive systems used to bond the Filtek Silorane and MBCs to dentin was different and this may also affect the sealing ability. In the current study, a two-step total-etch adhesive (Adper Single Bond) was used with MBCs and the two-step self-etch Silorane system adhesive was used with Filtek Silorane composite. The application of two-step total-etch adhesives has higher technical sensitivity than self-etch adhesives. Separate etching and water-rinsing phases can be omitted with use of acidic monomer-containing self-etching adhesive systems, making the application of adhesives less technique-sensitive for clinicians.[42]

CONCLUSIONS

Within the limitations of this in vitro study, the DC and the depth of cure of the MBCs were higher than that of the silorane-based composite. Although the hardness of the MBCs decreased during the storage period in an aqueous environment, the hardness of the silorane-based composite was unchanged. The silorane-based composite produced the lowest microleakage scores. Additionally, the LED and QTH LCUs used in the study demonstrated adequate performance in polymerizing a silorane-based composite under clinical circumstances.

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