

## Investigation of microhardness, surface roughness, and color change of preheated composite resins

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### Abstract

**Aim:** Applying heat is a method currently used to enhance the depth of polymerization in composite resin. This study aimed to evaluate the effects of heat treatment on resin hardness, color change, and surface roughness.

**Methodology:** In this study, 64 samples (8 mm<sup>2</sup> × 2 mm<sup>2</sup>) were produced (3M Filtek Universal, G-aenial A'CHORD, Neo Spectra and Clearfil Majesty ES-2) using a Teflon mold (n = 8). Half of the samples were preheated to 50°C, while the other half were polymerized at room temperature. Initial color measurements were performed using a spectrophotometer, the surface roughness was assessed with a profilometer, and the microhardness was determined using a Vickers microhardness device. Subsequently, all samples were immersed in a coffee solution at 37°C. The color changes were documented by the seventh day. The changes in color, roughness, and hardness of the materials were examined by the thirtieth day.

**Results:** The groups that received heat treatment exhibited higher hardness values. The unheated G-aenial A'CHORD composite resin demonstrated the most significant color change by the end of the thirtieth day, while heated and unheated Clearfil Majesty ES-2 composite samples exhibited the least color change. By the end of the thirtieth day, the surface roughness of all samples increased significantly from the baseline, with the 3M Filtek Universal samples, both heated and unheated, showing the highest surface roughness.

**Conclusion:** According to the results of this study, heat treatment of composite resins before polymerization reduces discoloration and improves hardness. Therefore, it is recommended to heat composite resins before application.

**Keywords:** Composite resin, microhardness, surface roughness, color change, preheating, polymerization.

## Introduction

The use of composite resins has increased due to growing aesthetic concerns and improved qualities of composite resins (1, 2). Composite resins, which have shown continuous development and change since their introduction to the present, exhibit reduced surface roughness, enhanced color stability, and increased wear resistance (3-6). Achieving a smoother surface leads to longer-lasting restorations characterized by less plaque accumulation, decreased discoloration, and a healthier periodontium (7, 8).

Besides all these developments, despite the improvements in chemical structures and filler types of composite resins, the discoloration that occurs over time in composite restorations is still a frequently experienced problem (9). The polymerization stage is crucial for the clinical success of composites. Studies have indicated that this phase affects the surface hardness, abrasion resistance, biocompatibility, residual monomer content, water absorption, and coloration of the resins (10, 11). The conversion rate of monomers into polymers during polymerization is termed the degree of polymerization or conversion. The degree of polymerization of composite resins is defined by the degree of conversion of monomeric C=C bonds into polymeric C-C bonds (12). An increase in the degree of polymerization reduces the amount of residual monomer that does not participate in the reaction in the resin (13). These residual monomers play a role in reducing the mechanical strength of the restoration. Oxidation of unsaturated methacrylate groups can contribute to discoloration in composite resin restorations (12).

Polymerization depth is crucial to the long-term clinical success of restorations made with composite resins. Applying heat to resins is a contemporary method of enhancing polymerization depth. After being heated to 50°C in a heating device (Ease-it) made for the specific purpose, composite tubes are prepared for processing. Preheating before polymerization produces a significant increase in monomer conversion and polymerization, considerably improving the physical and chemical properties of composite resins (12, 14-16). However, preheating before polymerization also increases the likelihood of pulp necrosis (16).

The objective of this study was to evaluate the effect of heat application before polymerization on the surface roughness, microhardness, and color change of four distinct composite resins (Filtek Universal, G-aenial A'CHORD, Neo Spectra, and Clearfil Majesty ES-2).

The study's first null hypothesis posits that no significant difference will be observed in the color changes of composite sample groups immersed in coffee by the end of the 7th and 30th days. The second null hypothesis suggests that no considerable difference will be noted in the microhardness changes of the samples immersed in coffee by the 30th day. The third null hypothesis asserts that no significant difference will be found between the surface roughness changes of the samples kept in coffee by the end of the 30th day.

## Materials and Methods

### Composite samples and their treatment

A total of 64 disc-shaped composite samples ( $8 \times 2 \text{ mm}^2$ ) were prepared by generating 16 samples from each of the 4 composite resins selected for the study (Table 1). These samples were randomly divided into two subgroups: heated and nonheated. Each composite resin tube was placed in the Ease-it (Ronvig, Denmark) composite heating device and heated to 50°C before being transferred to a Teflon mold specifically prepared for preheating before polymerization (Fig. 1).



Figure 1. Composite heating device

The samples in the unheated group were kept at room temperature and then placed in a Teflon mold. For both groups, a piece of transparent tape was placed on the lower surface of the Teflon mold during composite placement, and the composite was adapted to the cavity using a hand tool. A glass slide was placed on top of the composite and polymerized for 20 s using a light-emitting diode (LED) device (Woodpecker DTE Lux E; Woodpecker, China), achieving a smooth surface. The polymerizing tip of the device was brought into contact with the cement glass throughout this process, and three measurements were positioned from the center point to the center of the sample. Both surfaces of the samples were then polished with Shofu Super-Snap rainbow polishing disks (Shofu Inc., Kyoto, Japan). These four-stage disks—from coarse to fine-grained—were used with a rotary tool set at 20000 rpm for 10 s in a circular motion and under cooling water. The polishing disks were replaced after every five samples.

All polished samples were stored in distilled water at 37°C for 24 h for post-polymerization.

## Measurement of color values

The initial color values of the samples were measured using the Vita EasyShade V digital spectrophotometer (Vita EasyShade V, Vita Zahnfabrik, Bad Sackingen, Germany). Measurements were made in a color-measuring cabinet to ensure standardization. The interior of the cabinet was gray, and the floor to be measured was white. The luminous power was 6500K according to CIE standards (Master TL-D 90 Graphica 18W/965; Philips, Signify, Poland). The device was calibrated following the manufacturer's instructions before each measurement, and mean L, a, and b values were recorded by measuring the center of each sample three times. After initial color measurements, a coffee solution (pH: 5.5) was prepared by mixing 2 g of coffee (Nescafe Classic, Bursa, Türkiye) with 150 mL of boiling water. Once the coffee solution reached room temperature (37°C), the composite samples were immersed in the solution. After keeping the samples in the coffee solution for 7 and 30 days, the color measurements were repeated with a spectrophotometer, as previously described. The coffee solution was refilled every day during the experiment, and the samples were cleaned after each change to eliminate residue. After 30 days, the samples were removed from the solution, washed, dried, and measured once more with the spectrophotometer. The color change ( $\Delta E_{00}$ ) values between samples were computed using the CIEDE 2000 formula where;

- L\* is the lightness,
- a\* is the red (+)/green (-) color coordinate,
- b\* is the yellow (+)/blue (-) color coordinate.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right) \left(\frac{\Delta H'}{k_H S_H}\right)},$$

For this study, KL, KC, and KH were set to 1.0. The clinically accepted 50% : 50% color change threshold was determined at  $\Delta E_{00} = 1.8$  (17).

## Surface roughness analysis

For surface roughness analysis, a precision measuring profilometer (Mahr M2; Mahr GmbH, Gottingen, Germany) from Ankara University Research Laboratory was used. During measurement, the device's recording tip scanned the sample's surface at a set speed. The vertical movements of the recording tip depending on the roughness of the surface created differences in electrical current to record the surface profile, and the values related to the surface topography were obtained numerically and recorded.

## Scanning electron microscopy analysis

The scanning electron microscopy (SEM) images were taken at the beginning and end of day 30 after soaking in coffee by randomly selecting one sample from each composite group (Fig. 2). This process was conducted at varying magnifications (500x, 1000x, and 5000x) under a low vacuum of 20 kV, using the carbon coating method on samples set on an acrylic block. After 30 days, surface roughness values and SEM analysis data of the disc-shaped samples were compared.

## Surface microhardness measurement

The surface microhardness measurements were obtained using the Vickers microhardness device (Digital Display Microhardness Tester HVS-1000, Zhengzhou, China) at Ankara University Research Laboratory. Each sample was placed on a light microscope table. First, the surface to be measured was identified at the lowest magnification (10x), after which the area for the Vickers tip was determined at 40x magnification. Measurements were made by applying a Vickers diamond tip with a load of 300 g (1.961N) for 15 s. A trace was created on the sample with the square-bottomed pyramid-shaped tip with an apex angle of 136° in the device. The resulting square-shaped trace was transferred to the measuring screen with the help of a microscope attached to the device, where measurements were taken. The lengths of the trace diagonals created with the Vickers tip were examined under 40x magnification. Measurements were made by aligning the horizontal lines on the screen to both ends of the diagonals. The device automatically calculated the surface hardness values using the length data of the diagonal. Measurements were performed on the samples at the beginning and again on the 30th day after soaking them in coffee.

## Statistical analysis

The IBM SPSS v25 (Statistical Package for Social Sciences, Armonk, NY, US) program was used for statistical analysis. The Kolmogorov-Smirnov test was used to determine whether the numerical data were normally distributed, and the homogeneity of variance was performed using the Levene test.

Assumptions of normal distribution ( $p > 0.05$ ) and homogeneity of variance ( $p > 0.05$ ) were provided. The changes in microhardness values over time, according to the composite and method type, were analyzed with two-way analysis of variance and generalized linear models.

Bonferroni correction was used for multiple comparisons. The analysis results were presented as mean  $\pm$  standard deviation. The results were evaluated at a 95% confidence interval, with a significance level of  $p < 0.05$ .

The calculation of the sample size required for the study was made for the F test using G\*Power 3.1 program

(Heinrich Heine University, Dusseldorf, Germany), with  $\beta = 0.80$ ,  $\alpha = 0.05$ , and effect size = 0.60. A minimum of eight samples were taken for each group. A 10% sample

was allocated for nonparametric tests and another 10% for instances that might be excluded from the study.

**Table 1.** Properties of the composite resins used in this study

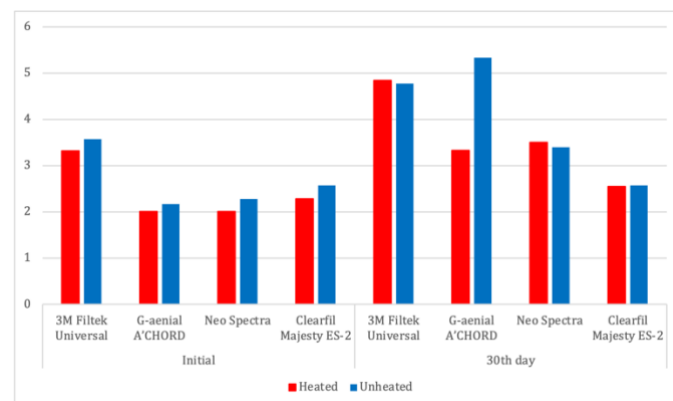
Composite trade	Brand	Filler type	Filler particle	% Filler by Weight (vol)	Organic matrix composition	Mean particle size of filler
3M Filtek Universal (A2)	3M ESPE, MN, USA	Nanofilled	Silica, zirconia, silica zirconia, and ytterbium trifluoride	76.5 (58)	AUDMA, AFM, diurethane-DMA, and 1.12-DDMA	20 nm silica, 4-11 nm zirconia
G-aenial A'CHORD (A2)	GC Europe, Tokyo, Japan	Nanohybrid	Barium glass and fumed silica	82	Bis-EMA, TEGDMA and UDMA	16 nm
Neo Spectra (A2)	Dentsply, Konstans, Germany	Nanohybrid	Spherical prepolymerized SphereTEC fillers, nonagglomerated barium glass, and ytterbium fluoride	78-80	Methacrylate-modified polysiloxane (organically modified ceramic) dimethacrylate, ethyl-4 (dimethylamino) benzoate, and bis (4-methyl-phenyl) iodonium hexafluorophosphate	15 $\mu\text{m}$
Clearfil Majesty ES-2 (A2)	Kuraray Medical Co., Tokyo, Japan	Nanohybrid	Barium glass Pre-polymerized organic fillers	78 (66)	BisGMA, hydrophobic aromatic DMA, dl-camphoroquinone	Silanated barium glass (0.37-1.5 $\mu\text{m}$ )

AUDMA, Aromatic urethane dimethacrylate; AFM, Addition fragmentation monomer; diurethane- dimethacrylate; DDMA, 1.12-dodecane-dimetakrilat; Bis-EMA, Ethoxylatedbisphenol-A-dimethacrylate; TEGDMA, Tetraethylene glycol dimethyl ether; UDMA, Urethane- dimethacrylate; BisGMA, Bisphenol A diglycidylmethacrylate.

## Results

The mean color change values at the end of the seventh day for all composite types were significantly lower in the heated group compared with the unheated group ( $p < 0.05$ ) (Table 2 and Fig. 2). Upon examining the average color change values at the end of the 30th day, the heated sample groups showed higher color change values in the 3M Filtek Universal and Neo Spectra composite groups. In contrast, the unheated samples showed higher color change values in other composite types (Table 2 and Fig. 2). The most significant color change was in the unheated G-aenial A'CHORD composite group ( $\Delta E_{00} : 2.17$ ) (Table 2 and Fig.2).

The analysis revealed that the method of heat application before polymerization did not result in a statistically significant difference in the surface roughness values ( $p > 0.05$ ) (Table 3 and Fig. 3).



**Figure 2.** Color change values of heated and unheated composite group

**Table 2.** Color change measurements of composite materials

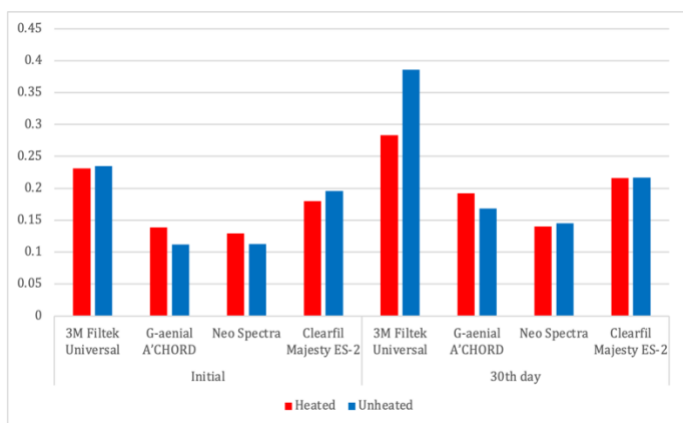
Time	Composite type	Heated	Unheated	Mean
Initial	3M Filtek Universal	3.32	3.57	3.44
	G-aenial A'CHORD	2.01	2.17	2.09
	Neo Spectra	2.01	2.28	2.14
	Clearfil Majesty ES-2	2.28	2.57	2.42
30 <sup>th</sup> day	3M Filtek Universal	4.84	4.77	4.81
	G-aenial A'CHORD	3.33	5.33	4.33
	Neo Spectra	3.5	3.4	3.45
	Clearfil Majesty ES-2	2.55	2.57	2.56

Regarding the average microhardness values at the beginning and end of the 30th day for composite types, the microhardness values for the heated groups were found to be higher than those for the unheated groups (Table 4 and Fig. 4).

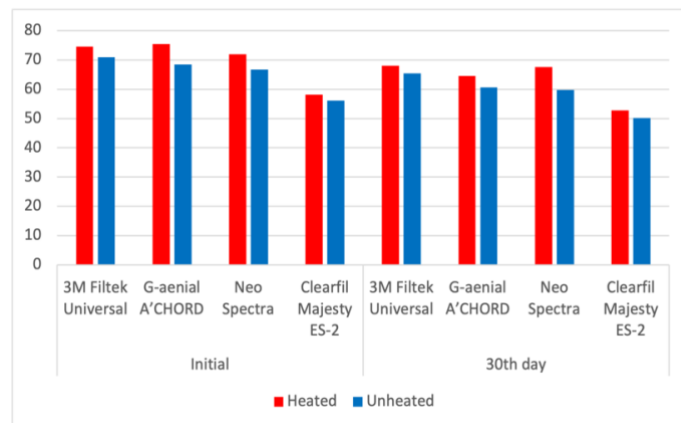
Notably, significant differences were observed between the heated and unheated G-aenial A'CHORD and Neo Spectra groups ( $p < 0.05$ ) (Table 4 and Fig. 4).

At the end of the 30th day, the maximum change in microhardness occurred in the G-aenial A'CHORD composite group (Table 4 and Fig. 4). The samples randomly selected from the composite groups were analyzed under 5000x magnification at the beginning and the end of the 30th day (Fig. 5).

The data revealed no difference in surface roughness between the heated and unheated groups. The images of the SEM analysis are shown in Fig. 5.



**Figure 3.** Surface roughness values of heated and unheated composite groups



**Figure 4.** Microhardness values of heated and unheated composite groups

**Table 3.** Surface roughness measurements of composite materials

Time	Composite type	Heated	Unheated	Mean
Initial	3M Filtek Universal	0.231	0.235	0.233
	G-aenial A'CHORD	0.139	0.112	0.13
	Neo Spectra	0.129	0.113	0.121
	Clearfil Majesty ES-2	0.18	0.196	0.188
30 <sup>th</sup> day	3M Filtek Universal	0.283	0.386	0.334
	G-aenial A'CHORD	0.192	0.168	0.18
	Neo Spectra	0.14	0.145	0.142
	Clearfil Majesty ES-2	0.216	0.217	0.216

Table 4. Microhardness values of composite materials

Time	Composite type	Heated	Unheated	Mean
Initial	3M Filtek Universal	74.48	70.92	72.7
	G-aenial A'CHORD	75.42	68.39	71.90
	Neo Spectra	71.94	66.66	69.3
	Clearfil Majesty ES-2	58.13	56.05	57.09
30 <sup>th</sup> day	3M Filtek Universal	67.98	65.34	66.66
	G-aenial A'CHORD	64.52	60.54	62.53
	Neo Spectra	67.62	59.72	63.67
	Clearfil Majesty ES-2	52.71	50.18	51.44

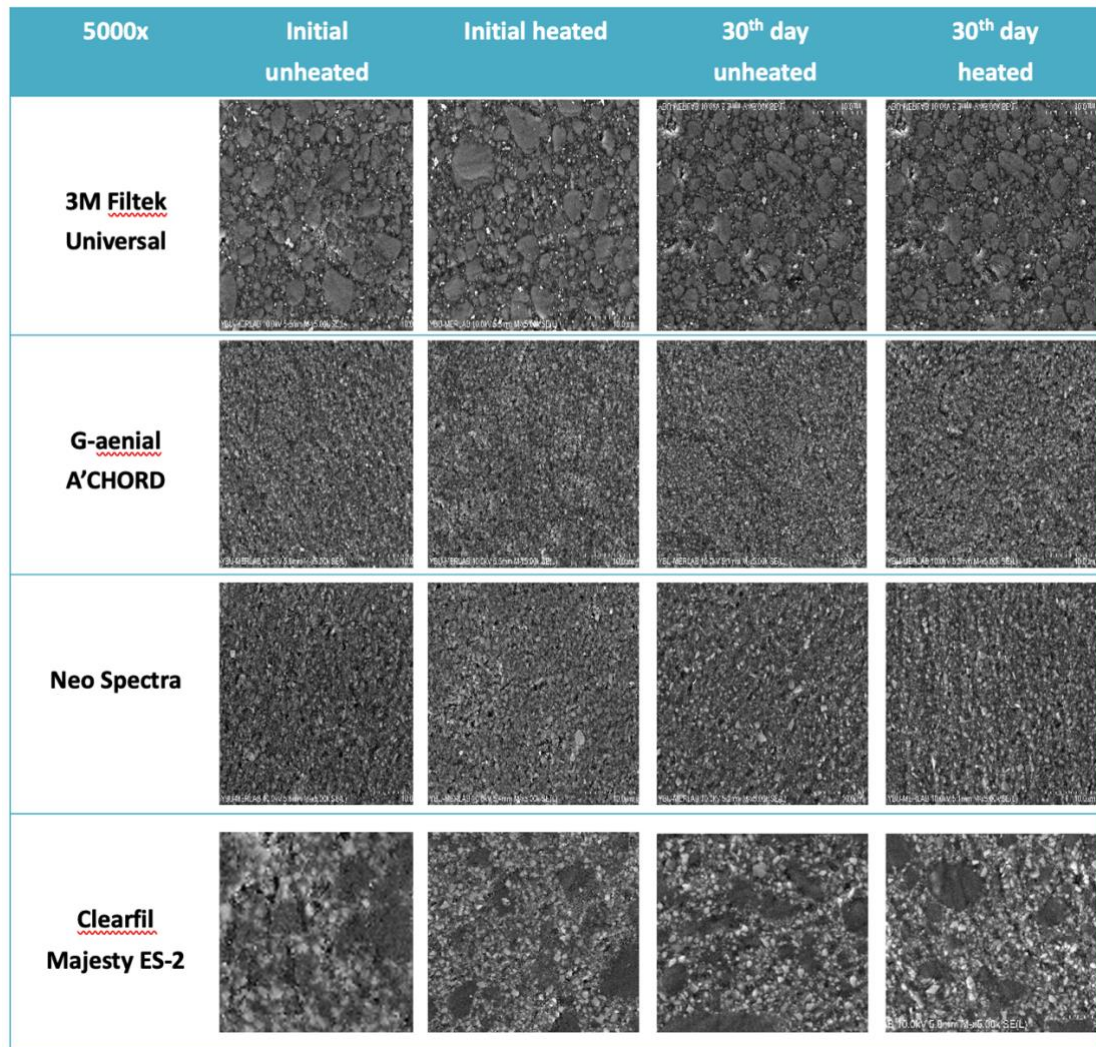


Figure 5. Images of SEM analysis of the samples

## Discussion

Many physical features of resin composite materials emerge with the increase in polymerization depth (12, 15, 18). Heating the composite resin to room temperature or above, before polymerization, affects monomer conversion and polymer properties. This

decreases the resin's viscosity by increasing free radical mobility with the temperature rise, and an additional polymerization occurs (1, 12, 15, 18). The results showed that heat treatment before polymerization increased the microhardness values of the samples in general but did not show a significant effect on roughness.

Jafarzadeh Kashi et al. examined the changes in the microhardness values of three different nanohybrid composite resins at three different temperatures (21°C, 37°C, and 54°C) and concluded that the microhardness values of the composite resins increased with the temperature rise (19). Awliya et al. (20) polymerized the micro-hybrid composite resin at three different temperatures (5°C, 25°C, and 37°C) using three different light application methods (halogen lamp, LED, and soft-start polymerization) and examined the change in hardness values. They found the difference between the hardness values of the groups kept in the refrigerator and cooled to 5°C and the other groups to be statistically significant. The results revealed that the groups kept at room temperature before polymerization and the groups heated up to 37°C before polymerization had harder surfaces than those polymerized at 5°C (20). The results of the present study were also compatible with the findings of Awliya et al. and Jafarzadeh Kashi et al. The analysis of the data obtained from this study showed that the microhardness mean values at the beginning and the end of the 30th day, for all composite types, were significantly lower than those in the unheated group ( $p < 0.05$ ).

Numerous clinical and laboratory studies have found a link between the degree of monomer conversion and the mechanical properties of composite resins, which directly affects their chemical stability (20, 21).

Untransformed double carbon bonds in composite resins are responsible for material degradation, reducing the color stability of the composite (20, 22).

Micali and Basting reported that adequate polymerization and a high degree of conversion positively affected color stability (23). Mundim et al. reported that composites heated to 60°C before polymerization achieved a higher degree of transformation than samples at 8°C and 25°C (20). Prasanna et al. showed that the degree of monomer conversion of composites increased significantly with heating prior to photoactivation (24). In the present study, the color change obtained for all composite types at the end of the seventh day had statistically more significant and lower mean values in the group that underwent heating ( $p < 0.05$ ).

Contrary to these findings, the study by Mundim et al. showed no advantage in terms of color change between the heated and unheated groups, even though an increase in the degree of transformation of the composite was observed after preheating it to 60°C (20). Al Kheraif et al. evaluated the effects of the degree of transformation on color stability using nanohybrid and micro-hybrid composites. They observed that the nanohybrid composite resin had a higher degree of transformation and showed less color stability. Consequently, they concluded that the degree of conversion and color stability might not show a linear correlation (25). The degree of transformation varied among composites and even among colored composites. In line with these studies, the color change values of 3M Filtek Universal and Neo Spectra heated groups were higher than those of the unheated groups at the end of the 30th day.

The data regarding the effect of heat on surface roughness are limited. The present study sought quantitative and qualitative data using a two-dimensional surface profilometer device and an SEM device. SEM is an effective qualitative method for studying surface topography. It is widely used to observe material surface structures, particle sizes, and surface scratches and imperfections. However, it has some disadvantages, such as the need to coat the samples before examining them and providing only a two-dimensional image. For this reason, many researchers recommend using multiple techniques simultaneously to study the surface structures of composite resins (26, 27). Ali-Atef et al. investigated the effect of temperature increase on the surface roughness of a nanofilled composite (Filtek Z350 XT), revealing no significant difference in surface roughness between the heated and unheated groups. Although the mean surface roughness Ra (nm) values in the preheated group were higher than those in the unheated group, the differences were not significant. Similarly, in the present study, preheating did not result in a significant difference in surface roughness at the end of the 30th day.

## Conclusion

To increase the microhardness of composite resins and reduce surface discoloration over time, preheating prior to polymerization will significantly improve clinical success.

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## Disclosures

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**Author Contributions:** Conception - M.B.Ç., N.A., B.E.; Design - S.K., N.A., B.E.; Supervision - E.A.O., N.A.; Materials - M.B.Ç., S.K., E.A.O.; Data Collection and/or Processing - S.K., E.A.O., N.A.; Analysis and/or Interpretation - S.K., E.A.O., N.A.; Literature Review - M.B.Ç., B.E.; Writer - M.B.Ç., S.K., N.A., B.E.; Critical Review - M.B.Ç., S.K., B.E.

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## References

1. Dayangaç B. Kompozit Rezin Restorasyonlar. Ankara: Güneş Kitabevi; 2000.
2. Ergücü Z, Türkün LS. Nano kompozitlerin mikrosüzüntüsünde adezivlerin önemi. EÜ Diş Hek Fak Derg 2005;26:59-64.
3. Tyas MJ. Colour stability of composite resins: a clinical comparison. Aust Dent J 1992;37:88-90.  
<https://doi.org/10.1111/j.1834-7819.1992.tb03042.x>
4. Yap A. Occlusal contact area (OCA) wear of two new composite restoratives. J Oral Rehabil 2002;29:194-200.  
<https://doi.org/10.1046/j.1365-2842.2002.00814.x>
5. Setcos J, Tarim B, Suzuki S. Surface finish produced on resin composites by new polishing systems. Quintessence Int 1999;30:169-73.
6. Senawongse P, Pongprueksa P. Surface roughness of nanofill and nanohybrid resin composites after polishing and brushing. J Esthet Restor Dent 2007;19:265-75.  
<https://doi.org/10.1111/j.1708-8240.2007.00116.x>
7. Weitman R, Eames W. Plaque accumulation on composite surfaces after various finishing procedures. J Am Dent Assoc 1975;91:101-6.  
<https://doi.org/10.14219/jada.archive.1975.0294>
8. Hachiya Y, Iwaku M, Hosoda H. Relation of finish to discoloration of composite resins. J Prosthet Dent 1984;52:811-14.  
[https://doi.org/10.1016/S0022-3913\(84\)80010-4](https://doi.org/10.1016/S0022-3913(84)80010-4)
9. Celik EU, Aladağ A, Türkün LŞ, Yılmaz Y. Color Changes of Dental Resin Composites before and after Polymerization and Storage in Water. J Esthet Restor Dent 2011;23(3):179-88. <https://doi.org/10.1111/j.1708-8240.2011.00421.x>
10. Asmussen E. Factors Affecting the Quantity of Remaining Double Bonds in Restorative Resin Polymers. Scand J Dent Res 1982;90(6):490-6.  
<https://doi.org/10.1111/j.1600-0722.1982.tb00767.x>
11. M. Daronch FA, Rueggeberg, De Goes MF. Monomer Conversion of Pre heated Composite. J Dent Res 2005;84: 663-7. <https://doi.org/10.1177/154405910508400716>
12. Bektaş Ö, Hergüner Ş, Eren D. Işık Kaynakları, Polimerizasyon ve Klinik Uygulamalar. EÜ Diş Hek Fak Derg 2006;27:117-24.
13. Deb S, Di Silvio L, Mackler HE, Millar BJ. Pre-warming of dental composites. Dent Mater 2011;27:51-9.  
<https://doi.org/10.1016/j.dental.2010.11.009>
14. Daronch M, Rueggeberg FA, Moss L, de Goes MF. Clinically relevant issues related to preheating composites. J Esthet Restor Dent 2006;18:340-51.  
<https://doi.org/10.1111/j.1708-8240.2006.00046.x>
15. Lohbauer U, Zinelis S, Rahiotis C, Petschelt A, Eliades G. The effect of resin composite preheating on monomer conversion and polymerization shrinkage. Dent Mater 2009;25:514-9.  
<https://doi.org/10.1016/j.dental.2008.10.006>
16. Luo MR, Cui G, Rigg B. The development of the CIE 2000 colour difference formula: CIEDE2000. Color Res Appl 2001;26:340-50.  
<https://doi.org/10.1002/col.1049>
17. Daronch M, Rueggeberg FA, De Goes MF, Giudici R. Polymerization kinetics of pre-heated composite. J Dent Res 2006;85:38-43.  
<https://doi.org/10.1177/154405910608500106>
18. Lovell LG, Lu H, Elliott JE, Stansbury JW, Bowman CN. The effect of cure rate on the mechanical properties of dental resins. Dent Mater 2001;17:504-11.  
[https://doi.org/10.1016/S0109-5641\(01\)00010-0](https://doi.org/10.1016/S0109-5641(01)00010-0)
19. Jafarzadeh Kashi TS, Fereidouni F, Khoshroo K, Heidari S, Masaeli R, Mohammadian M. Effect of Preheating on the Microhardness of Nanohybrid Resin- based Composites. Frontiers in Biomedical Technologies 2015;2(1):15-22.
20. Awliya WY. The influence of temperature on the efficacy of polymerization of composite resin. J Contemp Dent Pract 2007;8:9-16. <https://doi.org/10.5005/jcdp-8-6-9>
21. Mundim FM, Garcia Lda F, Cruvinel DR, Lima FA, Bachmann L, Pires-de-Souza Fde C. Color stability, opacity and degree of conversion of pre-heated composites. J Dent 2011;39:25-9. <https://doi.org/10.1016/j.jdent.2010.12.001>
22. Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. DentMater 2006;22:211-22.  
<https://doi.org/10.1016/j.dental.2005.05.005>
23. Micali B, Basting RT. Effectiveness of composite resin polymerization using light-emitting diodes (LEDs) or halogen-based light-curing units. Braz Oral Res 2004;18:266-70.  
<https://doi.org/10.1590/S1806-83242004000300016>
24. Prasanna N, Pallavi Reddy Y, Kavitha S, Lakshmi Narayanan L. Degree of conversion and residual stress of preheated and roomtemperature composites. Indian J Dent Res 2007;18:173-6.  
<https://doi.org/10.4103/0970-9290.35827>
25. Al Kheraif AAA , Bin QASIM SS, Ramakrishnaiah R, ur Rehman Ihtesham. Effect of different beverages on the color stability and degree of conversion of nano and microhybrid composites. Dent Mater J 2013;32(2):326-31.  
<https://doi.org/10.4012/dmj.2011-267>
26. Schlueter N, Hara A, Shellis RP, Ganss C. Methods for the measurement and characterization of erosion in enamel and dentine. Caries Res 2011;45 Suppl 1:13-23.  
<https://doi.org/10.1159/000326819>
27. Bergmans L, Moisiadis P, Van Meerbeek B, Quirynen M, Lambrechts P. Microscopic observation of bacteria: review highlighting the use of environmental SEM. Int Endod J 2005;38(11):775-88.  
<https://doi.org/10.1111/j.1365-2591.2005.00999.x>