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Aysun Avsar[1, A, C, F], Emir Yuzbasioglu[2, A–F], Duygu Sarac[3, D–F]

The Effect of Finishing and Polishing Techniques on the Surface Roughness and the Color of Nanocomposite Resin Restorative Materials

[1] Department of Pedodontics, Ondokuz Mayis University Faculty of Dentistry, Turkey
[2] Department of Prosthodontics, Istanbul Medipol University School of Dentistry, Turkey
[3] Department of Prosthodontics, Ondokuz Mayıs University, Faculty of Dentistry, Turkey

A – research concept and design; **B** – collection and/or assembly of data; **C** – data analysis and interpretation; **D** – writing the article; **E** – critical revision of the article; **F** – final approval of article

Abstract

Background. Rough, poorly polished surfaces contribute to staining, plaque accumulation, gingival irritation and recurrent caries. Finishing and polishing techniques are critical factors contributing to the longevity of the direct composite resin restorations.
Objectives. The aim of this *in vitro* study was to evaluate the effects of finishing and polishing systems on surface roughness of six nanocomposite restorative resins.
Material and Methods. Thirty specimens of each restorative material (n = 180) were placed in a teflon mould (6 mm in diameter and 3 mm in depth) and cured with a LED curing unit. Six specimens from each of restorative material were randomly assigned to four groups for finishing and polishing (carbide burs, diamond burs, aluminium oxide discs, silicon rubber polisher) techniques. Mylar strip formed specimens were served as control group. After finishing and polishing procedures surface roughness was evaluated by a profilometer. The data was analyzed by 2-way analysis of variance and the Tukey HSD test ($\alpha = 0.05$).
Results. Significant differences were found between the groups in terms roughness ($p < 0.001$). The control group and aluminium oxide discs group had the lowest Ra values and were significantly different from other groups ($p < 0.001$). The roughest surface was obtained with diamond burs followed by silicon rubbers and carbide burs. Overall, the smoothest surfaces were obtained with the use the complete sequence of aluminum oxide discs.
Conclusions. In areas that could not be reached by the aluminum oxide discs, the carbide burs produced satisfactory surface smoothness for the nanocomposite restorative materials. Although mylar matrix strip formed surfaces presents lower surface roughness values, recountouring and polishing of resin restorations are often required in clinical situations. Aluminium oxide discs and carbide finishing burs are suitable for finishing and polishing procedures for nanocomposite restorative resins (**Adv Clin Exp Med 2015, 24, 5, 881–890**).

Key words: surface roughness, color difference, nanocomposite resins, polishing techniques.

The clinical use of composite resins has increased substantially and they are recommended for restoring all cavity classes over the past few years [45]. Various classification systems for resin composites have developed through the years based on particle size. The traditional system includes traditional, small particle, microfilled and hybrid filler particles [24]. Nanotechnology is of great interest for the development of dental materials. This is particularly true for purpose-designed nano and microstructures, which can be used to produce low shrinkage dental composites with high wear resistance and biocompatibility [2]. Nanotechnology is known as the production and manipulation of materials and structures in the range of about 0.1–100 nm by various physical and chemical methods [4, 40]. Nanofilled resin composites utilize nano-meter-sized particles throughout the resin matrix [40]. Nanohybrids combine nanometer-sized particles with more conventional filler technology. Due

to the reduced dimension of the particles and to a wide size distribution, an increased filler load can be achieved with the consequence of reducing the polymerization shrinkage and increasing the mechanical properties such as tensile strength, compressive strength ad resistance to fracture [4]. Additionally, the small size of the filler particles improve the optical properties of resin composites because their diameter is a fraction of the wavelength of visible light (0.4–0.8 μm), resulting in the human's eye inability to detect the particles [25].

A smooth surface finish is clinically important for composite resin restorations, as it determines the esthetics and longevity of the composite resin restorations [11, 36, 45]. Finishing and polishing procedures which refer to gross contouring of the restoration to obtain the desired anatomy, to reduce and smooth the roughness and scratches created by finishing instruments, are essential to periodontal integrity, marginal integrity and wear reduction [18, 34] Also highly polished surfaces minimize the plaque accumulation, gingival irritation, poor esthetics, surface discoloration and secondary caries [36, 42]. However, it was stated that it is difficult to achieve a highly polished surface of composite resin restorations due to different hardnesses of resin matrix and filler particles of composite resins [14, 31]. For composite resins, the smoothest surfaces were produced when the materials were allowed to polymerize against a strip matrix [45, 14, 43]. Despite careful placement of the matrix, removing excess material and re-contouring restorations is often clinically necessary. This requires some degree of finishing and polishing, which may alter the smoothness obtained with a matrix [14, 43]. The flexibility of the backing material in which the abrasive is embedded, the hardness of the abrasive, and the grit size influence surface roughness (Ra) of resin restoration after finishing and polishing procedures [14, 19, 31].

Optical properties of the dental composite resins were influenced by surface changes during restorative procedures of finishing and polishing [19, 26]. Color change (ΔE) mathematically expresses the amount of difference between the L*a*b* coordinates of different specimens or the same specimen at different instances [9]. Various studies have reported different thresholds of ΔE values above which the color change is perceptible to the human eye [10, 20, 22, 27, 30, 35, 37]. These values ranged from ΔE equal to 1 [27], between 2 and 3 [35], greater than or equal to 3.3 [22, 30], and greater than or equal to 3.7 [20]. Values of ΔE in the range of 2 to 3 were perceptible, and values from 3 to 8 were moderately perceptible, and values above 8 were markedly perceptible [37]. A ΔE value of 3.7 or less is considered to be clinically acceptable by Johnston and Kao [20]. In general, polished composite resins tend to appear lighter, whiter, and less glossy than the corresponding matrix covered surfaces [15].

The objective of the present study was to evaluate the effects of four different finishing/polishing techniques on the surface roughness and color differences of 3 nanohybrid and 3 nanofilled composite resin restorative materials. The research hypothesis was that significantly different Ra and ΔE values would be found for different composite resins and polishing/finishing techniques.

Material and Methods

The materials used in this study are listed in Table 1. Thirty-two disc-shaped specimens were prepared for each composite resin material (6 × 3 mm), for a total of 192 specimens, using a plastic transparent mould with a hole in the center (6 mm in diameter and 3 mm in height). The mould was slightly overfilled with composite resin material, covered on each side with a strip matrix and placed between two glass slides. A weight of 2 kg was applied to extrude the excess material. Then the composite resin material was light polymerized for 20s with a quartz tungsten halogen polymerizing light (QTH) (Astralis 3; Ivoclar Vivadent) with an output of 600 mW/cm^2. The specimens were polymerized from the two sides. Following light curing, specimens were removed from the mold and stored in distilled water at 37°C for 24 h. Specimens of each composite resin were divided into 4 groups, each containing 8 specimens.

Before finishing and polishing procedures, the first color measurements of the specimens were made using a small area colorimeter (CR-300; Minolta, Osaka, Japan). Three colorimetric measurements were made for each specimen and the mean CIE L*a*b* values were recorded. In order to position the tip of the colorimeter to the same area of the specimens, a white custom-made mold made of polytetrafluoroethylene was prepared. The colorimeter was calibrated according to manufacturer's instructions, before each measurement period using the white calibration cap (CR-A43, Minolta, Osaka, Japan) supplied by the manufacturer.

After colorimetric evaluation, surface roughness of the specimens was measured using a profilometer (Mitutoyo Surf Test 402 Analyzer; Mitutoyo Corp, Japan). To measure the roughness profile value, the diamond stylus (5-μm tip radius) was moved across the surface under a constant load of 3.9 mN. The instrument was calibrated using a standard reference specimen, then set to travel at a speed of 0.1 mm/s with a range of 600 μm during testing. This procedure was repeated

Table 1. Materials used in this study

Material	Product	Code	Batch number	Manufacturer
Nanohybrid composite resin	Grandio	G	502162	VOCO, Cuxhaven, Germany
Nanohybrid composite resin	Ice	I	041117	SDI, Victoria, Australia
Nanohybrid composite resin	Smile	S	76910	Pentron, Wallingford, CT, USA
Nanofill composite resin	Aelite Enamel	A	050005319	Bisco, Inc. Schaumburg, IL, USA
Nanofill composite resin	Premise	P	014533	Kerr Corporation, CA, USA
Nanofill composite resin	Filtek Supreme XT	F	5AR	3M ESPE, St Paul, Minn
12-fluted carbide finishing bur	–	c	FG 7214F	KG, Sorensen, Barueri, Brazil
30-fluted carbide finishing bur	–	c	FG 9642FF	KG, Sorensen, Barueri, Brazil
Fine diamond finishing bur	–	d	2135F	KG, Sorensen, Barueri, Brazil
Extrafine diamond finishing bur	–	d	2135FF	KG, Sorensen, Barueri, Brazil
Aluminum oxide abrasive discs	Sof-Lex disk	a	H22742	3M ESPE, St Paul, MN, USA
Silicone rubber	–	s	–	Kerr Corporation, CA, USA

Table 2. Finishing and polishing procedures used in this study

Group	Finishing and polishing procedure
ct (control)	untreated
c	first 12-fluted then 30-fluted carbide burs were used
d	first fine then extrafine diamond burs were used
a	medium grit (40 μm), fine grit (24 μm), extra-fine grit (8 μm) aluminum oxide abrasive discs were used, respectively
s	first pre-polisher (yellow), then high gloss polisher (white) were used

3 times for all specimens and the average value was considered to be the first Ra value.

Subsequently, the surfaces of the specimens were grounded with a 1000 grit silicon carbide paper (Carbimet; Buehler, Lake Bluff, Ill) in the experimental groups (Table 2). In Group C the specimens were polished firstly with 12-fluted then with 30-fluted carbide burs; Group D specimens were polished with fine and extrafine diamond burs; Group A specimens were polished sequentially with medium grit (40 μm), fine grit (24 μm), and extra-fine grit (8 μm) aluminum oxide abrasive discs; and in Group S the specimens were polished firstly with pre-polisher (yellow), then with high gloss polisher (white). To reduce variability, specimen preparation, finishing and polishing procedures were carried out by the same operator. After each finishing and polishing step, specimens were flushed with water and air dried before starting the next step. At the completion of the finishing and polishing procedure, specimens were ultrasonically cleaned (Eurosonic energy; Euronda SpA, Vicenza, Italy) with distilled water and dried with a blast of air for 30 s before the measurements. Diamond and carbide burs were used with a slow-speed handpiece (NBBW-E; Nsk Nakanishi Inc., Tochigi, Japan) under water cooling for 15 s. The aluminum oxide discs and silicone-based polisher points were used with a slow-speed hand piece (NBBW-E; Nsk Nakanishi Inc., Tochigi, Japan) rotating at approx. 20,000 rpm with water cooling for 30 s. Each bur was applied using light pressure in multiple directions. The aluminum oxide discs and silicon-based polishers were changed after the polishing of each sample, while the diamond and carbide burs and carbide burs were changed every three samples. Subsequently, the specimens were stored in distilled water at 37°C for 24 h.

After finishing and polishing procedures the second color measurements of the specimens were made. The quantitative ΔE values between the first and second measurements of the specimens were calculated with the following formula [15, 22]:

$$\Delta E = [(L^*_S - L^*_F)^2 + (a^*_S - a^*_F)^2 + (b^*_S - b^*_F)^2]^{½}$$

where $(L^*_F - L^*_S)$, $(a^*_F - a^*_S)$, and $(b^*_S - b^*_F)$ are the differences in ΔL*, Δa*,Δb* values, respectively. F represents the first measurement and S represents the second measurement. The ΔE values were

analyzed statistically by 2-way analysis of variance (ANOVA) with the Tukey multiple comparison tests ($\alpha = 0.05$).

After colorimetric evaluation, the second Ra values were obtained with the same procedures as previously stated. The Ra mean difference (ΔRa) for each specimen was obtained by subtracting the mean first readings from the mean second readings. Therefore, a positive mean difference in ΔRa obtained would represent an increase in smoothness and the larger the value, the greater the smoothness. The data was analyzed by 2-way ANOVA followed by a Tukey multiple comparison test ($\alpha = 0.05$).

To evaluate the effect of polishing and finishing techniques on the composite resin surfaces at a microscopic level, an additional 5 specimens were prepared using Aelite Enamel composite resin since this composite resin showed the higher different values among the subgroups in terms of the polishing and finishing techniques. One of the specimens served as control and had no treatment. The surfaces of the 4 specimens were roughened with a medium-grit diamond rotary cutting instrument and polished with 1 of the 4 polishing and finishing techniques as previously described. Subsequently, these specimens were gold sputtered with a sputter coater (S150B; Edwards, Crawley, England) and examined under a field emission scanning electron microscope (SEM) (JSM-6335F; JEOL, Tokyo, Japan) at 15.0 kV. The SEM photomicrographs were made with ×500 magnification for visual inspection.

Results

The result of the 2-way ANOVA used to test the surface roughness of the composite resins showed that the type of composite resin, polishing techniques, and their interactions were statistically significant ($p < 0.001$) (Table 3). The mean values and standard deviations for surface roughness of composites finished and polished by different methods are summarized in Table 4.

When the Ra values of the groups compared according to the composite resin, it was seen that significant differences were found between the composite resins ($p < 0.001$). The significance was found between the nanohybrid and the nanofilled composite resins.

When the finishing and polishing techniques were compared, there were no significant differences between the Groups Ct, C, A ($p > 0.05$). The highest Ra values were obtained with the use of diamond burs ($p < 0.001$). The control groups for each composite resin showed lower Ra values than the experimental groups and there were no significant differences between the control groups ($p > 0.05$).

The color change results showed that while the polishing techniques affected the color change

Table 3. Two-way ANOVA results for comparison of surface roughness

Source of variation	Sum of squares	df	Mean square	F ratio	Sig.
Composite resin	1.361	5	0.272	16.582	0.0002
Polishing technique	17.579	3	5.860	357.091	0.0001
Composite resin × polishing technique	0.206	15	0.014	0.837	0.636
Error	2.757	168	0.016		
Total	73.716	192			

Table 4. The mean surface roughness values and standard deviations of the groups

	c	d	a	s
G	0.400 ± 0.07 a	1.120 ± 0.25 b	0.375 ± 0.15 a	0.406± 0.11 a
I	0.481 ± 0.14 a	1.045 ± 0.06 b	0.344 ± 0.16 a	0.504 ± 0.16 a
S	0.465 ± 0.10 a	1.153 ± 0.15 b	0.320 ± 0.06 a	0.598 ± 0.06 a
A	0.279 ± 0.06 a	0.960 ± 0.18 b	0.156 ± 0.06 a	0.314 ± 0.09 a
P	0.319 ± 0.15 a	1.009 ± 0.18 b	0.188 ± 0.08 a	0.341 ± 0.09 a
F	0.284 ± 0.14 a	0.923 ± 0.13 b	0.181 ± 0.04 a	0.305 ± 0.10 a

Groups with same letter are not significantly different ($p > 0.05$).

Table 5. Two-way ANOVA results for comparison of color difference

Source of variation	Sum of squares	df	Mean square	F ratio	Sig.
Composite resin	0.032	5	0.006	0.349	0.882
Polishing technique	14.452	3	4.817	264.617	0.0002
Composite resin × polishing technique	0.432	15	0.029	1.582	0.083
Error	3.058	168	0.018		
Total	696.280	192			

Table 6. The mean ΔE values and standard deviations of the groups

	c	d	a	s
G	1.855 ± 0.07 a	2.313 ± 0.23 b	1.641 ± 0.05 a	1.711 ± 0.21 a
I	1.765 ± 0.08 a	2.329 ± 0.18 b	1.676 ± 0.07 a	1.754 ± 0.21 a
S	1.836 ± 0.06 a	2.470 ± 0.08 b	1.616 ± 0.09 a	1.684 ± 0.11 a
A	1.758 ± 0.06 a	2.408 ± 0.18 b	1.605 ± 0.06 a	1.744 ± 0.20 a
P	1.733 ± 0.07 a	2.279 ± 0.13 b	1.678 ± 0.09 a	1.829 ± 0.20 a
F	1.784 ± 0.09 a	2.276 ± 0.13 b	1.628 ± 0.83 a	1.741 ± 0.18 a

Groups with same letter are not significantly different ($p > 0.05$).

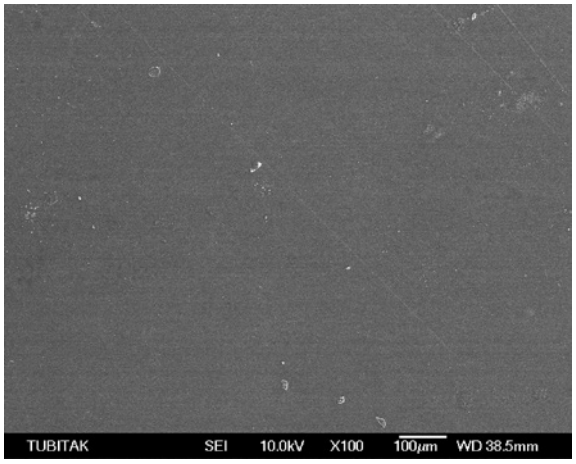

Fig. 1a. SEM micrographs of control specimen (no treatment). Original magnification ×100

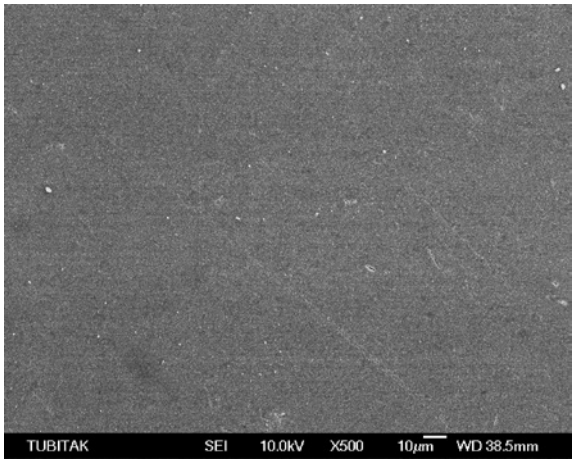

Fig. 1b. SEM micrographs of control specimen (no treatment). Original magnification ×500

($p < 0.001$), the type of the composite resin did not effect on the color change of the specimens ($p > 0.05$). The results of the statistical analysis are presented in Table 5 and the mean ΔE values are presented in Table 6. Diamond burs showed the highest ΔE values.

When the SEM photomicrographs were examined, it was seen that the smoothest surface was obtained with control specimen that had no surface treatment (Fig. 1a, 1b). The experimental specimens showed rougher surfaces when compared with the control (Fig. 2–5). Diamond burs created the roughest surface among the finishing and polishing techniques (Fig. 3a, 3b).

Discussion

The hypothesis of this study was that the different polishing and finishing techniques and the type of the nanocomposite resin affect the surface roughness. The results of this study support the research hypothesis. Significant differences were found in Ra values among the groups ($p < 0.001$). Surface roughness of the restorations is an important factor for bacterial adhesion. It was reported that a further reduction in Ra below a threshold level of 0.2 µm had no effect on supra and subgingival microbiological adhesion or colonization [23]. The composite materials tested in the

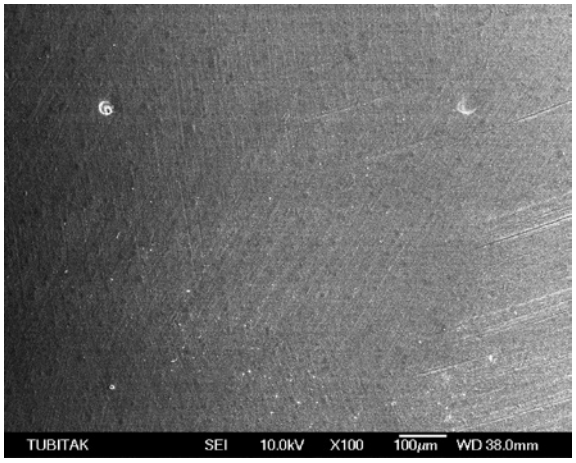

Fig. 2a. SEM micrographs of the specimen treated with carbide burs. Original magnification ×100

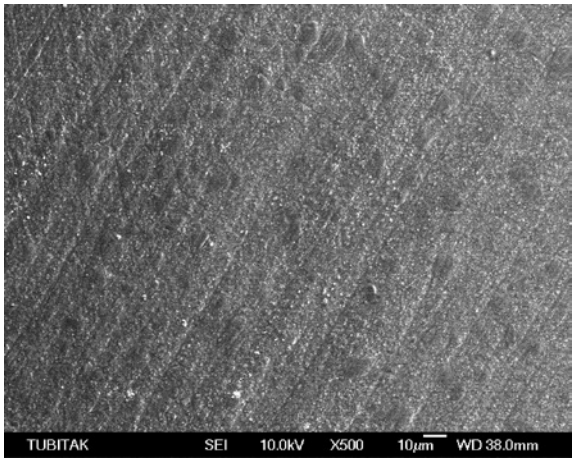

Fig. 2b. SEM micrographs of the specimen treated with carbide burs. Original magnification ×500

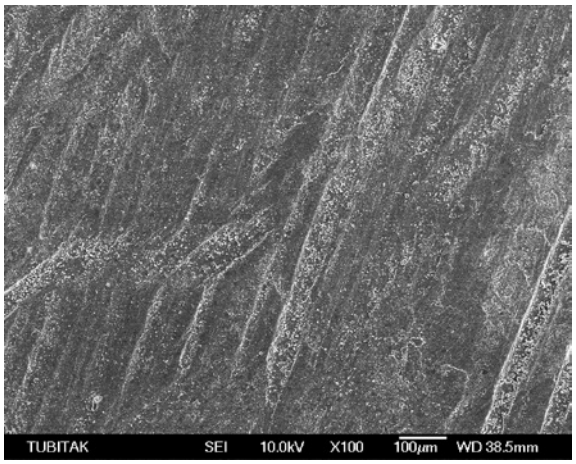

Fig. 3a. SEM micrographs of the specimen treated with diamond burs. Original magnification ×100

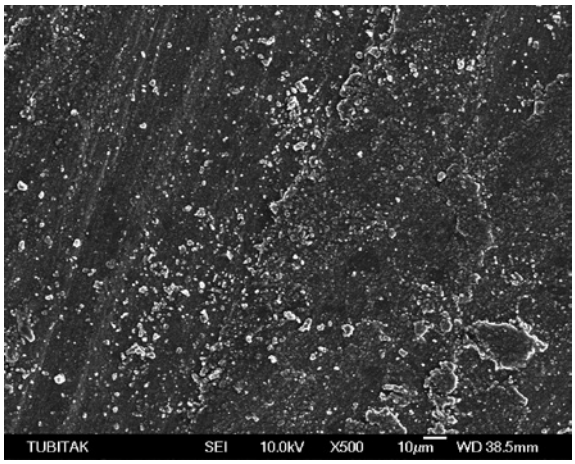

Fig. 3b. SEM micrographs of the specimen treated with diamond burs. Original magnification ×500

present study produced Ra values below or near to 0.2 μm before and after finishing and polishing techniques, except the use of diamond burs.

Previous studies have shown that the smoothest obtainable surface of composite resin restorations is achieved by polymerizing the material in direct contact with a smooth polyester matrix surface [1, 29, 32, 45]. In the present study, the Ra values of the control specimens for all composite resins which were polymerized in direct contact with polyester matrix surface were found to be lower than the other groups polished with different polishing techniques. Although the control groups for each restorative material has the lowest Ra values, the surfaces produced were not perfect (Ra value = 0). This was because the surfaces produced were only as good as the matrix strip itself any surface imperfections present in the matrix will be reproduced in the surface of the specimens [5]. In this present study, as well as in others [17, 28, 44], mylar matrix strip formed the smoothest surface. Nevertheless, resin-rich surface layer needs to be eliminated; thus, finishing is indispensable [16].

For recountouring restorations or removing excess material some abrasive instruments such as flexible discs, finishing burs and etc. are used. Ryba et al. [34] noted that aluminum oxide discs provided a smoother surface than rubber polishers. Numerous studies indicate that flexible aluminum oxide discs produce smoother surfaces than diamond finishing burs, tungsten carbide burs, mounted stones and rubber points when used with polishing pastes [16, 44].

In the present study, aluminum oxide discs created smoother surfaces than the other finishing and polishing techniques. In a similar study it was reported that after polyester matrix group, the lowest Ra values were obtained with the aluminum oxide abrasive disc group and the highest Ra values were obtained with the use of polishing wheels [32]. To be an effective composite finishing system, the cutting particles (abrasive) must be relatively

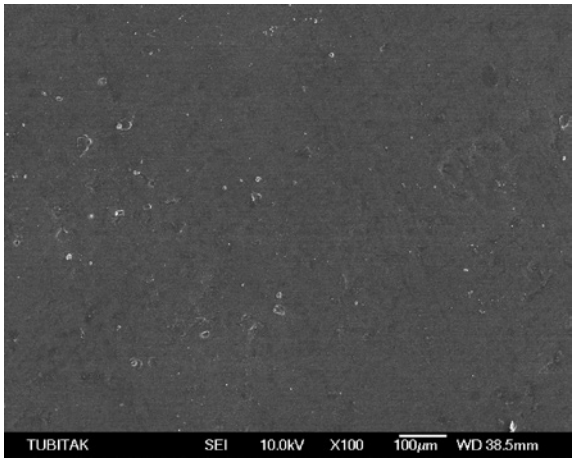

Fig. 4a. SEM micrographs of the specimen treated with aluminum oxide abrasive discs. Original magnification ×100

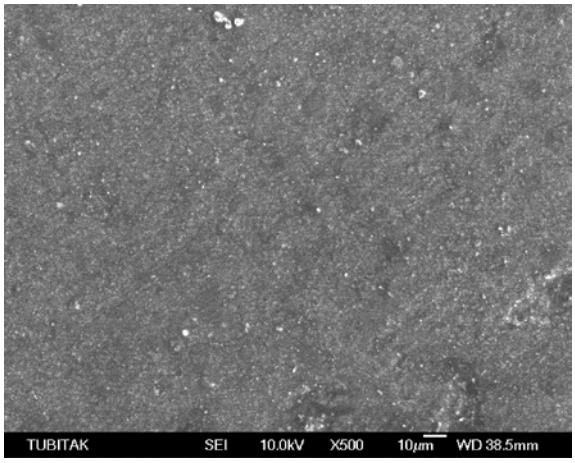

Fig. 4b. SEM micrographs of the specimen treated with aluminum oxide abrasive discs. Original magnification ×500

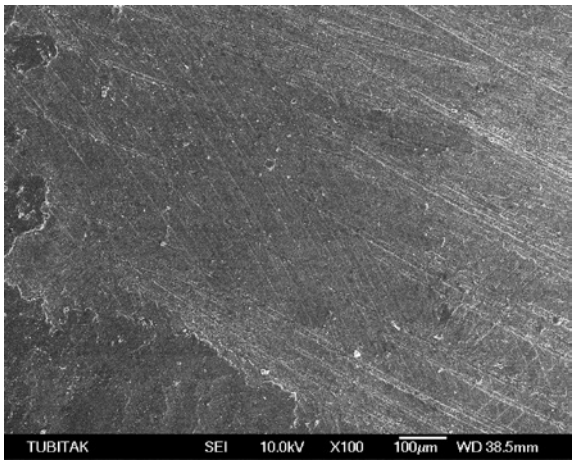

Fig. 5a. SEM micrographs of the specimen treated with polishers. Original magnification ×100

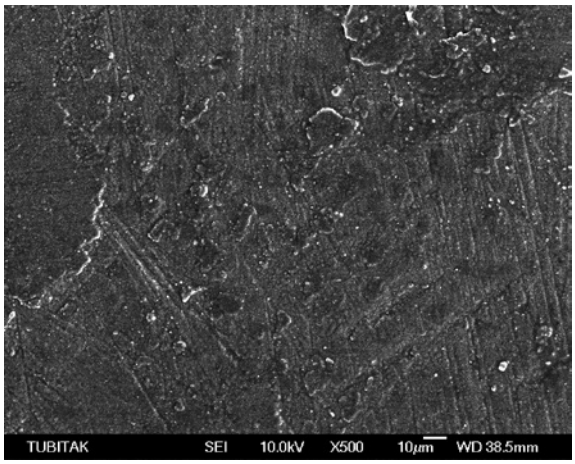

Fig. 5b. SEM micrographs of the specimen treated with polishers. Original magnification ×500

harder than the filler materials [3]. Otherwise, the polishing agent will only remove the soft resin matrix and leave the filler particle protruding from the surface [7]. According to Weinstein, by systematically decreasing the particle size of the abrasive, a superior surface can be achieved. The grit in the polishing material should be smaller than the particle size of the restorative material that is being polished in order to produce better results [41].

An earlier study showed that aluminum oxide disc's capability of producing smooth surfaces was related to their ability to cut the filler particle and matrix equally [39]. According to Tate and Powers, the aluminum-oxide discs appear to finish the materials without dislodging the glass particles [38]. The aluminum oxide discs have been shown to produce better surface smoothness because they do not displace the composite fillers [6, 26].

In the present study, diamond and carbide burs showed higher Ra values than the other groups. These instruments are necessary for contouring anatomically structured and concave surfaces such as the lingual surface of anterior teeth or the occlusal surfaces of posterior teeth [6, 26]. Jung suggested that finishing diamonds were best suited for gross removal and contouring because of their high cutting efficiency of composite surface, while carbide finishing burs would be best suited for smoothing and finishing as a result of their low cutting efficiency. With hybrid composites, finishing diamonds have been shown to produce rough surfaces compared with those produced by carbide burs [21]. Another study also found that finishing diamonds were more efficient in removing material from the composite surface, although they tended to leave a more irregular surface when compared with a finishing carbide bur [13]. Moreover, studies have reported that using finishing burs alone provided a rough composite surface [8] and the literature [12] shows that diamond burs are responsible for the highest surface roughness. Although

diamond burs allow the elimination of material excesses especially in regions with difficult access, they produce a relatively rough surface [12]. According to the authors, if diamond burs are used, the material surface roughness should be reduced or eliminated. In the present study, the diamond bur groups showed the highest surface roughness and this situation was confirmed by SEM photomicrographs (Fig. 1–5).

The use of tungsten carbide finishing burs created smoother surfaces and showed the lower Ra values than diamond burs in the study. This result showed that they are not effective to produce smooth surface for resin restorations. Tungsten carbide finishing burs are only recommended for trimming restorations that require only little or no excess removal and contouring, because they are ineffective when a high cutting efficiency is required [21].

Polishability of a resin composite is affected by the filler particle size. Generally, the smaller the average particle size, the easier it will be to polish the resin. The filler content of the composite also affects its roughness, as microfilled composites show smoother surfaces than hybrid composites [33]. In the present study, the composite resins showed significantly different surface roughness, especially nanofilled composite resins showed smoother surfaces than nanohybrid composite resins. As it was stated before nanofilled composite resins contain fillers with size ranging from around 5–100 nm, and the particle size are similar [4, 40]. However, nanohybrid composite resins contain fillers with different particle size, but the majority of the fillers are nanoparticles. For this reason nanofilled composite resin groups showed smoother surfaces than nanohybrid composite resin groups.

When the results were investigated in terms of color difference, it was seen that no statistically differences were between the composite resin materials. The use of a diamond bur showed statistically higher ΔE values ($p < 0.001$) and no differences were found between the other groups. This effect is thought to be related to the surface morphology. Optical properties of dental composite resins are directly affected by surface roughness [15]. As it was stated previously diamond bur groups also showed higher Ra values. An increasingly roughened surface will reflect the individual segment of the specular beam at slightly different angles [15]. If the surface configuration has a matte finish, there would be an excessive amount of light reflected at a surface level and a reduction of light transmission through the material. Surface texture controls the degree of scattering or reflection of the light striking on the natural tooth or the material [15]. The color differences among 4 composite resin materials and 4 polishing methods tested were found between 1.6 and 2.47 in this study. Although polishing methods reveal statistically significant color differences, these differences are within a clinically acceptable level, as they are below 3.7 ΔE value.

In this study a limited number of nano-composite resins and polishing techniques were used and these are the limitations of this *in vitro* study.

Within the limitations of this study the following conclusions were drawn;

1. The smoothest surfaces were obtained with control groups which were polymerized in direct contact with polyester matrix.
2. Diamond burs showed the highest surface roughness with all composite resin materials.
3. Nanofilled composite resin materials showed smoother surface than nanohybrid composite resin materials.
4. While the color difference was not affected by the type of the composite resin, surface treatments increased the color differences.

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Address for correspondence:

Emir Yuzbasioglu
Department of Prosthodontics
Istanbul Medipol University School of Dentistry
Ataturk Bulvari No. 27
Unkapani-Fatih
34083 Istanbul
Turkey
E-mail: eyuzbasioglu@medipol.edu.tr

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