Dental Materials Journal 2016; 35(2): 278–289

Evaluation of the surface hardness, roughness, gloss and color of composites after different finishing/polishing treatments and thermocycling using a multitechnique approach

Kanşad PALA[1], Neslihan TEKÇE[2], Safa TUNCER[3], Merve Efe SERİM[2] and Mustafa DEMİRCİ[3]

[1] *Department of Restorative Dentistry, Faculty of Dentistry, Erciyes University, Kayseri, Turkey*
[2] *Department of Restorative Dentistry, Faculty of Dentistry, Kocaeli University, Kocaeli, Turkey*
[3] *Department of Restorative Dentistry, Faculty of Dentistry, Istanbul University, Istanbul, Turkey*
Corresponding author, NeslihanTEKÇE; E-mail: neslihan_arslann@hotmail.com

The objectives of this study were to evaluate the mechanical and physical properties of resin composites. The materials evaluated were the Clearfil Majesty Posterior, Filtek Z550 and G-aenial Posterior composites. A total of 189 specimens were fabricated for microhardness, roughness, gloss and color tests. The specimens were divided into three finishing and polishing systems: Enhance, OneGloss and Sof-Lex Spiral. Microhardness, roughness, gloss and color were measured after 24 h and after 10,000 thermocycles. Two samples from each group were evaluated using SEM and AFM. G-aenial Posterior exhibited the lowest microhardness values. The mean roughness ranged from 0.37 to 0.61 µm. The smoothest surfaces were obtained with Sof-Lex Spiral for each material. G-aenial Posterior with Enhance was determined to be the glossiest surfaces. All of the materials exhibited similar ΔE values ranging between 1.69 and 2.75. Sof-Lex Spiral discs could be used successfully to polish composites.

Keywords: AFM, SEM, Microhardness, Roughness, Color stability, Gloss

INTRODUCTION

Extensive efforts have been made to develop the esthetic and mechanical properties of dental restorative materials. To obtain the ideal esthetics, any restorative material must simulate the natural tooth in color and surface texture and must exhibit stability over time. Finishing and polishing procedures directly influence the esthetics and longevity of restorations, regardless of cavity type and location[1-3]. Thus, finishing and polishing dental instruments are indispensable for improving restoration margins, producing appropriate contours and obtaining a glossy and perfectly smooth surface[4,5]. Various finishing and polishing techniques have been examined with different types of composite resins in an attempt to produce a smooth surface. Instrument selection depends on the nature of the restorative material and on the location and size of a given restoration[6]. Carbide burs, diamond burs, abrasive-impregnated rubber cups and points, abrasive strips, stones, polishing pastes and abrasive discs could be used for this purpose[3,6,7].

A rough surface or a sub-optimally finished/polished restoration has a major influence on staining, plaque retention, secondary caries, gingival inflammation and restoration gloss reduction[3,8,9]. Gloss is the ability of the surface to reflect light. In general, high surface gloss is associated with a smooth surface of a restoration. Reductions in gloss and smoothness could potentially lead to discoloration of the material[8]. Surface hardness is a mechanical property of the material which is important for maintaining the form stability of restorations[10]. Some characteristics of filler particles impact surface smoothness, gloss, hardness and susceptibility to staining[11]. Thus, the content of composites and the finishing/polishing system used both directly influence surface properties, such as gloss and roughness, and mechanical features, such as hardness and resistance against chemical degradation.

Composites consist of hard inorganic particles dispersed in a soft organic resin matrix. The properties of composites are greatly influenced not only by the properties of their fillers but also by the chemical structure of the monomers[12,13]. Due to the major influence of fillers on the physical properties of a composite, the classification of dental composites is based on the type and the particle size of fillers. Currently, three main categories have been proposed for widely used resin composites: microfilled, microhybrid, and nanocomposites (*i.e.*, nanofill or nanohybrid resin composites[14,15]. Microfilled composites exhibit good surface properties and superior aesthetic qualities; however, these composites have poor mechanical properties. Microhybrid composites are used most widely, as these composites provide optimal mechanical and physical properties and good polishing properties[15]. Dental nanocomposites are claimed to combine the good mechanical strength of hybrids[16,17] and the superior polishing properties of microfills[4]. Nanohybrid composites are hybrid resin composites that contain a glass filler and a nanofiller in a prepolymerized filler form (40–50 nm).

The surface roughness of composite resin restorations can be analyzed using scanning electron

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Aug 3, 2015: Accepted Nov 5, 2015
doi:10.4012/dmj.2015-260 JOI JST.JSTAGE/dmj/2015-260

microcopy (SEM) and atomic force microscopy (AFM). AFM is capable of providing detailed three-dimensional topographical images of surface roughness on the nanometer scale. This approach allows the determination of the surface roughness with high accuracy[18]. Thus, these features make AFM a promising technique for evaluating the surface quality of dental materials[19,20].

In the oral cavity, saliva, food components, and beverages, as well as interactions among these materials, can degrade and age dental restorations[21]. Cyclical thermal stresses, together with the presence of water and other fluids, may degrade the filler matrix interfaces[22,23]. Although several studies[1,2,4,5,7,18] have investigated the effects of polishing systems on the microhardness, roughness, gloss and color of composite restorations, the effect of thermocycling on these features of resin composites has not been investigated. The objectives of this study were to evaluate the effect of different polishing systems on the microhardness, roughness, gloss and color of resin composite restorations in the presence and absence of thermocycling. The following null hypotheses were tested: (1) the use of different polishing and polishing systems does not affect the microhardness, roughness, gloss and color of composite restorations and (2) thermocycling does not influence the microhardness, roughness, gloss and color of resin composites.

MATERIALS AND METHODS

The composites used in this study, including two posterior [Clearfil Majesty Posterior (Kuraray Medical, Tokyo, Japan) and G-aenial Posterior (GC, Dental Products, Alsip, IL, USA)] and one universal (Filtek Z550, 3M ESPE, St. Paul, MN, USA) dental resin composite with shade A2, and the three finishing and polishing (F/P) systems Enhance (Dentsply Caulk, Milford, DE, USA) (G1), OneGloss (Shofu Dental Corporation, San Marcos, CA USA) (G2) and Sof-Lex Spiral (3M ESPE) (G3) used in this study are described in Tables 1 and 2.

Sixty-three specimens of each resin composite were prepared for each F/P system group. Thus, a total of 189 discs were used for the three F/P system groups for each composite. Sixty three specimens were used for Vickers hardness measurement, 63 specimens were used to evaluate surface roughness and color, and 63 specimens were used for gloss measurement. In addition to these specimens, 18 specimens were prepared for SEM evaluation.

The specimens were fabricated using a cylindrical stainless steel mold (8.0 mm diameter ×2.0 mm height for hardness, surface roughness and color test and 15 mm diameter ×1.0 mm height for gloss measurements). After each composite was placed, the mold was compressed between two glass microscope slides using finger pressure to remove excess material and to obtain a flat surface. All of the samples were polymerized for 40 s through the glass slide and polyester matrix using an LED light unit (Elipar S10, 3M ESPE) calibrated at 1,200 mW/cm^2. The light intensity of the curing light was evaluated during specimen preparation using a radiometer (Hilux Curing Light Meter, Benlioglu Dental, Ankara, Turkey). The composite specimens were removed from the molds after they were light-cured. Afterwards, all specimens were stored in distilled water at 37ºC for 24 h prior to testing. The top surfaces of the specimens were ground with 600 grit silicon carbide (SiC) paper for 20 s under stream water. The specimen preparation, finishing, and polishing procedures were carried out by the same operator (M.E.S). The finishing and polishing procedures were performed using three F/P systems. New discs, polishing cups and points were used to polish each specimen. The three F/P systems used are described below.

Table 1 Properties of the resin composite materials used in the present study

Dental resin composite	Manufacturer (Batch number)	Organic matrix	Filler type	% Filler Wt/Vol
Majesty Posterior Nanohybrid	Kuraray Medical, Tokyo, Japan (00119B)	Bis-GMA, TEGDMA, hydrophobic aromatic dimethacrylate	Glass ceramics, surface-treated alumina microfiller, silica	92/82
Filtek Z550 Nanohybrid	3M ESPE, St. Paul, MN, USA (N327148)	Bis-GMA, UDMA, Bis-EMA, PEGDMA and TEGDMA	Surface-modified zirconia/silica with a median particle size of approximately 3 microns or less. Non-agglomerated/non-aggregated 20 nanometer surface-modified silica particles	82/68
G-aenial Posterior Microhybrid	GC, Dental Products, Alsip, IL, USA (140208B)	UDMA and dimethacrylate co-monomer.	Pre-polymerized fillers (16–17 µm). Silica, strontium and lanthanide fluoride. Silica and fluoroaluminosilicate>100 nm, fumed silica<100 nm	76/62

Bis-GMA: Bisphenol A-glycidyl methacrylate, Bis-EMA: ethoxylated bisphenol-A dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate, UEDMA: Urethane dimethacrylate

Table 2 Composition of the polishing system

Finishing Polishing System	Composition	Application method
Enhance (Rubber Point) Dentsply Caulk, Milford, DE, USA	Aluminum oxide-silicone dioxide finishing points, cups impregnated with UDMA (40 µm) Prisma gloss polishing paste fine (1 µm) and x-fine (0.3 µm)	Step 1: Enhance Finishing Points (composed of 40 µm aluminum oxide particles) were applied to the resin composite surfaces without water spray and with light intermittent pressure for 20 s with a hand piece speed of 10,000 rpm, rinsed and dried for 10 s. Step 2: Prisma Gloss Composite Polishing Paste (1 µm aluminum oxide) was applied with a light circular buffing action for 20 s with a hand piece speed of 10,000 rpm and then rinsed for 10 s. Step 3: Prisma Gloss Extra Fine Composite Polishing Paste (0.3 µm aluminum oxide) was applied with a light circular buffing action for 20 s with a hand piece speed of 10,000 rpm and then rinsed for 10 s.
OneGloss PS (Silicon Point) Shofu Dental Corporation, San Marcos, CA USA	Aluminum oxide one-step finisher and polisher are mounted on sturdy plastic mandrels	OneGloss points were applied with light pressure on the discs for 20 s with a hand piece speed of 10,000 rpm. The surfaces were then rinsed for 10 s.
Sof-lex Spiral (Aluminum-impregnated discs) 3M ESPE, St. Paul, MN, USA	Elastomer impregnated with aluminum oxide particles (25–29 µm)	Firstly, Sof-Lex medium discs were applied the surfaces of specimens. Step 1: A beige Sof-Lex Spiral Finishing Wheel was applied under dry conditions with light pressure for 20 s with a hand piece speed of 10,000 rpm. The surfaces were then rinsed for 10 s. Step 2: A white Sof-Lex Spiral Polishing Wheel was applied under dry conditions with light pressure for 20 s with a hand piece speed of 10,000 rpm. The surfaces were then rinsed for 10 s.

Microhardness measurements

For the microhardness tests, 7 disc-shaped specimens (n=7) were used for each resin and F/P system, with a total of 21 disc-shaped specimens for the three F/P groups. The Vickers hardness number (VHN) was determined before the thermocycling process using a Struers Duramin-5 microhardness tester (Struers, Tokyo, Japan). Three indentations were made on the surface under a 200 g load with a 15 s dwell time. The average hardness value for each specimen was then calculated. Next, the measured specimens were immersed in a water bath and repeatedly thermocycled between 5 and 55°C with a dwell time of 30 s in each bath. The same measurements were performed after 10,000 cycles. Each measurement was performed near the previously measured position to maintain consistency.

Surface roughness and color

For the surface roughness and color, 7 disc-shaped specimens (n=7) were used for each resin and F/P system, with a total of 21 disc-shaped specimens for the three F/P groups. The surface roughness and color were made before (baseline) and after thermocycling.

Surface roughness measurements

The assessed surface properties included the average roughness (R_a, in µm), which was measured using a two-dimensional profilometer (Surtronic 3^+, Taylor Hobson, Leicester, UK). A 5 µm diamond stylus and a stylus angle of 90° traversed a length of 1.25 mm with a cut-off length of 0.25 mm. Five measurements were performed in the center of each sample in different directions.

Color measurements

After profilometric examination, spectrophotometric analysis was performed. Before each measurement, the specimens were cleaned in distilled water for 1 min and dried under airflow. All values were recorded in the Commission Internationale de l'Eclairage (CIE) CIELAB color system relative to CIE standard illuminant A (incandescent light) using a VITA Easyshade Compact (Model DEASYCHP, VITA Zahnfabrik, Bad Sackingen, Germany). Before measuring the color of the specimens, the Vita Easyshade was calibrated using its calibration block according to the manufacturer's instructions. The probe tip was placed perpendicular and flush to the surfaces of the specimens to obtain accurate measurements. Measurements were performed at the centers of the resin composite discs and repeated three times. The CIELAB system is an approximately uniform color space with coordinates for lightness: white/black (L^*), red/green (a^*), and yellow/blue (b^*). The mean of the obtained values was calculated, and the L^*, a^*, and b^* parameters were determined. All measurements were made on a white Plexiglass background to eliminate background light.

Color changes (ΔE^*) after thermocycling were calculated as $\Delta E^*=[(\Delta L^*)+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$. Changes in CIE L^*, a^*, and b^* values (ΔL^*, Δa^*, Δb^*) during thermocycling were calculated as 'the value after thermocycling —the value before thermocycling'.

Gloss measurements

Gloss measurements, which are expressed in gloss units (GU), were also performed using a glossmeter (Elcometer 407 Statistical glossmeter, Manchester, UK) with a square measurement area of 15×10 mm and a 60º geometry to determine the baseline gloss of the samples. The instrument measures the intensity of a reflected light beam after striking the surface and compares the measured value to a reference value. An opaque black plastic mold was placed over the specimen during measurement to eliminate the influence of ambient light and maintain the exact position of the sample for repeated measurements. Three measurements were performed for each specimen.

Scanning electron (SEM) and atomic force (AFM) microscopy evaluation

For each composite and F/P system, scanning electron microscope (SEM) and atomic force microscope (AFM) images were obtained before and after 10,000 thermocycles.

Two specimens from each group of polished composites were analyzed qualitatively using SEM (JEOL JCM-5000 NeoScope™, JEOL, Tokyo, Japan) after sputter coating with gold (Emitech K-550X sputter coater, Emitech, Ashford, UK).

In addition, two specimens were observed using a commercial AFM (Veeco Metrology Group, Santa Barbara, CA, USA), using the contact mode. Cantilevers with a constant spring of 0.1 N/m and OTR 8-35 type Nanoprobe SPM Tips were used. Deflection and height-mode images were obtained simultaneously, with a resolution of 512×512 pixels. Images were acquired with a size of 30×30 μm and analyzed using specific software (Nanoscope v616r1, Veeco Metrology and WS×M 4.0 Develop 11.1, Nanotec Electronica, Trea Cantas, Spain).

Statistical analysis

All statistical analyses were performed using IBM SPSS for Windows version 20.0 (SPSS, Chicago, IL, USA). The distribution of the data was first checked for normality using the Kolmogorov-Smirnov test. The data were then subjected to three-way analysis of variance (ANOVA) to evaluate the effect of independent variables on surface microhardness and surface roughness and gloss; the evaluated factors were the composite, the F/P system and thermocycling. A two-way variance analysis test was performed to identify statistically significant differences in color stability among the composites and F/P groups.

When a difference was statistically significant ($p<0.05$), *post-hoc* pair-wise multiple comparisons with Bonferroni's correction were performed with the probability level set to $\alpha=0.05$ to determine statistical significance. Correlations between gloss and roughness were calculated using a Pearson correlation analysis. Normally distributed continuous variables were expressed as mean±standard deviation. p Value <0.05 was considered statistically significant.

RESULTS

Surface microhardness results

The mean VHN values and standard deviations for the resin composites tested under the experimental conditions used in this study are shown in Table 3. According to the ANOVA test, all of the analyzed factors (*i.e.*, resin composite, F/P group, and thermocycling process) had a statistically significant influence on the

Table 3 Microhardness values (VHN, kg/mm^2) (mean±SD) of the tested materials

Resin Composite	Group 1 (Enhance)			Group 2 (OneGloss)			Group 3 (Sof-Lex Spiral)		
	Baseline	After TC	p	Baseline	After TC	p	Baseline	After TC	p
Majesty Posterior	123.06±7.12 Aa	105.58±6.04 A^1	<0.05	109.80±8.68 Aab	102.72±7.75 A^1	>0.05	106.73±14.14 Ab	98.68±13.75 A^1	>0.05
Z550	115.10±9.07 Aa	103.84±15.51 A^1	>0.05	122.45±23.7 Aa	111.34±24.56 A^1	>0.05	108.81±5.42 A a	99.68±6.54 A^1	<0.05
G-aenial Posterior	83.76±11.92 Ba	77.73±9.46 B^1	>0.05	71.62±4.24 Bab	64.78±5.59 B^2	<0.05	67.12±10.72 Bb	62.06±8.84 B^2	>0.05

p^* represent statistically significant differences in each group between the baseline and thermocycled specimens (TC) of the same composite.

Means followed by distinct capital letters represent statistically significant differences in each column ($p<0.05$).

Means followed by distinct lower case letters (comparisons of baseline values between the groups) represent statistically significant differences in each row ($p<0.05$).

Means followed by distinct superscript numbers (comparisons of thermocycled specimen values between the groups) represent statistically significant differences in each row ($p<0.05$).

TC=thermocycled specimens.

resin composite hardness (p<0.001).

In all F/P groups, the G-aenial Posterior exhibited the lowest (p<0.05) VHN values when compared with the other tested composites. Pair-wise multiple comparisons with the Bonferroni test revealed no significant differences between Majesty Posterior and Z550 at baseline and after thermocycling in any group (p>0.05).

The Enhance-applied Majesty Posterior and G-aenial Posterior exhibited significantly higher microhardness values than their Sof-Lex Spiral-applied counterparts. For the Z550, no significant differences were observed between the F/P groups at baseline or after thermocycling (p>0.05). After thermocycling, G1 exhibited significantly higher hardness values than G2 and G3 for G-aenial Posterior (p<0.05).

Surface roughness results

The mean Ra values for the resin composites tested after different F/P systems are displayed in Table 4. The lowest surface roughness results were observed in G3 for all resin composites; however, no significant differences were observed between the composites in any of the F/P groups at baseline or after thermocycling (p>0.05). Among the F/P groups, a significant difference was only observed between Enhance and Sof-Lex Spiral for Z550. In addition, thermocycling did not significantly affect the surface roughness of the resin composites.

Gloss results

The mean gloss values (GU) and standard deviations for the resin composites tested under the experimental conditions used in this study are shown in Table 5. According to the three-way ANOVA test, all of the analyzed factors (*i.e.*, resin composite, F/P group, and

Table 4 Surface roughness values (Ra, μm) (mean±SD) of the tested materials

Resin Composite	Group 1 (Enhance)			Group 2 (OneGloss)			Group 3 (Sof-Lex Spiral)		
	Baseline	After TC	p	Baseline	After TC	p	Baseline	After TC	p
Majesty Posterior	0.513±0.25 Aa	0.546±0.151 A^1	>0.05	0.394±0.084 Aa	0.500±0.132 A^1	>0.05	0.321±0.099 Aa	0.379±0.236 A^1	>0.05
Z550	0.581±0.294 Aa	0.524±0.228 A^1	>0.05	0.454±0.11 Aab	0.526±0.156 A^1	>0.05	0.304±0.084 Ab	0.427±0.098 A^1	>0.05
G-aenial Posterior	0.633±0.274 Aa	0.504±0.119 A^1	>0.05	0.550±0.153 Aa	0.611±0.275 A^1	>0.05	0.414±0.126 Aa	0.406±0.067 A^1	>0.05

TC=thermocycled specimens.
Means followed by distinct capital letters represent statistically significant differences in each column (p<0.05).
Means followed by distinct lower case letters (comparisons of baseline values between the groups) represent statistically significant differences in each row (p<0.05).
Means followed by distinct superscript numbers (comparisons of thermocycled specimen values between the groups) represent statistically significant differences in each row (p<0.05).

Table 5 Mean gloss values (GU) and (±) standard deviations with aging

Resin Composite	Group 1 (Enhance)			Group 2 (OneGloss)			Group 3 (Sof-Lex Spiral)		
	Baseline	After TC	p	Baseline	After TC	p	Baseline	After TC	p
Majesty Posterior	12.16±3.04 Aa	10.66±2.80 A^1	>0.05	4.68±0.58 Ab	4.24±0.77 A^2	>0.05	19.58±1.99 Ac	18.60±2.69 A^3	>0.05
Z550	29.52±4.51 Bab	25.46±4.24 B^{12}	>0.05	25.48±2.44 Ba	20.40±2.46 B^1	<0.05	34.24±3.20 Bb	30.30±3.34 B^2	>0.05
G-aenial Posterior	34.84±6.45 Ba	28.52±5.43 B^1	>0.05	28.04±3.29 Ba	15.56±3.34 C^2	<0.05	28.22±2.33 Ca	25.12±2.03 C^1	>0.05

TC=thermocycled specimens.
Means followed by distinct capital letters represent statistically significant differences in each column (p<0.05).
Means followed by distinct lower case letters (comparisons of baseline values between the groups) represent statistically significant differences in each row (p<0.05).
Means followed by distinct superscript numbers (comparisons of thermocycled specimen values between the groups) represent statistically significant differences in each row (p<0.05).

thermocycling process) had a statistically significant influence on the resin composite gloss ($p<0.001$).

When we compared the resin composites within the F/P groups at baseline and after thermocycling in all F/P groups, the Majesty Posterior exhibited the lowest ($p<0.05$) gloss values. In G1 and G2, no significant differences were observed between G-aenial Posterior and Z550 at baseline ($p>0.05$). However in G3, Z550 had a significantly higher gloss value than G-aenial Posterior ($p<0.05$). After thermocycling, specimens of Z550 exhibited significantly higher gloss than G-aenial Posterior in G2 and G3.

When we compared the F/P groups within the resin composites, Sof-Lex Spiral exhibited significantly higher gloss values than Enhance and OneGloss for the Majesty Posterior. For the Z550, Sof-Lex Spiral exhibited the highest gloss; however, these values were only significantly different from OneGloss ($p<0.05$). For the G-aenial Posterior, no significant differences were observed between the groups at baseline, but after thermocycling, OneGloss exhibited a significantly lower gloss value ($p<0.05$).

The gloss values of the baseline and thermocycled specimens were compared. The baseline values were higher than the values obtained for the thermocycled specimens. However, this result was only significantly different in G2 for Filtek Z550 and G-aenial Posterior ($p<0.05$).

Pearson correlation analysis revealed that there was no relationship between the mean surface roughness and surface gloss [(baseline; correlation coefficient=0,007; p=0,965) (after aging correlation coefficient =−0,183; p=0,229)].

Color results

The mean values for the color changes in the different F/P groups after thermocycling are presented in Table 6. The color changes of the resin composites were in the range of 1.28–2.75 ΔE units. The color change was influenced by the resin composite type and the F/P system ($p<0.05$). In G1, the lowest mean ΔE value was observed for Z550, and this value was significantly different from the values obtained for the Majesty Posterior and the G-aenial Posterior ($p<0.05$).

When the F/P groups were compared, Enhance, OneGloss and Sof-Lex Spiral exhibited similar color changes for the Majesty Posterior and the Z550. For the G-aenial Posterior, Sof-Lex Spiral exhibited significantly smaller color changes than those observed for Enhance and OneGloss.

SEM and AFM evaluations

SEM and AFM images for all composites and polishing groups are shown in Figs. 1–6. SEM observation revealed more prominent grooves in the composite surfaces with OneGloss specimens (Fig. 3C–D, Fig. 6C–D). In general, SEM revealed scratches and shallow pits on the surfaces of all of the composites. However, the most evident scratches were observed on Enhance applied composites (Fig.1C–D–Fig.5C–D). The smoothest surfaces were primarily observed with Sof-Lex Spiral (Fig. 2C–D, Fig. 4C–D). In addition, surface irregularity increased after thermocycling, and this effect was evident for OneGloss applied composites (Fig. 3C–D, and Fig. 6C–D). Deeper and more frequent scratch lines were evident for the G-aenial Posterior with Enhance (Fig. 5C–D), the G-aenial Posterior with OneGloss (Fig. 6C–D) and the Z550 with OneGloss (Fig. 3C–D), whereas some scratches were observed for the Z550 with the Sof-Lex Spiral system (Fig. 4C–D). In addition, a high density of pitting with some filler debonding was observed for the Majesty Posterior with Enhance (Fig. 1C–D) and for the Z550 with the OneGloss systems (Fig. 3C–D).

The Enhance and OneGloss caused deep pits with some filler debonding and a more undulating surfaces (Figs. 1, 3, 5 and 6). On the other hand, the Sof-Lex Spiral created slight uniform irregularities for the composites (Figs. 2 and 4). When the AFM images were compared at baseline and after thermocycling, changes in the surface morphology were observed in all groups. According to the AFM images, the grooves and valleys that were observed after thermocycling turned into a thorn formation as a result of the destructive influence of thermocycling; these formations were spread throughout the entire surface (Figs. 1–6A–B).

Table 6 Color change values (ΔE) (mean±SD) of the tested materials after thermocycling

Resin Composite	Group 1 (Enhance)	Group 2 (OneGloss)	Group 3 (Sof-Lex Spiral)
Majesty Posterior	2.75±0.73 Aa	2.15±0.82 Aa	2.44±0.61 Aa
Z550	1.28±0.57 Ba	1.90±0.88 Aa	2.25±0.71 Aa
G-aenial Posterior	2.75±0.48 Aa	1.94±0.66 Aa	1.69±0.28 Ab

Means followed by distinct capital letters represent statistically significant differences in each column ($p<0.05$), and means followed by distinct lower case letters represent statistically significant differences in each row ($p<0.05$).

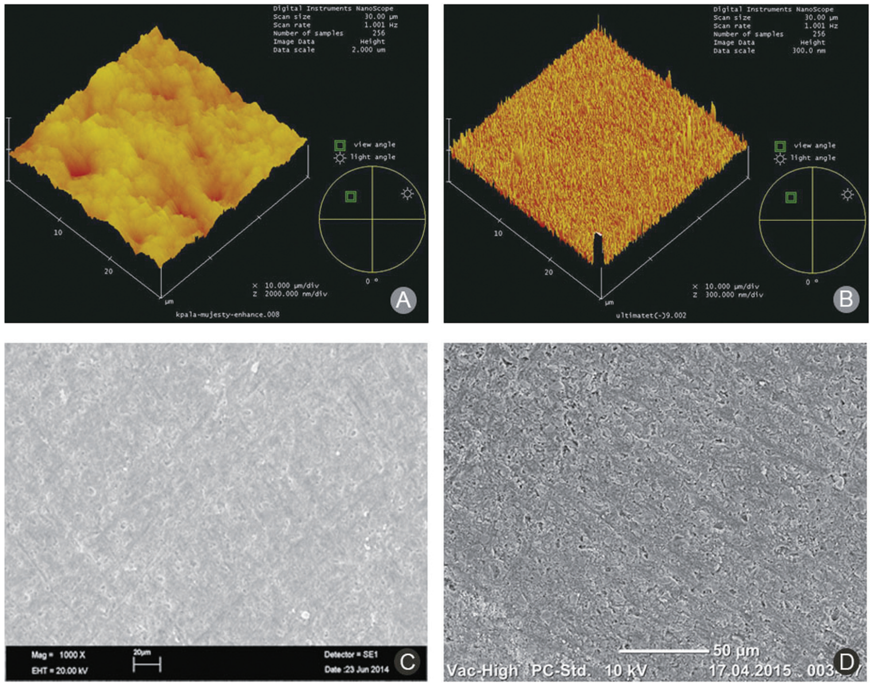

Fig. 1 A and B: AFM images of the Majesty Posterior surface with the Enhance F/P system (A: before thermocycling, B: after thermocycling). This material was characterized by deep pits and a more undulating surface.
C and D: SEM images of the Majesty Posterior surface with the Enhance F/P system (A: before thermocycling, B: after thermocycling). This material was characterized by deep pits and a more undulating surface. Rare superficial scratches were seen.

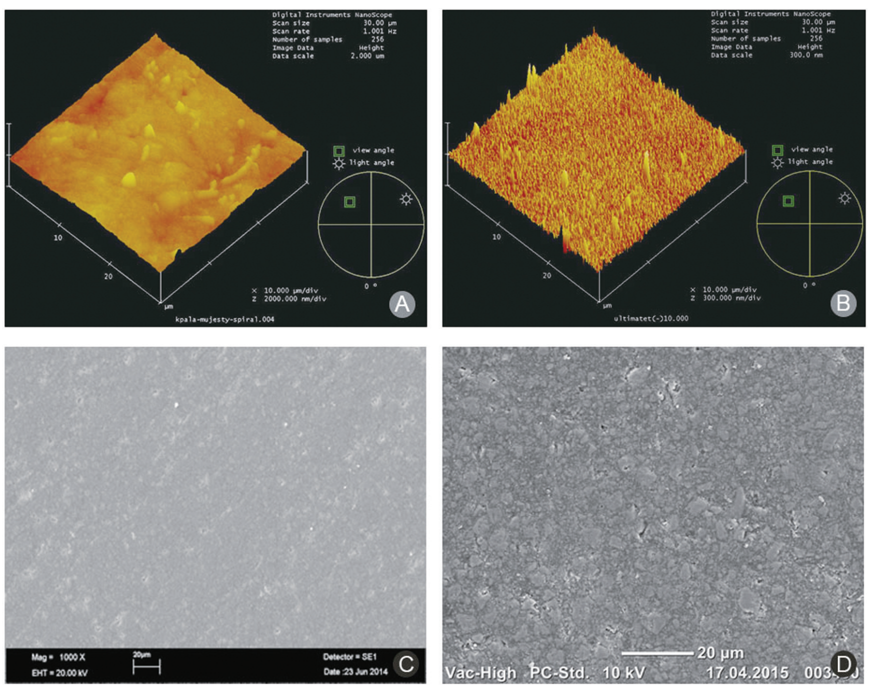

Fig. 2 A and B: AFM images of the Majesty Posterior surface with the Sof-Lex Spiral F/P system (A: before thermocycling, B: after thermocycling).
C and D: SEM images of the Majesty Posterior surface with the Sof-Lex Spiral F/P system (A: before thermocycling, B: after thermocycling).

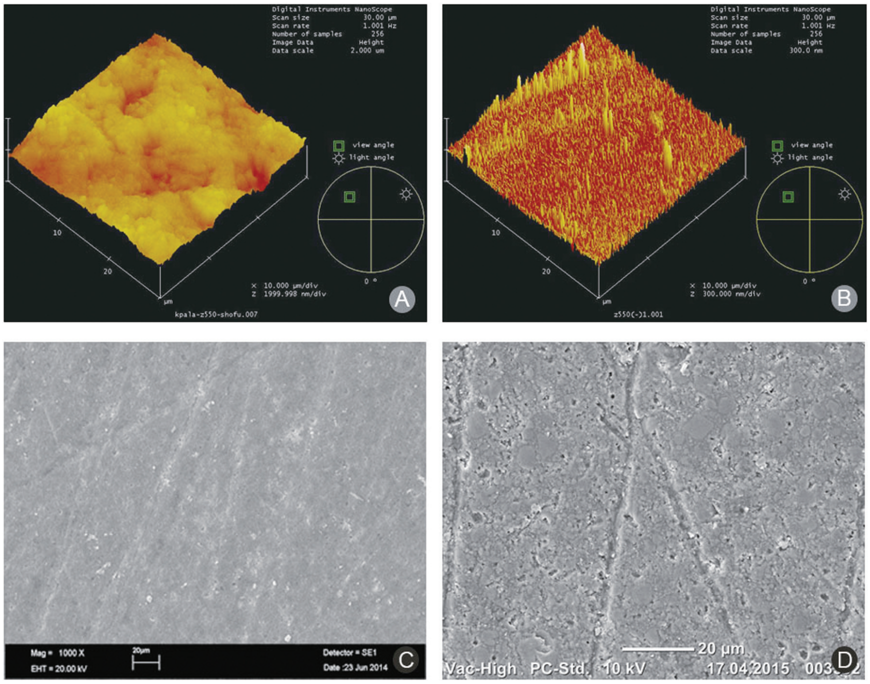

Fig. 3 A and B: AFM images of the Z550 surface with the OneGloss F/P system (A: before thermocycling, B: after thermocycling). This material was characterized by deep pits and a more undulating surface.
C and D: SEM images of the Z550 surface with the OneGloss F/P system (A: before thermocycling, B: after thermocycling). Some deep scratches were seen.

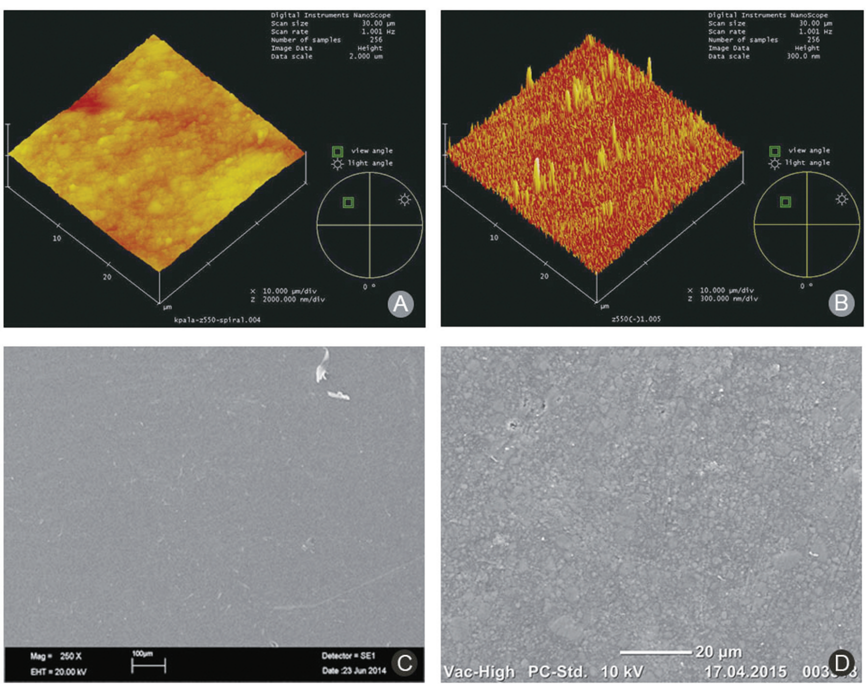

Fig. 4 A and B: AFM images of the Z550 surface with the Sof-Lex Spiral F/P system (A: before thermocycling, B: after thermocycling). A uniform surface was seen.
C and D: SEM images of the Z550 with the Sof-Lex Spiral F/P system (A: before thermocycling, B: after thermocycling). This material was characterized by a uniform surface.

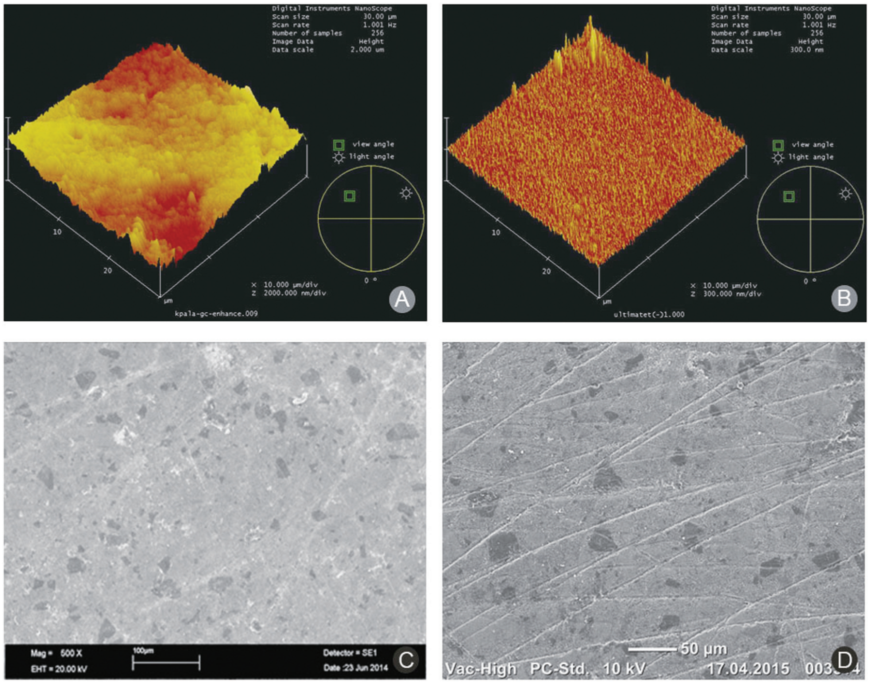

Fig. 5 A and B: AFM images of the G-aenial Posterior surface with the Enhance F/P system (A: before thermocycling, B: after thermocycling).
C and D: SEM images of the G-aenial Posterior surface with the Enhance F/P system (A: before thermocycling, B: after thermocycling). Frequent deep scratches were evident.

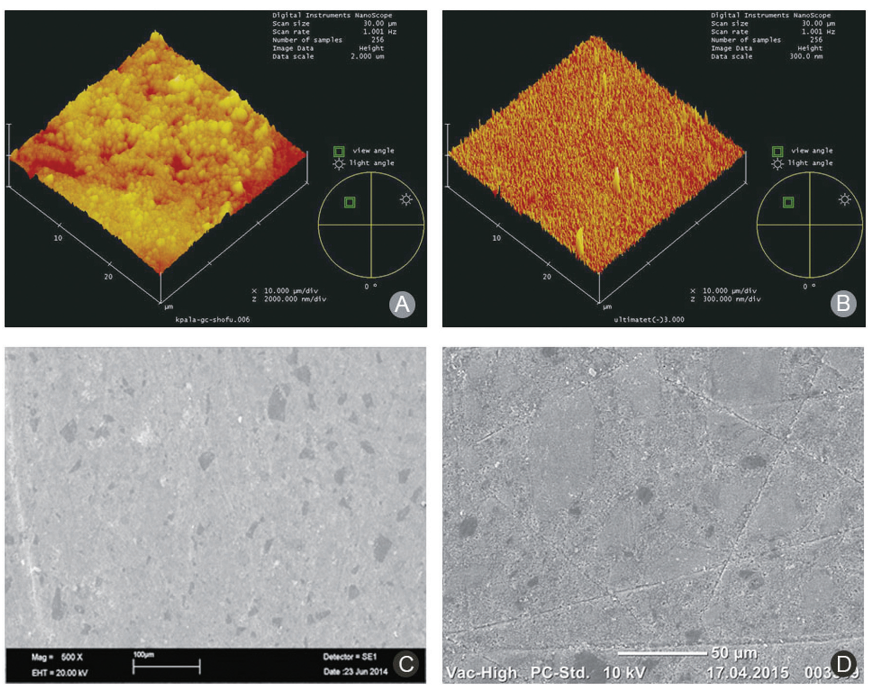

Fig. 6 A and B: AFM images of the G-aenial Posterior surface with the OneGloss F/P system (A: before thermocycling, B: after thermocycling).
C and D: SEM images of the G-aenial Posterior surface with the OneGloss F/P system (A: before thermocycling, B: after thermocycling). Some deep scratches were seen.

DISCUSSION

The most common composite restoration placed in contemporary dental practice is a direct posterior composite. The mechanical and physical properties of these materials, along with the correct indication, determine the longevity of restorations. The filler type affects both the handling characteristics and esthetic properties of composites. However, the eventual aesthetic properties of the restorative are strongly influenced by the final surface polish[24)]. Thus, this *in vitro* study aimed to evaluate the effects of different finishing and polishing protocols and thermocycling on the hardness, surface roughness, gloss and color of different posterior composites using both quantitative and qualitative (*i.e.*, SEM and AFM) methods. The results of this study partially supported both of the null hypothesis that the use of different finishing and polishing systems does not affect the microhardness, roughness, gloss and color of composite restorations and also thermocycling does not influence the microhardness, roughness, gloss and color of resin composites.

Hardness has been used to predict the wear resistance of a material and its ability to abrade or be abraded by opposing dental structures or materials[25)]. In this study, the Majesty Posterior and the Z550 exhibited similar microhardness values. The G-aenial Posterior exhibited significantly lower hardness values in all groups, regardless of the polishing system used. The lower hardness of UDMA-based resins (*i.e.*, G-aenial Posterior) in comparison to Bis-GMA-based resins (*i.e.*, Majesty Posterior and Z550) has been attributed to differences in the degree of polymerization, the molecular rigidity and the final strength[26)]. The lower hardness values of the G-aenial Posterior can also be explained by the difference in filler content per volume of resin composite. In addition, the incorporation of pre-polymerized fillers into G-aenial Posterior could cause decreasing hardness when using glass, ceramic and zirconia fillers. Ikejima *et al.*[27)] reported mechanical properties increase with the amount of inorganic fraction. St Germain *et al.*[28)] reported that increased filler levels result in trends for increased hardness and stiffness. In agreement with Ikejima *et al.*[27)] and St Germain *et al.*[28)], according to the hardness results of our study, the level of hardness seems to be related to the content of the composite material. Materials with a low surface hardness are more susceptible to scratching. In this study, the SEM and AFM results were consistent with the quantitative microhardness results. SEM observations revealed that deeper and more frequent scratch lines were evident for the G-aenial Posterior. The effect of thermocycles on microhardness has been reported in several studies[29-31)]. Similar to the previous studies, thermocycling significantly affected the microhardness of resin composites in the present study[29-31)]. Tuncer *et al.*[29)] and Söderholm *et al.*[31)] reported that a decrease in microhardness could be expected after thermocycling due to water absorption.

The highest mean Ra value for all composite materials tested in the current study was 0.63 µm; this value was produced with Enhance. Although Bollen *et al.*[32)] stated that the threshold surface roughness for bacterial plaque retention was 0.2 µm, other studies have found no appreciable differences in plaque on surfaces with Ra values that ranged from 0.7 to 1.4 µm[19,33,34)]. Chung[35)] found that restorations appear to be optically smooth when the Ra is lower than 1 µm. So, all composites used in this study produced acceptable Ra values for all the tested polishing systems from the clinical point of view. In this study, two steps of Sof-lex Spiral Wheels created smoother surfaces than three steps of Enhance and one step of OneGloss for all resin composites; however, no significant differences were observed between these systems. The only significant difference was observed between Enhance and Sof-Lex Spiral for Z550. The Sof-Lex Spiral Wheel design employs 2 parallel rows of 15 individually radiating elastomeric “bristles” uniformly impregnated with abrasives. The flexible form can adapt to nearly every surface of a restoration, minimizing heat formation and unwanted pressure in the F/P system[36)]. Several studies concluded that flexible aluminum oxide discs are the best instruments for producing the best surface smoothness[3,7,37)].

OneGloss is a one-step, aluminum oxide-impregnated silicone polisher, which is designed to save operative time and to be used for either finishing or polishing simply by altering the contact pressure. However, according to the outcomes of this study, the specimens that were polished with OneGloss exhibited a relatively high surface roughness and a lower gloss than those that were polished with the Sof-lex Spiral. Consistent with the qualitative SEM and AFM results, more prominent grooves in the composite surfaces were observed with OneGloss specimens.

Gloss is the ability of the surface to reflect light. In general, a high surface gloss is associated with a smooth surface of a restoration[38)]. In this study, the glossiest materials were determined to be the Z550 and the G-aenial Posterior. The Majesty Posterior exhibited relatively lower gloss than the other materials. With respect to the polishing system, the least glossy surfaces were obtained when the composites were used with OneGloss. Consistent with our study, Rodrigues *et al.*[39)] reported that multistep systems produced higher gloss, while the one-step system produced the lowest gloss. According to the American Dental Association (ADA) professional product review, 40–60 GU was identified as a typically desired gloss based on observations from an expert panelist[40)]. Cook and Thomas[41)] reported that poor finish is generally considered to be below 60 GU, an acceptable finish between 60 and 70 GU. According to this, any composite material used in the study did not exhibit successful gloss results. The results were between 4.68 and 34.84 GU. The reason of this result could be that all of the chosen composite materials for this study were posterior composites. Also, the result may be related to a large measurement area of the gloss meter used for this study. Nevertheless, some similar results with our study were available in literature like Da Costa *et al.*[42] who reported relatively lower GU values for the composites.

Heintze *et al.*[38] and Watanabe *et al.*[43] revealed a correlation between surface gloss and surface roughness. Heintze *et al.*[38] reported that the surface gloss improved consistently during the polishing procedures. But researchers also reported that the improvement of surface roughness was not similar to the improvement of surface gloss, and differed from material to material. In generally, it has been stated that when the surface roughness is increased, decreased gloss occurs[43]. However, this effect was not observed in this study. Consistent with our study, Antonson *et al.*[44] reported that no relationship has been established between gloss and roughness.

In this study, all tested composites exhibited acceptable color changes after 10,000 thermocycles, with a range of ΔE=1.28–2.75. It has been reported that color difference values (ΔE^*) ranging from 1 to 3 are perceptible, whereas values greater than 3.3 are clinically unacceptable for all composites studied[45,46]. Karaarslan *et al.*[47] reported that the composite resin type and the polishing method (*i.e.*, Sof-Lex or Enhance) significantly affected the color stability of composite resins after accelerated aging. Similar to our study, Lee *et al.*[45] reported that the color change of composites after 5,000 thermocycles ranged from 0.3–1.2 ΔE; thus, the color change was negligible.

Ergücü and Türkün[48] and Yap *et al.*[1] reported that OneGloss produced rougher surfaces than the other systems tested. Similarly with Ergücü and Türkün[48] and Yap *et al.*[1], we found that OneGloss-Majesty Posterior, OneGloss-Z550, and OneGloss-G-aenial Posterior combinations had higher roughness values than Sof-Lex Spiral-Majesty Posterior, Sof-Lex Spiral-Z550 and Sof-Lex Spiral-G-aenial Posterior combinations. Enhance-Majesty Posterior, Enhance-Z550, and Enhance-G-aenial Posterior combinations had highest roughness values in all materials. In this study, most smooth surfaces were obtained with Sof-Lex Spiral-Z550 combination and most glossy surfaces were obtained with Sof-Lex Spiral-Z550 and Enhance-G-aenial Posterior combinations. It had been reported that surface roughness is a necessary but not sufficient variable for gloss[38]. Heintze *et al.*[38] reported a higher press-on force of 4 N increased the surface roughness compared to the values obtained with 2 N in the hybrid composites. Higher surface roughness values with OneGloss and Enhance may be related to these systems being suitable for the implementation of pressure. Also, according to the color results, Enhance-Majesty Posterior and Enhance-G-aenial Posterior combinations showed the highest color change in this study.

It is clinically significant to determine the performance of the restoratives as a consequence of F/P procedures and aging because these phenomena could affect mechanical and physical properties of materials and longevity of restorations. As a conclusion, the reason for the different results of the different combinations of composites and polishing systems may be related to the content of the composite or abrasive particles of finishing and polishing systems. Moreover, the quantity, the size and the shape of the fillers affect the hardness, roughness, gloss, and color results of dental composites. Another contributing factor on the results might be the pressure exerted during finishing and polishing or the polishing time spent with each abrasive, the strokes, and the geometry of the abrasive instruments.

Within the limitations of this study, the hardest and most smooth materials were Majesty Posterior and Z550 while the glossiest materials were G-aenial Posterior and Z550. The smoothest surfaces were obtained with Sof-Lex Spiral for each material. The glossiest surfaces were obtained with Sof-Lex Spiral and Enhance. All composites exhibited acceptable color change after aging noticing used polishing system.

REFERENCES

1) Yap AU, Yap SH, Teo CK, Ng JJ. Finishing/polishing of composite and compomer restoratives: effectiveness of one-step systems. Oper Dent 2004; 29: 275-279.
2) Choi MS, Lee YK, Lim BS, Rhee SH, Yang HC. Changes in surface characteristics of dental resin composites after polishing. J Mater Sci Mater Med 2005; 16: 347-353.
3) Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. Dent Clin North Am 2007; 51: 379-397.
4) Turssi CP, Saad JR, Duarte SL, Rodrigues AL. Composite surfaces after finishing and polishing techniques. Am J Dent 2000; 13: 136-138.
5) Ozgünaltay G, Yazici AR, Görücü J. Effect of finishing and polishing procedures on the surface roughness of new tooth-colored restoratives. J Oral Rehabil 2003; 30: 218-224.
6) Botta AC, Duarte S Jr, Paulin Filho PI, Gheno SM, Powers JM. Surface roughness of enamel and four resin composites. Am J Dent 2009; 22: 252-254.
7) da Costa JB, Goncalves F, Ferracane JL. Comparison of two-step versus four-step composite finishing/polishing disc systems: evaluation of a new two-step composite polishing disc system. Oper Dent 2011; 36: 205-212.
8) Furuse AY, Gordon K, Rodrigues FP, Silikas N, Watts DC. Color-stability and gloss-retention of silorane and dimethacrylate composites with accelerated aging. J Dent 2008; 36: 945-952.
9) Endo T, Finger WJ, Kanehira M, Utterodt A, Komatsu M. Surface texture and roughness of polished nanofill and nanohybrid resin composites. Dent Mater J 2010; 29: 213-223.
10) Kanca J 3rd. Visible light-activated posterior composite resins--a comparison of surface hardness and uniformity of cure. Quintessence Int 1985; 16: 345-347.
11) Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. Dent Mater 2008; 24: 1243-1247.
12) Manhart J, Kunzelmann KH, Chen HY, Hickel R. Mechanical properties and wear behavior of light-cured packable composite resins. Dent Mater 2000; 16: 33-40.
13) Peutzfeldt A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci 1997; 105: 97-116.
14) LeSage BP. Aesthetic anterior composite restorations: a guide to direct placement. Dent Clin North Am 2007; 51: 359-378.
15) Ritter AV. Direct resin-based composites: current recommendations for optimal clinical results. Compend Contin Educ Dent 2005; 26: 481-482, 484-490.

16) Moszner N, Klapdohr S. Nanotechnology for dental composites. Int J Nanotechnol 2004; 1: 130-156.
17) Moszner N, Salz U. New developments of polymeric dental composites. Prog Polym Sci 2001; 26: 535-576.
18) Botta AC, Duarte S Jr, Paulin Filho PI, Gheno SM. Effect of dental finishing instruments on the surface roughness of composite resins as elucidated by atomic force microscopy. Microsc Microanal 2008; 14: 380-386.
19) Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. J Mater Sci Mater Med 2007; 18: 155-163.
20) Silikas N, Lennie AR, England K, Watts DC. AFM as a tool in dental research. Microsc Anal 2001; 82: 19-21.
21) Sideridou ID, Vouvoudi EC, Adamidou EA. Dynamic mechanical thermal properties of the dental light-cured nanohybrid composite Kalore, GC: effect of various food/oral simulating liquids. Dent Mater 2015; 31: 154-161.
22) Montes GGM, Draughn RA. In vitro surface degradation of composites by water and thermal cycling. Dent Mater 1986; 2: 193-197.
23) Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999; 27: 89-99.
24) Yap AU, Lye KW, Sau CW. Surface characteristics of tooth-colored restoratives polished utilizing different polishing systems. Oper Dent 1997; 22: 260-265.
25) Anusavice KJ. Physical properties of dental materials in Philip's science of dental materials. 10 th ed. Philadephia: Saunders Co; 2003. p. 43.
26) Sekiya K, Okamoto A, Fukushima M, Iwaku M. In vivo wear pattern of experimental composite resins based on different resin monomers. Dent Mater 1993; 1: 12-14.
27) Ikejima I, Nomoto R, McCabe JF. Shear punch strength and flexural strength of model composites with varying filler volume fraction, particle size and silanation. Dent Mater 2003; 19: 206-211.
28) St Germain H, Swartz ML, Phillips RW, Moore BK, Roberts TA. Properties of microfilled composite resins as influenced by filler content. J Dent Res 1985; 64: 155-160.
29) Tuncer S, Demirci M, Tiryaki M, Unlü N, Uysal Ö. The effect of a modeling resin and thermocycling on the surface hardness, roughness, and color of different resin composites. J Esthet Restor Dent 2013; 25: 404-419.
30) Hahnel S, Henrich A, Burgers R, Handel G, Rosentritt M. Investigation of mechanical properties of modern dental composites after artificial aging for one year. Oper Dent 2010; 35: 412-419.
31) Söderholm KJ, Zigan M, Ragan M, Fischlschweiger W, Bergman M. Hydrolytic degradation of dental composites. J Dent Res 1984; 63: 1248-1254.
32) Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater 1997; 13: 258-269.
33) Weitman RT, Eames WB. Plaque accumulation on composite surfaces after various finishing procedures. J Am Dent Assoc 1975; 91: 101-106.
34) Shintani H, Satou J, Satou N, Hayashihara H, Inoue T. Effects of various finishing methods on staining and accumulation of Streptococcus mutans HS-6 on composite resins. Dent Mater 1985; 1: 225-227.
35) Chung KH. Effects of finishing and polishing procedures on the surface texture of resin composites. Dent Mater 1994; 10: 325-330.
36) Blank JT. Optimize finishing and polishing of posterior composites. Dent Today 2014; 33: 118, 120-121.
37) Watanabe T, Miyazaki M, Takamizawa T, Kurokawa H, Rikuta A, Ando S. Influence of polishing duration on surface roughness of resin composites. J Oral Sci 2005; 47: 21-25.
38) Heintze SD, Forjanic M, Rousson V. Surface roughness and gloss of dental materials as a function of force and polishing time in vitro. Dent Mater 2006; 22: 146-165.
39) Rodrigues Jr S, Chemin P, Piaia P, Ferracane J. Surface roughness and gloss of actual composites as polished with different polishing systems. Oper Dent 2014; 40: 418-429.
40) ADA Professional Product Review. Polishing systems 2010; 5: 2-16.
41) Cook MP, Thomas K. Evaluation of gloss meters for measurement of moulded plastics. Polym Test 1990; 9: 233-244.
42) Da Costa J, Ferracane J, Paravina RD, Mazur RF, Roeder L. The effect of different polishing systems on surface roughness and gloss of various resin composites. J Esthet Restor Dent 2007; 19: 214-226.
43) Watanabe T, Miyazaki M, Moore BK. Influence of polishing instruments on the surface texture of resin composites. Quintessence Int 2006; 37: 61-67.
44) Antonson SA, Yazici AR, Kilinc E, Antonson DE, Hardigan PC. Comparison of different finishing/polishing systems on surface roughness and gloss of resin composites. J Dent 2011; 39: 9-17.
45) Lee YK, Yu B, Lim HN, Lim JI. Difference in the color stability of direct and indirect resin composites. J Appl Oral Sci 2011; 19: 154-160.
46) Nasim I, Neelakantan P, Subbarao CV. Color stability of microfilled, microhybrid and nanocomposite resins: An in vitro study. J Dent 2010; 385: 137-142.
47) Karaarslan ES, Bulbul M, Yildiz E, Secilmis A, Sari F, Usumez A. Effects of different polishing methods on color stability of resin composites after accelerated aging. Dent Mater J 2013; 32: 58-67.
48) Ergücü Z, Türkün LS. Surface roughness of novel resin composites polished with one-step systems. Oper Dent 2007; 32: 185-192.