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Influence of surface roughness on the color of dental-resin composites*

Razvan GHINEA[1], Laura UGARTE-ALVAN[1], Ana YEBRA[1], Oscar E. PECHO[2],
Rade D. PARAVINA[3], Maria del Mar PEREZ†‡[1,3]
(*[1]Department of Optics, Faculty of Science, University of Granada, Campus Fuentenueva s/n 18071, Granada, Spain*)
(*[2]Department of Stomatology, Faculty of Odontology, University of Granada, Campus de Cartuja s/n 18071, Granada, Spain*)
(*[3]Houston Center for Biomaterials and Biomimetics & Department of Restorative Dentistry and Biomaterials,
University of Texas Dental Branch at Houston, Houston, TX 77030, USA*)
†E-mail: mmperez@ugr.es

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Abstract: This study deals with the influence of surface roughness on the color of resin composites. Ten resin composites (microfilled, hybrid, and microhybrid) were each polished with 500-grit, 1200-grit, 2000-grit, and 4000-grit SiC papers. The roughness parameter (R_a) was measured using a Plμ confocal microscope, and field-emission scanning electron microscope (Fe-SEM) images were used to investigate filler morphology. Color was measured using a spectroradiometer and a D65 standard illuminant (geometry diffuse/0° specular component excluded (SCE) mode). Surface roughness decreased with grit number and was not influenced by filler size or size distribution. A significant influence of R_a on lightness (L^*) was found. Lightness increased with decreases in roughness, except for specimens that underwent polishing procedure 4 (PP4; 500-grit, 1200-grit, 2000-grit, and 4000-grit SiC papers consecutively). Generally, it was found that surface roughness influenced the color of resin composites. The composites that underwent PP1 (500-grit SiC paper) exhibited significant differences in chroma (C^*), hue ($h°$), and lightness (L^*) compared to composites that underwent PP3 (500-grit, 1200-grit, and 2000-grit SiC papers consecutively) and PP4. Color difference (ΔE^*) between the polishing procedures was within acceptability thresholds in dentistry.

Key words: Color measurement, Dental resin composites, Roughness
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1 Introduction

One of the most challenging tasks related to rising aesthetic demands in dentistry is to achieve a restoration that matches the color and appearance of a natural tooth. Often, dental restorations are replaced because of a color mismatch. More than 80% of patients are reportedly aware of color differences between the restored and the adjacent natural teeth (Joiner, 2004).

Tooth-colored resin composites are widely used as restorative materials. These heterogeneous materials are composed of three major constituents: resin matrix (generally methacrylates), filler particles (generally silica), and silane coupling (Phillips, 1993). The surface properties of these materials are critical for their success because they mediate the interaction of restorative materials with the oral environment.

Light-cured resin composites need to be polymerized in order to achieve adequate mechanical properties. The resin composite should be polished after polymerization because rough, unpolished restoration increases the coefficient of friction and may increase the rate of wear (Krejci *et al.*, 1999). In addition, a smooth surface can reduce plaque retention, thereby minimizing possible gingival irritation, surface staining, patient discomfort, and secondary caries (Chan *et al.*, 1980; Strassler and Bauman, 1993).

After polymerization, the resin matrix and filler particles have different levels of hardness that cause variations in polishing efficiency. This variability can

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‡ Corresponding author

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lead to differences in surface roughness. Because of composition diversity, various resin composites exhibit different levels of surface roughness after polishing. Materials with fillers of larger sizes generally show more surface roughness than those with fillers of smaller sizes (Tjan and Chan, 1989; Yap *et al.*, 1997).

During the last few decades, the development of resin composites has included the designing of inorganic fillers with smaller particles. According to the filler particle size, universal resin composites are classified as hybrids, microhybrids, and microfills (Dos Santos *et al.*, 2008; Lim *et al.*, 2008). Recent studies have shown that the particle size and distribution of the inorganic filler can influence the optical properties of the material (Dos Santos *et al.*, 2008; Lee, 2008; Lim *et al.*, 2008).

The color of an object depends on its surface spectral reflectance. The reflectance of a surface is a sensitive function of its roughness (Bennett and Porteus, 1961), and therefore the optical properties of the dental-resin composites may be influenced by the surface changes occurring during restorative procedures of finishing and polishing (Chung, 1994).

Color changes and notable gloss changes of dental-resin composites that occur between finishing and polishing, under routine clinical practice, have been clearly established in the literature (Stanford *et al.*, 1985; Lee *et al.*, 2002; Reis *et al.*, 2003; Paravina *et al.*, 2004) using mechanical devices (tactile profilometers) to measure the surface roughness. However, these devices are limited by the spatial dimension of the stylus, the measuring force, the sampling rate, and the calibration on the Z-axis (Wennerberg *et al.*, 1996). Recent publications have emphasized the importance of three dimensional (3D) surface topography in scientific applications since surface topography is 3D by nature (Al-Shammery *et al.*, 2007; Kakaboura *et al.*, 2007). In contrast to tactile or optical profilometry techniques, this method can scan the surface, and these surface areas can also be directly visualized in 3D topographical image (Al-Shammery *et al.*, 2007). The roughness parameter (R_a) usually employed in dentistry can be calculated from profiles of these 3D topographies (Gadelmawla *et al*., 2002).

Lee *et al.* (2002) evaluated the surface roughness after polishing with 600 to 1500-grit SiC papers using a spectrophotometer, which can operate with the specular component excluded (SCE) and specular component included (SCI) geometries, illuminating/ measuring conditions Commission Internationale de l′Eclairage (CIE) diffuse/8°, and CIE standard illuminant A. It was found that CIE lightness values (L^*) changed after polishing, while the two other color coordinates (a^* and b^*) did not change significantly. From this study, Lee *et al.* (2002) concluded that color-measuring geometry influenced the measurement of resin composites with different surface roughnesses.

Recognition of color by an observer is a combined physical and psychophysical phenomenon. Therefore, changes in color or in color coordinates are recognized differently depending on the viewing and illuminating conditions. The above-mentioned geometry and illuminating conditions are used in color measurements of dental-resin composites, but they differ from those usually used in visual assessment experiments, which normally require a viewing cabinet using the CIE D65 standard illuminant. Other illuminating/viewing geometries recommended by CIE (2004) for the reflection measurement of color (e.g., diffuse/0° and diffuse/45°) are more adequate for visual assessment experiments. The use of a spectroradiometer to measure and assess color is a non-contact and objective method that has been used in dentistry (Hasegawa *et al.*, 2000; Reno *et al.*, 2001; Martin-de las Heras *et al.*, 2003; Luo *et al.*, 2009) since it can measure colors in a way that matches the geometry of the visual assessments, with low discrepancies between measurement and assessment. Recently, Lim *et al*. (2010) found significant correlations between the spectrophotometric and the spectroradiometric values of a^*, b^* and chroma for all-ceramic materials. However, no correlations were found for lightness and, generally, they concluded that color coordinates measured by spectrophotometer differ significantly from those measured by spectroradiometer.

The purposes of this study were to evaluate the influence of surface roughness on the color of the universal dental-resin composites using the diffuse/0° illuminating/measuring geometry, to determine the color differences caused by the varied surface conditions of dental-resin composites, and to compare these differences with the acceptability and perceptibility thresholds in dentistry.

2 Materials and methods

2.1 Resin composite samples

The resin composites used in this study are listed in Table 1. They have the same polymeric matrix, methacrylates (bis-GMA: bisphenol A diglycidylether methacrylate; bis-EMA: bisphenol A polyethylene glycol dietherdimethacrylate; UDMA: urethane dimethacrylate; TEGDMA: triethylene glycol dimethacrylate), and the same filler particle type (zirconia/silica). However, the filler particle size range and size distribution were different: microfilled, microhybrid, and hybrid resin composites were evaluated.

The filler size, content, distribution, and composition might influence the surface roughness of the resin composites. To exactly ascertain these characteristics of the dental-resin composites studied, we obtained images of inorganic fillers of the three different types of restorative materials (microfilled, microhybrid, and hybrid). Previously, we separated the organic and inorganic matrixes of each sample by dissolution in pro-analysi acetone (ACS, ISO, 14.100; Merck, Darmstadt, Germany). Then, the inorganic matrix was mixed in an ultrasound agitator and centrifuged for 30 min at 3000 r/min. Finally, the samples were dried at 37 °C for 12 h and placed in the ultrasonic agitator to reduce particle agglomeration (Willems *et al.*, 1992).

Next, the samples were coated with gold (Polaron E-5000, Polaron-Equipment, Watford, UK) and screened under field-emission scanning electron microscope (Fe-SEM; LEO Gemini, Germany). The filler particle size and particle-size distribution were determined via digital image analysis (Ghinea *et al.*, 2008).

2.2 Specimen fabrication

Each resin composite was packed into a polyethylene mold (5 mm in diameter and 4 mm in thickness) over a slide cover. Materials were handled according to the manufacturer's instructions. After packing the composite, another slide cover was pressed on top of the specimen. Each specimen underwent light polymerization for 40 s, using a light-curing unit (Spectrum 800, Dentsply/Caulk, Spain) with an irradiance of 400 mW/cm^2, according to the manufacturer's instructions.

Different levels of roughness were achieved by applying four different polishing procedures to each material as in a previous work (Lee *et al.*, 2002),

Table 1 Resin composites used in this study

Material (Shade)	Particle size (type)	Filler type	Filler content (%)	Organic matrix	Batch No.	Manufacturer
Filtek A110 (B1)	0.01–0.09 µm (microfilled)	Colloidal silica	40 (v/v)	Bis-GMA, TEGDMA	0AH	3M Dental Products, St. Paul, MN, USA
Helio Molar (A3)	0.04–0.20 µm (microfilled)	Silicondioxide, ytterbium trifluoride	76.5 (w/w), 64 (v/v)	Bis-GMA, UDMA, Decanodiol-Dma	D52398	Ivoclar-Vivadent, Schaan, Liechtenstein
Artemis (Super Clear)	0.04–3.00 µm (hybrid)	Barium glass, Ba-Al-fluorosilicate glass	75–77 (w/w), 55–58 (v/v)	Bis-GMA, UDMA, TEGDMA	F34461	Ivoclar-Vivadent, Schaan, Liechtenstein
Tetric Ceram (C3)	0.04–3.00 µm (hybrid)	Barium glass, Ba-Al-fluorosilicate glass	81 (w/w), 63 (v/v)	Bis-GMA, UDMA, TEGDMA	C06318	Ivoclar-Vivadent, Schaan, Liechtenstein
Tetric (A1)	0.04–3.00 µm (microhybrid)	Barium glass, ytterbium trifluoride	82 (w/w), 62 (v/v)	Bis-GMA, UDMA	C09835	Ivoclar-Vivadent, Schaan, Liechtenstein
InTen-S (A3)	0.20–7.00 µm (microhybrid)	Barium glass, ytterbium trifluoride	74 (w/w), 51 (v/v)	Bis-GMA, UDMA	E43412	Ivoclar-Vivadent, Schaan, Liechtenstein
Synergy Nano (A2/B2)	0.04–2.50 µm (hybrid)	Strontium glass, amorphous silica	74 (w/w), 59 (v/v)	Bis-GMA, TEGDMA	IG271	Coltene-Whaledent AG, Altstatenn, Switzerland
Synergy Duo (A1/D2)	0.04–2.90 µm (hybrid)	Barium glass, amorphous silica	77 (w/w), 58 (v/v)	Bis-GMA, TEGDMA	CE013	Coltene-Whaledent AG, Altstatenn, Switzerland
Miris Dentin (Shade 4)	0.02–2.50 µm (microhybrid)	Barium glass, amorphous silica	80 (w/w), 65 (v/v)	Bis-GMA, TEGDMA	NB205	Coltene-Whaledent AG, Altstatenn, Switzerland
Miris Enamel (Neutral)	0.02–2.50 µm (microhybrid)	Barium glass, amorphous silica	80 (w/w), 65 (v/v)	Bis-GMA, TEGDMA	NB205	Coltene-Whaledent AG, Altstatenn, Switzerland

Bis-GMA: bisphenol A diglycidylether methacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate where samples were polished against a sheet of SiC paper for 50 strokes of 15 cm length under constant irrigation. The polishing procedures applied in our work were polishing procedure 1 (PP1, 500-grit SiC paper), PP2 (500- and 1200-grit SiC papers consecutively), PP3 (500-, 1200-, and 2000-grit SiC papers consecutively), and PP4 (500-, 1200-, 2000-, and 4000-grit SiC papers consecutively), as shown in Fig. 1. Twelve specimens were prepared for each material (three specimens for each polishing procedure). To reduce the variability, specimen fabrication, finishing, and polishing were performed by the same user.

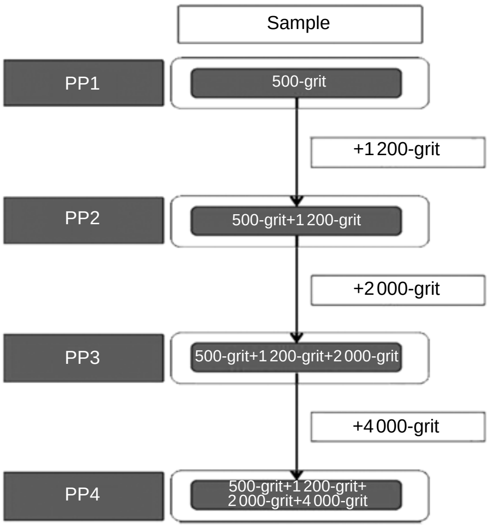


Fig. 1 Schematic representation of the polishing process for one sample

Although each manufacturer recommends a specific polishing system for most of the materials, we applied the same polishing system to all the materials to avoid any difference that might be caused by different polishing systems (Paravina *et al.*, 2004).

2.3 Roughness and color measurements

The R_a parameter of each specimen was measured using a Plμ confocal imaging profiler microscope (Sensofar-Tech 2003; Barcelona, Spain), which used SensoScan software at 100× magnification. The image size was 762 pixels×560 pixels, corresponding to an area of 139 μm×102 μm. Topographies were obtained with the following parameters: symmetrical Z with 0.2-μm resolution in height, and X and Y with 0.18 μm each. The mean roughness was calculated from three measurements.

Color was measured using a spectroradiometer (SpectraScan PR-704, Photo Research; Chatsworth, USA) with high measurement repeatability and standard deviation (SD) of repeated measurements over a 15-min period less than 0.1% (Pérez *et al.*, 2000). For the color measurement, the samples were positioned in the center of a color-assessment cabinet (CAC portable, Verivide Limited, Leicester, England) and illuminated using a source simulating the relative spectral irradiance of CIE standard illuminant D65. The illuminating/viewing configuration (CIE, 2004) was CIE diffuse/0° (SCE) while the CIE 1931 2° standard observer was used. The spectroradiometer was placed at 30 cm, a distance that allowed measurements of the whole surface of the specimen, and the aperture field of measurement was 1°. Measurements were repeated thrice.

The L^*, a^* and b^* values for all the samples were calculated, but it is often desirable to express color specification in terms of correlates of the perceived L^*, chroma (C^*), and hue ($h°$):

$$C^*=[(a^*)^2+(b^*)^2]^{1/2},$$
$$h°=\arctan(b^*/a^*).$$

Values of the three polished specimens were averaged to establish a single set of values for each resin composite. Color differences (ΔE^*_{ab}) were calculated with CIELAB color-difference formula (CIE, 2004):

$$\Delta E^*_{\mathrm{ab}}=[(\Delta L^*)^2+(\Delta C^*)^2+(\Delta H^*)^2]^{1/2},$$

where

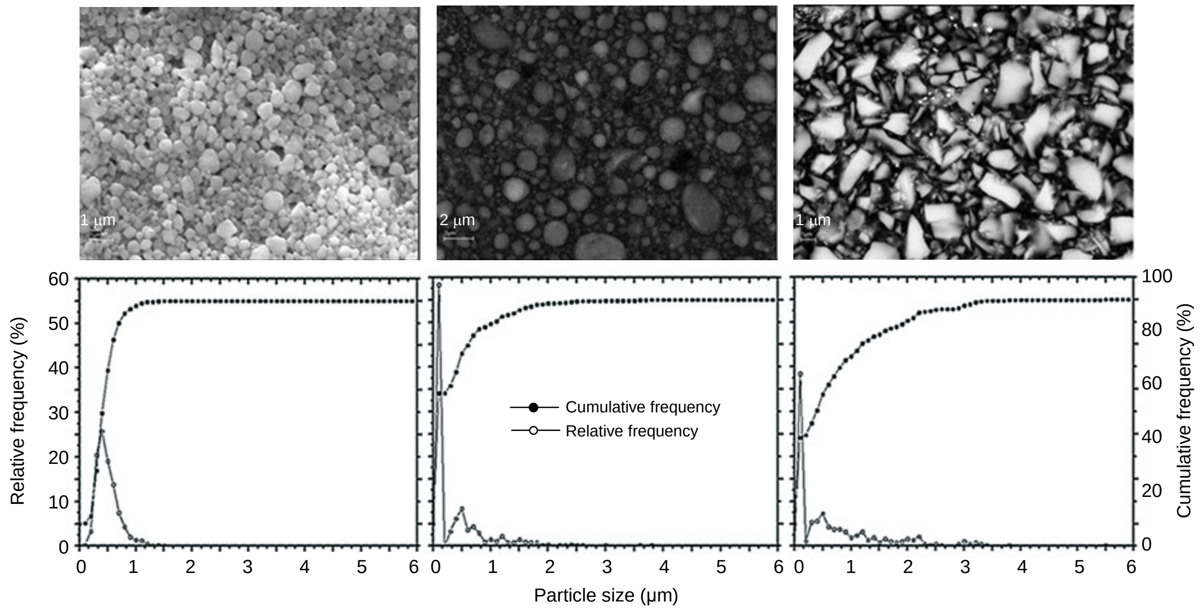
$$\Delta H^*=2(C_1^*\cdot C_0^*)^{1/2}\cdot\sin(\Delta h^\circ/2).$$

Since the value distribution was normal ($P>0.05$) and it was always the same sample that passed through the different polishing procedures, we made a t-test for paired samples between each pair of polishing procedures in order to examine the overall effects of the polishing procedure on the roughness and color (significant differences for $P\leq0.05$). One-way analysis of variance (ANOVA) ($P\leq0.05$) and Tukey's multiple-comparison test were used to compare the R_a values among the three different groups of resin composites (hybrid, microhybrid, microfilled) for all polishing procedures. All statistical analyses were performed using a standard statistical software package (SPSS 15.0.1, Chicago, USA).

3 Results and discussion

As mentioned above, filler size, content, distribution, and composition can influence the surface roughness of a resin composite (Lim *et al.*, 2008). According to manufacturers (Table 1), all restorative materials evaluated in this study had similar polymer matrix and different filler particle-size distributions: microfills, hybrids, and microhybrids. Fig. 2 shows the Fe-SEM images of the filler particles with their corresponding particle-size distributions for representative dental-resin composites of each group examined (microfilled, microhybrid, and hybrid). From the analyses of the relative and cumulative frequencies of the filler particle size, we found that the microfilled dental-resin composites contained small particles (ranging from 0.01 to 1.40 μm with 96% of the total particles smaller than 1.00 μm), but with a well-balanced distribution (a maximum relative frequency of 26% for 0.50 μm). The filler particle size of the microhybrid composites was within the interval of 0.01–3.80 μm, but with less than 90% of the particles smaller than 1.00 μm, while the hybrid resins had larger particles (ranging from 0.01 to 4.00 μm) with more than 10% of the particles larger than 2.00 μm. As reflected in Fig. 2, the particle-size distribution differed for each type of composite and this is important to take into account when assessing differences in surface roughness and in color coordinates between different polishing procedures.

Surface-roughness changes caused by different polishing procedures are shown in Fig. 3. Although these polishing methods are not usually used in clinical practice, the use of these methods enables us to achieve a wide range of roughness values so that we could establish the effects of this parameter on the color of resin composites, the main objective of this study. The representation of R_a values for all the polishing procedures revealed lower R_a values with higher grit numbers (Fig. 4). The interval of the R_a values for PP1 was wide, ranging from 0.12 to 0.29 μm. This range narrowed as the grit number increased, showing similar roughness for all materials evaluated (R_a close to 0.05 μm) after the PP4. These results are similar to the values of R_a found in a previous study (Lee *et al.*, 2002) on hybrid dental-resin composites, which employed a polishing system (wet SiC papers; 600-1000-1500 grits) similar to the one used in this work. However, Hosoya *et al.* (2010), using SiC polishing papers and a laser scanning microscope for evaluating surface roughness, obtained, for hybrid resin composites, R_a values ranging from 4.56 μm



(a) (b) (c)

Fig. 2 Fe-SEM images of the inorganic fillers of microfilled (a), microhybrid (b), and hybrid (c) dental-resin composites and corresponding filler-size distribution

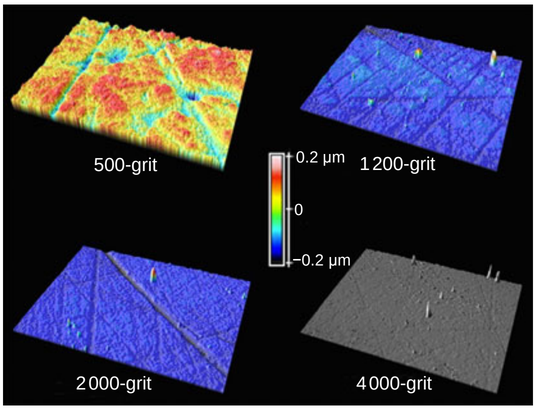


Fig. 3 Changes in surface roughness of Miris Dentin restorative material after applying the four different polishing procedures, observed with a Plμ confocal imaging profiler microscope

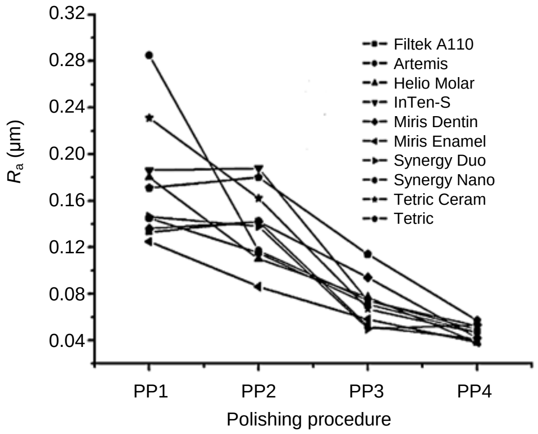


Fig. 4 Roughness parameter (R_a) values of all materials for each polishing procedure

(1000-grit) to 6.24 μm (180-grit). This large difference from our results could be due to the experimental measuring device and to the filler size (0.2–100.0 μm, average 0.7 μm) of the studied composites.

Some resin composites showed slight rises in R_a values from PP1 to PP2. This result might be due to the polishing procedures, which removed some parts of the material, including areas of damage caused by the polishing itself, since the SiC paper had a coarser grain.

The statistical analysis indicated no significant differences ($P>0.05$) for the R_a values among the three different groups of resin composites (microfilled, hybrid, and microhybrid) for any of the polishing procedures applied (especially PP2, PP3, and PP4). This implies that the surface roughness value of resin composites after polishing is not influenced by filler size or distribution. Other types of composites, such as nanocomposites, may behave differently, since the filler particle-size range is very narrow (Mitra *et al.*, 2003). The above mentioned, along with these reached results, suggest the need to perform future research to answer these questions.

Previous works showed that the polishing system significantly affected the R_a values (Reis *et al.*, 2002; Nagem Filho *et al.*, 2003; Sarac *et al.*, 2006). Korkmaz *et al.* (2008) compared the effects of four different polishing systems on a microhybrid resin composite, and found R_a values ranging from 0.05 μm (using Mylar Strip) to 0.20 μm (using PoGo, Dentsply/Caulk, Milford, DE, USA). Sarac *et al.* (2006) found that R_a values were included within the 0.46–1.30 μm interval when they evaluated the surface roughness of a microhybrid resin composite after polishing with polishing wheels and polishing discs. Nagem Filho *et al.* (2003) showed R_a values ranging from 0.39 to 0.61 μm when evaluating roughnesses of seven dental-resin composites after finishing with a polyester matrix strip and aluminium oxide disks. Although the above mentioned studies used different types of polishing systems (commercial polishing systems), the values obtained for the roughness parameter R_a are comparable with values of the same parameter in our work (Fig. 4).

L^*, C^*, and h° values of specimens for each polishing procedure are listed in Tables 2–4. In Fig. 5 the L^* values are plotted for the four polishing procedures. For the evaluated dental-resin composites, L^* increased slightly from PP1 to PP3, while R_a decreased, and there was a small decrease in L^* values from PP3 to PP4.

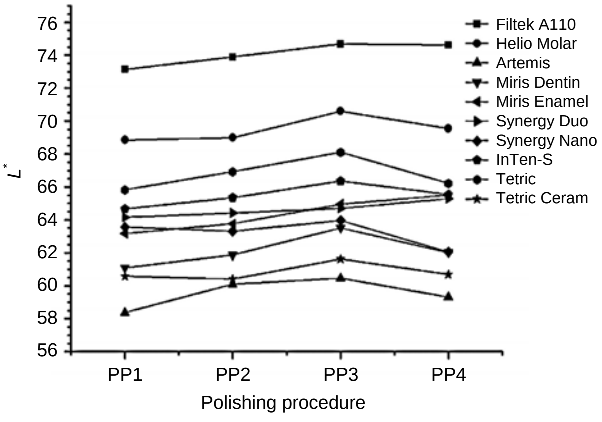


Fig. 5 Lightness (L^*) values of all materials for each polishing procedure

One explanation for this finding might be that a SiC paper of high grit number resulted in over-polishing that could damage not only the inorganic filler but also the organic matrix of the composite, thereby making the surface look darker. The behavior found for very smooth SiC paper has not been reported earlier, since previous studies (Lee *et al.*, 2002; Paravina *et al.*, 2004) have not evaluated polishing procedures with SiC papers finer than 1500 grits.

In the present study, no clear trends of chroma and hue were related to roughness. There was an increase in C^* values with the decrease of roughness (except for Filtek A110 and Synergy Nano), regardless of the filler particle size. This increase was not linear and was material-dependent (Tables 2–4). The most pronounced change in chroma was registered for Artemis Super Clear, Miris Enamel, Synergy Duo, and InTen-S, between PP3 and PP4 (2000 to 4000 grits). For Tetric, the highest variation occurred between PP1 and PP2, while for Tetric Ceram the highest variation was registered between PP2 and PP3. For Helio Molar and Miris Dentin, there were no significant changes between any of the polishing procedures. We found no clear trend in the variation of the hue angle associated with roughness.

Table 5 lists the probability values from the *t*-test of related samples (comparing each of the polishing procedures) for the R_a, L^*, C^*, and $h°$ parameters. The R_a registered significant differences ($P<0.05$) between all the polishing procedures. In the case of

Table 2 CIE L^*, C^*, $h°$ coordinates and R_a parameter for microfilled dental-resin composites

Material	Polishing procedure	R_a (μm)		L^*		C^*		$h°$	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Filtek A110	PP1	0.133	0.03	73.14	0.41	6.95	0.04	69.88	0.02
	PP2	0.152	0.07	73.88	0.18	7.20	<0.01	68.86	0.02
	PP3	0.052	<0.01	74.68	0.32	7.72	<0.01	65.81	0.02
	PP4	0.041	0.01	74.63	0.58	6.70	<0.01	66.57	<0.01
Helio Molar	PP1	0.180	0.05	68.86	0.19	17.22	<0.01	74.43	<0.01
	PP2	0.110	0.01	69.00	0.41	18.01	<0.01	73.15	0.03
	PP3	0.077	0.02	70.61	0.72	17.37	<0.01	73.49	<0.01
	PP4	0.038	0.01	69.56	0.36	18.34	<0.01	73.63	<0.01

Table 3 CIE L^*, C^*, $h°$ coordinates and R_a parameter for microhybrid dental-resin composites

Material	Polishing procedure	R_a (μm)		L^*		C^*		$h°$	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Miris Dentin	PP1	0.136	0.02	61.10	0.70	22.51	0.06	75.37	0.02
	PP2	0.142	0.03	61.88	0.42	21.88	0.05	75.30	<0.01
	PP3	0.094	0.02	63.53	0.31	22.05	<0.01	75.95	0.01
	PP4	0.042	<0.01	62.03	0.51	22.64	0.06	75.69	0.08
Miris Enamel	PP1	0.125	0.02	63.18	0.19	18.77	0.05	65.42	0.01
	PP2	0.086	0.01	63.76	0.25	20.07	<0.01	66.06	0.01
	PP3	0.058	<0.01	64.97	0.13	19.78	0.05	65.98	0.01
	PP4	0.038	<0.01	65.51	0.75	21.90	<0.01	64.23	0.01
InTen-S	PP1	0.186	0.05	64.66	0.15	20.15	<0.01	70.43	<0.01
	PP2	0.188	0.03	65.36	0.41	21.06	0.05	68.90	0.01
	PP3	0.074	0.01	66.36	0.50	19.86	1.08	71.99	0.01
	PP4	0.052	0.04	65.55	0.12	21.42	0.05	71.12	0.02
Tetric	PP1	0.171	0.01	65.82	0.41	19.36	<0.01	70.21	<0.01
	PP2	0.180	0.08	66.93	0.63	17.21	<0.01	69.56	<0.01
	PP3	0.114	0.03	68.11	0.12	19.27	<0.01	68.25	0.01
	PP4	0.057	0.04	66.22	0.74	20.40	0.05	66.86	<0.01

Table 4 CIE L^*, C^*, $h°$ coordinates and R_a parameter for hybrid dental-resin composites

Material	Polishing procedure	R_a (μm)		L^*		C^*		$h°$	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Artemis	PP1	0.285	0.08	58.37	0.51	23.03	<0.01	79.65	<0.01
	PP2	0.117	0.01	60.09	0.55	23.39	<0.01	77.89	<0.01
	PP3	0.074	<0.01	60.46	0.55	23.33	<0.01	74.20	<0.01
	PP4	0.049	0.01	59.32	0.27	27.01	<0.01	77.18	<0.01
Synergy Duo	PP1	0.146	0.04	64.16	0.35	15.33	0.05	72.79	0.02
	PP2	0.138	0.02	64.42	0.32	15.53	<0.01	70.11	<0.01
	PP3	0.050	0.01	64.71	0.30	14.89	0.05	69.11	0.02
	PP4	0.053	<0.01	65.30	0.19	16.91	0.05	69.29	0.01
Synergy Nano	PP1	0.145	0.01	63.56	0.31	18.26	0.05	72.09	<0.01
	PP2	0.115	<0.01	63.32	0.41	18.89	0.05	71.71	<0.01
	PP3	0.071	0.01	63.96	0.28	19.67	0.06	71.43	0.02
	PP4	0.047	0.01	62.05	0.08	18.60	0.18	71.32	0.01
Tetric Ceram	PP1	0.231	0.09	60.57	0.19	17.99	0.06	74.58	0.01
	PP2	0.162	0.11	60.40	0.66	17.21	<0.01	74.43	<0.01
	PP3	0.067	0.03	61.62	0.40	19.92	0.06	74.59	0.01
	PP4	0.046	0.02	60.68	0.16	20.60	0.01	71.85	0.01

Table 5 Statistical results of the *t*-test of related samples for parameters R_a, L^*, C^*, and $h°$ between each of the polishing procedures

Polishing procedure	*P* value			
	R_a	L^*	C^*	$h°$
PP1 vs. PP2	0.002	<0.001	0.627	<0.001
PP1 vs. PP3	<0.001	<0.001	0.006	0.002
PP1 vs. PP4	<0.001	<0.001	<0.001	<0.001
PP2 vs. PP3	<0.001	<0.001	0.127	0.137
PP2 vs. PP4	<0.001	0.261	<0.001	0.006
PP3 vs. PP4	<0.001	<0.001	<0.001	0.275

lightness (L^*), statistically significant differences were found between all the polishing procedures, except between PP2 and PP4. As indicated earlier, this might have occurred due to the decrease in lightness of resin composites caused by the over-polishing in PP4.

With respect to chroma (C^*), significant differences were found between all the polishing procedures except PP1-PP2 and PP2-PP3. For the hue angle ($h°$), there were significant differences between PP1 and all the other procedures, while for PP2-PP3 and PP3-PP4, no significant differences were detected.

According to our results, using diffuse/0° illuminating/measuring geometry, the surface roughness can generally influence the color of the resin composites. Resin composites that underwent PP1 (smaller grit, higher roughness) presented significant differences in chroma, hue angle, and lightness when compared to the ones subjected to PP3 and PP4 (higher grit, lower roughness).

Table 6 shows the CIELAB color differences (ΔE^*_{ab}) registered between the different polishing procedures for each dental-resin composite studied. It is more convenient to present the ΔE^*_{ab} color difference values since in almost all available literature, the acceptability/perceptibility thresholds are expressed in ΔE^*_{ab} units. Color differences (ΔE^*_{ab}) ranged from 0.42 to 2.86. Unexpectedly, the color difference values did not increase with greater grit differences. For example, the dental-resin composite Miris Dentin presented the greatest color difference ($\Delta E^*_{ab}=2.10$) between PP1 and PP3 and not between PP1 and PP4 ($\Delta E^*_{ab}=0.81$), as expected. Only for Miris Enamel and Synergy Duo, the greatest color difference was found between PP1 and PP4. The decrease in lightness found between PP3 and PP4 might explain the higher values of color difference recorded between not-so-different polishing procedures.

Data on acceptability and perceptibility thresholds in the dental literature are somewhat arbitrary (Lindsey and Wee, 2007). A study by Kuehni and Marcus (1979) is frequently cited as a standard for

Table 6 Color differences between polishing procedures for each resin composite

Polishing procedure	ΔE^*_{ab}									
	Microfilled		Microhybrid				Hybrid			
	Filtek A110	Helio Molar	InTen-S	Miris Dentin	Miris Enamel	Tetric	Synergy Nano	Synergy Duo	Tetric Ceram	Artemis
PP1 vs. PP2	0.62	0.68	0.97	0.74	0.87	1.50	0.43	0.90	0.47	1.69
PP1 vs. PP3	1.53	1.40	1.52	2.10	1.59	1.97	0.90	1.23	1.39	2.86
PP1 vs. PP4	1.22	0.90	1.01	0.81	2.63	1.43	1.32	1.83	1.81	2.32
PP2 vs. PP3	0.94	1.31	1.59	1.43	1.02	1.61	0.70	0.52	1.83	1.50
PP2 vs. PP4	0.73	0.50	0.86	0.42	1.90	2.19	1.09	1.16	2.18	1.86
PP3 vs. PP4	0.86	0.98	1.12	1.31	1.42	1.73	1.71	1.30	1.38	2.31

the perceptibility threshold of dental color differences. In this study, $\Delta E^*_{\mathrm{ab}}=1.00$ was found to be the 50:50% perceptibility threshold. Ruyter *et al*. (1987) studying color-difference acceptability, reported that 50% of their observers considered a pair of dental-resin composite samples to be unacceptable at $\Delta E^*_{\mathrm{ab}}=3.30$. Ragain and Johnston (2000) also examined the color difference acceptability for dental restorative materials, and found that the mean 50:50% acceptability threshold was $\Delta E^*_{\mathrm{ab}}=2.72$. Ishikawa-Nagai *et al*. (2009), investigating all-ceramic crowns, found that $\Delta E^*_{\mathrm{ab}}=1.60$ units represented a color difference that could not be detected by the human eye. Recently, Ghinea *et al*. (2010) using the same color measurement protocol as in this study (a spectroradiometer and diffuse/0° geometry) and an advanced Takagi-Sugeno-Kang fuzzy approximation for the threshold calculation procedure, established $\Delta E^*_{\mathrm{ab}}=$ 3.48 units as a new 50:50% acceptability threshold and $\Delta E^*_{\mathrm{ab}}=1.80$ units as a new 50:50% perceptibility threshold for dentistry. Recent studies reported that the CIEDE2000 color difference formula (ΔE_{00}) provided a better fit than the CIELAB formula in the evaluation of color difference and color thresholds (Pérez *et al*., 2007; Ghinea *et al*., 2010). Notwithstanding the possible beneficial use of this improved formula, most of the papers recently published in the dental literature still refer to ΔE^*_{ab}. This is probably due to the relative complexity of the ΔE_{00} formula, as well as to the ease of comparison with earlier studies.

According to our results, polishing-dependent differences in the color of resin composites were within the acceptability threshold (Ghinea *et al*., 2010) for all composites and for all comparisons involving any of the polishing procedures. In some cases, especially for color differences between PP1 and PP2 for the same material, the values were even below the perceptibility threshold.

4 Conclusions

Within the limitations of this study, the surface roughness levels found after applying different polishing procedures influenced the color of the resin composites. Color differences between polishing procedures were within the acceptability thresholds for dental restorative materials. However, the color differences between specimens of the same material polished with different procedures were higher than the perceptibility thresholds, being more pronounced when the materials underwent polishing procedures involving SiC paper with higher grit numbers.

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References

Al-Shammery, H., Bubb, N., Yougson, C., Fasbinder, D., Wood, D., 2007. The use of confocal microscopy to assess surface roughness of two milled CAD-CAM ceramics following two polishing techniques. *Dent. Mater.*, **23**(6):736-741. [doi:10.1016/j.dental.2006.06.012]

Bennett, H.E., Porteus, J.O., 1961. Relation between surface roughness and specular reflectance at normal incidence. *J. Opt. Soc. Am.*, **51**(2):123-129. [doi:10.1364/JOSA.51.000123]

Chan, K.C., Fuller, J.L., Hormati, A.A., 1980. The ability of foods to stain two composite resins. *J. Prosthet. Dent.*,

43(5):542-545. [doi:10.1016/0022-3913(80)90328-5]

Chung, K.H., 1994. Effects of finishing and polishing procedures on the surface texture of resin composites. *Dent. Mater.*, **10**(5):325-330. [doi:10.1016/0109-5641(94)90041-8]

CIE (Commission Internationale de l′Eclairage), 2004. Technical Report: Colorimetry. CIE Pub. No. 15.3, CIE Central Bureau, Vienna, Austria.

Dos Santos, G.B., Monte Alto, R.V., Sampaio Filho, H.R., Da Silva, E.M., Fellows, C.E., 2008. Light transmission on dental resin composites. *Dent. Mater.*, **24**(5):571-576. [doi:10.1016/j.dental.2007.06.015]

Gadelmawla, E.S., Koura, M.M., Maksoud, T.M.A., Elewa, I.M., Soliman, H.H., 2002. Roughness Parameters. *J. Mater. Process. Technol.*, **123**(1):133-145. [doi:10.1016/S0924-0136(02)00060-2]

Ghinea, R., Ugarte-Alvan, L., Ionescu, A.M., Cardona, J.C., Pérez, M.M., Yebra, A., 2008. Influence of the Size and Distribution of Filler Particles on the Colour of Resin Composites. *In*: Proceedings of the IS&T’s Fourth European Conference on Color in Graphics, Imaging, and Vision (CGIV). Terassa, Spain.

Ghinea, R., Perez, M.M., Herrera, L.J., Rivas, M.J., Yebra, A., Paravina, R.D., 2010. Color difference thresholds in dental ceramics. *J. Dent.*, **38**(Suppl. 2):e57-e64. [doi:10.1016/j.jdent.2010.07.008]

Hasegawa, A., Motonomi, A., Ikeda, I., Kawaguchi, S., 2000. Color of natural tooth crown in Japanese people. *J. Color Res. Appl.*, **25**(1):43-48. [doi:10.1002/(SICI)1520-6378(200002)25:1<43::AID-COL6>3.0.CO;2-P]

Hosoya, Y., Shiraishi, T., Odatsu, T., Ogata, T., Miyazaki, M., Powers, J.M., 2010. Effects of specular component and polishing on color of resin composites. *J. Oral Sci.*, **52**(4):599-607. [doi:10.2334/josnusd.52.599]

Ishikawa-Nagai, S., Yoshida, A., Sakai, M., Kristiansen, J., 2009. Clinical evaluation of perceptibility of color differences between natural teeth and all-ceramic crowns. *J. Dent.*, **37**(Suppl. 1):e57-e63. [doi:10.1016/j.jdent.2009.04.004]

Joiner, A., 2004. Tooth colour: a review of the literature. *J. Dent.*, **32**(Suppl. 1):3-12. [doi:10.1016/j.jdent.2003.10.013]

Kakaboura, A., Fragouli, M., Rahiotis, C., Silikas, N., 2007. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. *J. Mat. Sci. Mater. Med.*, **18**(1):155-163. [doi:10.1007/s10856-006-0675-8]

Korkmaz, Y., Ozel, E., Attar, N., Aksoy, G., 2008. The influence of one-step polishing systems on the surface roughness and microhardness of nanocomposites. *Oper. Dent.*, **33**(1):44-50. [doi:10.2341/07-28]

Krejci, I., Lutz, F., Boretti, R., 1999. Resin composite polishing: filling the gaps. *Quintessence Int.*, **30**(7):490-495.

Kuehni, R.G., Marcus, R.T., 1979. An experiment in visual scaling of small color differences. *Color Res. Appl.*, **4**(2):83-91.

Lee, Y.K., 2008. Influence of filler on the difference between the transmitted and reflect colors of experimental resin composites. *Dent. Mater.*, **24**(9):1243-1247. [doi:10.1016/j.dental.2008.01.014]

Lee, Y.K., Lim, B.S., Kim, C.W., 2002. Effect of surface conditions on the color of dental resin composites. *J. Biomed. Mater. Res.*, **63**(5):657-663. [doi:10.1002/jbm.10383]

Lim, H.N., Yu, B., Lim, J.I., Lee, Y.K., 2010. Correlations between spectroradiometric and spectrophotometric colors of all-ceramic materials. *Dent. Mater.*, **26**(11):1052-1058. [doi:10.1016/j.dental.2010.07.005]

Lim, Y.K., Lee, Y.K., Lim, B.S., Rhee, S.H., Yang, H.C., 2008. Influence of filler distribution on the color parameters of experimental resin composites. *Dent. Mater.*, **24**(1):67-73. [doi:10.1016/j.dental.2007.02.007]

Lindsey, D.T., Wee, A.G., 2007. Perceptibility and acceptability of CIELAB color differences in computer-simulated teeth. *J. Dent.*, **35**(7):593-599. [doi:10.1016/j.jdent.2007.03.006]

Luo, W., Westland, S., Ellwood, R., Pretty, I., Cheung, V., 2009. Development of a whiteness index for dentistry. *J. Dent.*, **37**(1):e21-e26. [doi:10.1016/j.jdent.2009.05.011]

Martin-de las Heras, S., Valenzuela, A., Bellini, R., Salas, C., Rubino, M., Garcia, J.A., 2003. Objective measurement of dental color for age estimation by spectroradiometry. *Forensic Sci. Int.*, **132**(1):57-62. [doi:10.1016/S0379-0738(02)00454-1]

Mitra, S.B., Wu, D., Holmes, B.N., 2003. An application of nanotechnology in advanced dental materials. *J. Am. Dent. Assoc.*, **134**(10):1382-1390.

Nagem Filho, H., Soares D′Azevedo, M.T.F., Nagem, H.D., Marsola, F.P., 2003. Surface roughness of composite resins after finishing and polishing. *Braz. Dent. J.*, **14**(1):37-41. [doi:10.1590/S0103-64402003000100007]

Paravina, R.D., Roeder, L., Lu, H., Vogel, K., Powers, J.M., 2004. Effect of finishing and polishing procedures on surface roughness, gloss and color of resin-based composites. *Am. J. Dent.*, **17**(4):262-266.

Pérez, M.M., Melgosa, M., El Moraghi, A., Hita, E., 2000. Usefulness of cathode ray tube color displays in chromaticity-discrimination experiments. *Appl. Opt.*, **39**(22):4021-4030. [doi:10.1364/AO.39.004021]

Pérez, M.M., Saleh, A., Yebra, A., Pulgar, R., 2007. Study of the variation between CIELAB ΔE^* and CIEDE2000 color-differences of resin composites. *Dent. Mater. J.*, **26**(1):21-28. [doi:10.4012/dmj.26.21]

Phillips, R.W., 1993. Skinner Science of Dental Materials, 9th Ed. McGraw-Hill Interamericana, Mexico (in Spanish).

Ragain, J.C., Johnston, W.M., 2000. Color acceptance of direct dental restorative materials by human observers. *Color Res. Appl.*, **25**(4):278-285. [doi:10.1002/1520-6378(200008)25:4<278::AID-COL8>3.0.CO;2-F]

Reis, A.F., Giannini, M., Lovadino, J.B., Santos Dias, C.T., 2002. The effect of six polishing systems on the surface roughness of two packable resin-based composites. *Am. J. Dent.*, **15**(3):193-197.

Reis, A.F., Giannini, M., Lovadino, J.R., Ambrosano, G.M., 2003. Effects of various finishing systems on the surface roughness and staining susceptibility of packable composite resins. *Dent. Mater.*, **19**(1):12-18. [doi:10.1016/S0109-5641(02)00014-3]

Reno, E.A., Poore, C.L., Anastasia, M.K., Miller, J.M., Crisanti, M.M., 2001. Reproducibility of Non-Contact Tooth Color Measurement System. *In*: Proceedings of 30th Annual Meeting of the AADR. Chicago, IL, p.1365.

Ruyter, I.E., Niler, K., Moller, B., 1987. Color stability of dental composite materials for crowns and bridge veneers. *Dent. Mater.*, **3**(5):246-251. [doi:10.1016/S0109-5641(87)80081-7]

Sarac, D., Sarac, Y.S., Kulunk, S., Ural, C., Kulunk, T., 2006. The effect of polishing techniques on the surface roughness and color change of composite resins. *J. Prosthet. Dent.*, **96**(1):33-40. [doi:10.1016/j.prosdent.2006.04.012]

Stanford, W.B., Fan, P.L., Wozniak, W.T., Stanford, J.W., 1985. Effect of finishing on color and gloss of composites with different fillers. *J. Am. Dent. Assoc.*, **110**(2):211-213.

Strassler, H.E., Bauman, G., 1993. Current concepts in polishing composite resins. *Practical Periodontics Aesthet. Dent.*, **5**(3 Suppl. 1):12-17.

Tjan, A.H., Chan, C.A., 1989. The polishability of posterior composites. *J. Prosthet. Dent.*, **61**(2):138-146. [doi:10.1016/0022-3913(89)90361-2]

Wennerberg, A., Ohlsson, R., Rosen, B.G., Andersson, B., 1996. Characterizing three-dimensional topography of engineering and biomaterials surface by confocal laser scanning and stylus technique. *Med. Eng. Phys.*, **18**(7):548-556. [doi:10.1016/1350-4533(95)00005-4]

Willems, G., Lambrechts, P., Braem, M., Celis, J.P., Vanherle, G., 1992. A classification of dental composites according to their morphological and mechanical characteristics. *Dent. Mater.*, **8**(5):310-319. [doi:10.1016/0109-5641(92)90106-M]

Yap, A.U., Lye, K.W., Sau, C.W., 1997. Surface characteristics of tooth-colored restoratives polished utilizing different polishing systems. *Oper. Dent.*, **22**(6):260-265.