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Can wheel polishers improve surface properties and color stability of monochromatic resin composites?

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Abstract

Background To overcome the color layering procedure, monochromatic resin composites have been introduced. However, little is known about their polishability, gloss and color stability. This study aimed to investigate the surface roughness, gloss, and color change of monochromatic resin composites polished with wheel systems after being immersed in coffee.

Materials and methods Omnichroma, Zenchroma, Essentia Universal, Charisma Diamond One and NeoSpectra ST were used to obtain 120-disc samples of 8 × 2 mm. Only one side of the sample was polished with Twist Dia (TWD) or Nova Twist (NOV). The samples were examined for surface roughness, gloss, and color (ΔE and ΔE_{00}) before and after 7 days of immersion in coffee and subsequent repolishing. The discs were examined via SEM. Surface roughness and gloss values were analyzed using ANOVA, Tukey and Pearson correlation tests. ΔE and ΔE00 values were evaluated using T tests, multivariate ANOVA, and Dunnett's post-hoc tests.

Results For TWD groups, the smoothest material was Omnichroma ($p < 0.05$), while for NOV groups, it was Omnichroma and Zenchroma. Omnichroma was the glossiest, while Charisma Diamond One was the least glossy. In TWD groups, Charisma Diamond One and Essentia Universal were the most discolored, while Zenchroma and Omnichroma were the least. For NOV groups, Essentia Universal and Charisma Diamond One were the most discolored, while NeoSpectra ST, Omnichroma and Zenchroma were the least. After repolishing, Charisma Diamond One did not reach the level of $\Delta E < 2$, while the other groups showed values below. Color evaluation with the CIELab and CIEDE2000 systems revealed similar results for the TWD groups after post-staining.

Conclusions Smooth and glossy surfaces could be achieved with the wheel system regardless of the composite resin. Repolishing after discoloration ensures that the color recovery is below the acceptable limit. Color evaluations with CIELab and CIEDE2000 yielded similar results.

Keywords Monochromatic resin composite, Wheel polishers, Color stability, Roughness, Surface gloss

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Introduction

Patient demand for an attractive facial and dental appearance with a minimally invasive approach has steadily increased over the past few decades. Currently, resin composites (RCs) are the most widely used and accepted dental material group for fulfilling these expectations in the anterior and posterior regions [1]. However, the esthetic rehabilitation and patient acceptance of these treatments are usually difficult tasks that depend largely on the clinician's experience, ability to mimic the natural tooth, and skills in layering with resin composites [2].

To achieve an acceptable esthetic result, the color of the restorations should mimic that of the adjacent teeth. To this end, different resin composite shades must be used in succession to mimic the natural tooth color and appearance [3]. Some manufacturers have adapted their shade guides to Vita Classical shades from A1 to D4 in their resin composite kits [3]. To circumvent the color layering procedure, simplified shading options have been introduced. They are referred to as 'group-shading' or 'cloud-shading' and have a narrow shade range based on the value level of the classical shades of VITA [4]. Later, the concept of 'single' resin composites was introduced. They are designed to simulate all the classic VITA shades with only a single color. The colors of the material are not created by the addition of pigments, but by deliberately induced structural colors that blend with the reflected color of the surrounding tooth. Some of these materials use 'smart chromatic technology' along with spherical fillers made using the "cultured pearl principle" [5], while others have a blending effect (chameleon effect) [6] that refers to the ability of a material to acquire a similar color to the surrounding tooth structure. The blending effect helps the clinician achieve an optimal esthetic result for both the patient and the operator. However, experience and clinical skills are required to mimic the surrounding tooth structure and color [4, 6–11]. Since this group of materials is relatively new, few in vitro studies have evaluated their surface properties.

Due to developments in nanotechnology, many resin composites from different manufacturers containing these nanoparticles are now available. Smaller particle sizes allow for better layering, easy and effective finishing, and polishing procedures that offer lower surface roughness, higher gloss retention, less discoloration, and better color stability over time [5, 12–14].

In esthetic dentistry, restorative materials should replicate the appearance of a natural tooth. A resin composite restoration may be imperceptible to the naked eye if its smooth surface resembles the surrounding enamel [15]. In addition, the surface roughness of dental materials has a major impact on plaque accumulation, superficial discoloration, gingival inflammation, wear, and the esthetic appearance of direct and indirect restorations. Usually, the smoothest surface of a restoration can be achieved when the resin composite is polymerized against a translucent strip (Mylar). However, this surface cannot be preserved because it consists mainly of an organic matrix and is susceptible to discoloration and wear [16]. Therefore, resin-based esthetic restorations should be functionally adjusted, properly finished and polished. The classic method of finishing restorations is to use diamond/tungsten carbide burs and then use finer grit discs [17]. After occlusal adjustment and fine finishing, the use of polishing pastes or tools is required to obtain an enamel-like restoration surface. However, all these steps remove considerable amounts of material from the surfaces, resulting in the disappearance of the surface morphology created when the restorations are modeled [17, 18].

There is no consensus on which system is more efficient, cost effective and less time consuming for achieving excellent surface quality [19, 20]. In addition, the search for an ideal polishing tool for resin composites is still ongoing. To facilitate that process, diamond-coated polishing wheels have been introduced to help resin composites achieve high gloss with fewer working steps. This type of polishing meets the clinical demand for a smooth surface in the shortest possible time. Timesaving and reduced-step one-step systems have been shown to be as successful as multi-step polishers in previous studies [18, 19]. However, no studies have compared the repolishing ability after the discoloration of single-shaded resin composites in combination with various diamond-coated polishing wheels.

According to Bollen et al. [21], surface roughness is key to bacterial adhesion, and values above 0.2 µm indicate that these surfaces are susceptible to bacterial adhesion. Furthermore, a proper finishing and polishing procedure not only affects bacterial adhesion and gingival health, but also increases the esthetic acceptability and longevity of the restoration [22]. However, in the long term, especially depending on the patient's habits, resin composite restorations are prone to changes in surface roughness, gloss and color [12, 13, 22–24].

The surface roughness of a resin composite restoration can be determined with profilometers (Stylus, optical, contact, etc.) or with atomic force microscopy (AFM). Proper finishing and polishing also affects the glossiness of the restoration surface as the surface roughness decreases [24], which can be assessed with glossmeters.

Exposure to the oral environment and external fluids may cause discoloration of the resin composite surfaces. External factors such as water absorption, and excessive consumption of red wine, tea or coffee cause discoloration of resin-based restorations [25, 26]. This phenomenon can lead to a color discrepancy between the restoration and the natural tooth. In addition, the surface roughness of the restoration also affects the color stability. However, new materials on the market with smaller particles that allow better finishing and polishing are much more color stable [1, 5, 6, 13, 14].

Visual and instrumental methods have been used for many years to determine the color changes of esthetic restorations, using various methods, such as visual inspection, calorimeters, and spectrophotometers [27]. The degree of discoloration can be easily and accurately measured with a color spectrophotometer and is expressed as a color difference. Over time, many color difference evaluation formulas have been proposed. In 2001, due to the limitations of the CIELab system, the CIE developed a more sophisticated formula, the CIEDE2000, to calculate color differences [28]. This formula seems better than the previous version, but its use is more complex [29]. The color differences can be quantified using the CIELab formulation (ΔE) or the new CIEDE200 formula (ΔE_{00}).

Several studies have identified different detectable color difference (ΔE) limits to evaluate CIELAB values (ΔE) [30–33]. The color difference was interpreted as undetectable ($\Delta E<1$) [7], within acceptable clinical limits ($\Delta E<2$) [30], critical value for visual perception/observation ($\Delta E>3.3$) [32], or poor ($\Delta E\geq 3.7$) [33]. For the newly used CIEDE2000 (ΔE_{00}) system, according to the study of Paravina et al. [7], the CIELAB 50:50% perceptual threshold (PT) was set at $\Delta Eab=1.2$, whereas the 50:50% acceptance threshold (AT) was $\Delta Eab=2.7$. The corresponding CIEDE2000 values were $\Delta E_{00}=0.8$ and $\Delta E_{00}=1.8$, respectively [8]. In the present study, the acceptable thresholds for ΔE were set at less than 2 and at 1.8 for ΔE_{00}.

Replacement of restorations due to discolored surfaces induces additional costs for the patient [9, 10]. Therefore, more conservative methods, such as repolishing or tooth brushing with whitening toothpastes, should be advocated before suggesting further treatment options to patients [11, 18].

The aim of this in vitro study was to investigate the surface roughness, gloss, and color change of single-shaded resin composites polished with simplified systems after being immersed in coffee for one week and repolished.

The first null hypothesis was that the surface roughness and gloss of single-shaded resin composites would not differ from those of the nanohybrid resin composite tested. The second null hypothesis was that long-term immersion in coffee would not affect the color of the single-shaded resin composites compared to that of the nanohybrid resin composites tested. The third null hypothesis was that the original color of the single-shaded resin composites cannot be restored by repolishing.

Materials and methods

Study materials

Four single-shaded resin composites were used in the study: Omnichroma (OMN; Tokuyama, Japan), Zenchroma (ZEN; President, Germany), Essentia Universal (EU; GC, Japan), and Charisma Diamond One (CDO; Kulzer, Germany). A multi-shaded nanohybrid resin composite, NeoSpectra ST HV (NS; Dentsply, Germany), served as a control group. The composition, filler load, manufacturer and lot numbers of the tested resin composites are listed in Table 1.

Two simplified wheel type polishing systems, Twist Dia (TWD-Noritake, Japan) and Nova Twist (NOV-President, Germany), were used for finishing and polishing the resin composite disc specimens. The properties of the polishing systems tested are listed in Table 2.

Table 1 Composition, filler load, manufacturer and batch numbers of the resin composites tested

Resin Composites	Compositions	Filler Ratio %(w) %(v)	Manufacturers	Lot #
Charisma Diamond One (CDO)	TCD-matrix, UDMA, **Nanohybrid fillers**	64% ---	Kulzer, Germany	K010025 K010021 K010024
Essentia Universal (EU)	UDMA, Bis-MEPP, Bis-EMA, Bis-GMA, TEGDMA. **Prepolymerized fillers** (17 µm): strontium glass (400 nm), lanthanide fluoride (100 nm), fumed silica (16 nm) FAlSi glass (850 nm)	91% 65% (with pre-polymerized fillers)	GC, Japan	2,109,021
Zenchroma (ZEN)	Glass powder, di-UDMA, silicon dioxide, Bis-GMA, tetramethylene dimethacrylate. **Micohybrid and ultrafine fillers**	*75%* *53%*	President, Germany	2,021,007,297 2,021,005,749
Onmichroma (OMN)	UDMA, TEGDMA, Uniform sized **supra-nano spherical filler** (260 nm SiO2 -ZrO2)	79% 68%	Tokuyama, Japan	150S4
NeoSpectra ST HV (NS)	Methacrylate-, acid-modified methacrylate-, inorganic polycondensate- or epoxide based, Blend of **spherical, prepolymerized SphereTEC fillers** (d3,50 ≈ 15 µm), non-agglomerated barium glass and ytterbium fluoride	78–80% 60–62%	Dentsply, Konstanz, Germany	2,110,001,361 1,911,000,672

Table 2 Type, particle size, manufacturer and lot numbers of the polishing wheels used in the study

Polishing wheels	Type	Sub Type	Particle Size	Manufacturer	Lot #
Twist Dia (TWD)	Two-step rubber wheel polishing system	Pre-polisher	Diamond particles embedded rubber spirals. Medium grit (25–35 µm)	Noritake, Japan	462,857
		High-shine polisher	Diamond particles embedded rubber spirals. (Fine grit 4–8 µm)		
Nova Twist (NOV)	Two-step rubber wheel polishing system	Pre-polisher	Diamond particles embedded rubber spirals. (Medium grit)	President Dental, Germany	466,014
		High-shine polisher	Diamond particles embedded rubber spirals (Fine grit)		458,792

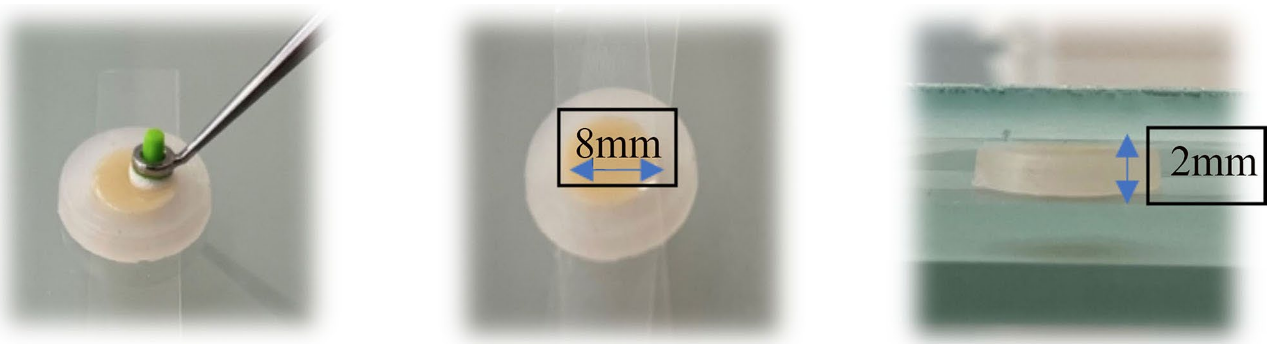

Fig. 1 The samples were prepared under Mylar strips and glass slides with an OptraSculpt Pad (Ivoclar, Liechtenstein) instrument

Preparation of the samples

A total of 120-disc samples of 8×2 mm (n=24) were prepared in plastic molds for OMN, ZEN, EU, CDO and NS under the pressure of Mylar strips (M) and glass slides to avoid any bubbles or folds on the resin composites using the OptraSculpt Pad (Ivoclar, Liechtenstein) hand instrument (Fig. 1). Polymerization was performed using an LED light curing unit (ZenoLite, President, Germany) with an intensity of 1300 mW/cm^2 in continuous curing mode with a perpendicular angle. The output of the light intensity was measured with a radiometer after every 5-sample preparation. Each surface was polymerized for 20 s, resulting in an exposure time of 40 s for each sample. Immediately after the light-curing cycle, the specimens were immersed in deionized water at 37 °C for 24 h.

One side of the specimen was left as a Mylar strip control surface (M; no F/P), and the other side was first roughened with the first two polishing discs of the multi-step finishing and polishing disc system, OptiDisc (grit sizes of 80 and 40 µm; Kerr, Bioggio, Switzerland) to obtain standardized baseline surfaces. Subsequently, the surfaces were dry polished with slight pressure by the same person to minimize variability with Twist Dia (n=12) or Nova Twist (n=12) for 30 s at a maximum of 9000 rpm with a slow-speed handpiece in constant circular movements to prevent heat buildup and the formation of grooves. After every six test specimens, the OptiDisc, Twist Dia and Nova Twist wheels were replaced with new ones.

Evaluations planned on the samples

The surface roughness and gloss of the single-shaded composite resin samples and their initial color were evaluated. Then, the specimens were immersed in coffee solutions for one week for discoloration. After this period, the color of the samples was measured again, the discs were repolished with the same wheels, and the final color was recorded. All procedural sequences are shown schematically in Fig. 2.

Evaluation of surface roughness

The average surface roughness (Ra, µm) of the specimens was measured by a single operator using a surface profilometer (Mitutoyo Surftest/SJ-301, Tokyo, Japan) for both the Mylar strips and polished surfaces. Profilometer measurements were made with a cutoff length of 0.25 mm, a tracing length of 0.8 mm, and a stylus speed of 0.25 mm/s. Three consecutive measurements were taken at different places and in various directions for each specimen. The average values (Ra) were recorded.

Evaluation of gloss

The surface glossiness of the polished specimens and Mylar strips was evaluated using a glossmeter (Glossmeter PCE-SGM60 Plus, USA). The glossmeter has a small measuring area of 22 mm and a 60° geometry. Three consecutive measurements were taken by a single operator from each surface in the center of each sample, and the average values were recorded. Gloss measurements were

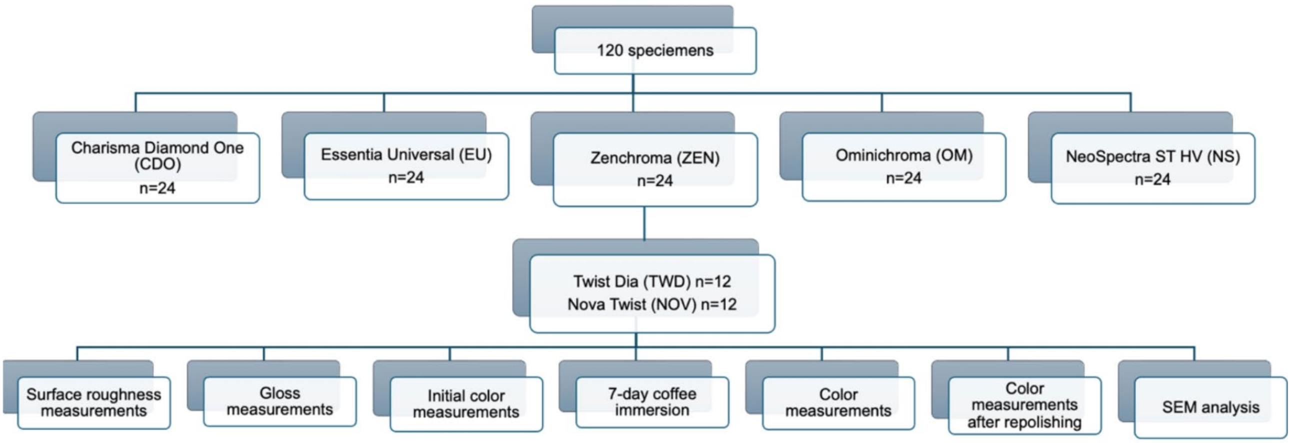

Fig. 2 Flowchart of the procedure applied to monochromatic resin composite specimens

Fig. 3 The specimens were perpendicularly immersed in coffee solution

expressed in gloss units (GU). A custom-made, 10-mm-thick, black polytetrafluoroethylene mold was placed over the specimen during the measurements to enable accurate specimen positioning and eliminate the influence of the overhead light.

Evaluation of color changes

The color of the samples was measured according to the CIELab and CIEDE2000 systems using a non-contact spectrophotometer (SpectroShade Micro, MHT, Milan, Italy) against a white background, under daylight conditions in air, and at the same time of day to obtain initial values. The device was calibrated at the beginning of every sixth measurement according to the manufacturer's recommendations using the white and dark calibration standard provided. The positioning of the device on the sample was achieved by an angle control system of the device, which calculates the optimal angle of incidence between the optic handpiece and a target sample. This angle was verified by a horizontal green line representing the accurate geometry. The spectral data obtained were translated into CIELab and CIEDE2000 coordinates by software using the standard D65 illuminant and 2° observer angle as a reference. Three consecutive measurements were taken on the samples, and the mean value was recorded as the final value (ΔE and ΔE_{00}).

According to Ertas et al. [34], the average consumption time for one cup of coffee is 15 min, and the quantity is 3.2 cups/day. Therefore, 24-hour storage time simulates about one month of coffee consumption. The samples were immersed in a coffee solution for seven days to simulate approximately 6-month of consumption. For this purpose, 2 g of instant coffee (Nescafe Classic, Nestle, Switzerland) was mixed with 200 ml of hot water to obtain the solution. The samples were immersed in individual containers perpendicularly to achieve uniform staining on each surface (Fig. 3). The coffee solution was refreshed every day.

After one week of storage, the samples were rinsed in distilled water for 1 min to remove excess colorant and were subsequently dried. The color of the samples was measured again using the same spectrophotometer and converted to the formula of the CIELab and the CIEDE2000 systems. These measurements were made by a single operator at the same time of day and under similar lighting conditions to provide a standard evaluation.

Color measurements were repeated three times for each specimen, and averages were recorded for L1*, a1*, and b1* using the CIELab color system. L* indicates 0 to

100 (lightness to darkness), a* represents chroma; green and red content ranking from -a (green) to +a (green), and b* represents hue ranking from -b (blue) to +b (yellow). The following formula was used to determine the ΔE values between color measurements according to the CIELab system [4, 28]:

$$\Delta E^* = \left[(L1^* - L0^*)2 + (a1^* - a0^*)2 + (b1^* - b0^*)^2\right]^{1/2}$$

Values according to the CIEDE2000 were also recorded as a second color evaluation. For each pair of samples, $\Delta L'$, $\Delta C'$, and $\Delta H'$ indicate the differences in lightness, chroma, and hue, respectively, according to the CIEDE2000 metric system. The weighting functions S_L, S_C, and S_H were used to adjust for the location of the color differences in the L', a', and b' values. The parametric factors K_L, K_C, and K_H served as correction terms for the experimental conditions. In addition, R_T was used as a rotation function that accounts for how chroma and hue variations interact in the blue region. The CIEDE2000 color formula was as follows [8, 28]:

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

After these color measurements, the discolored surfaces were repolished using the same systems (TWD or NOV) as those used at the beginning to restore the original color. The color recovery of the samples was measured as ΔE values using the CIELab and as ΔE00 values using the CIEDE2000 systems, as for the baseline and coffee immersion.

Scanning electron microscopy evaluation

The surfaces of the specimens were examined under a scanning electron microscope (SEM; Thermo Scientific Apreo S, The Netherlands) for possible damage caused by F/P procedures, and for discoloration. For this purpose, a randomly selected representative specimen (total of 10 specimens) from each subgroup was prepared for scanning electron microscopy without gold coatings. SEM photomicrographs of representative areas of the surfaces were taken at 10000x magnification.

The surfaces of the Mylar strips were also scanned to provide a comparative surface. After repolishing, the surfaces were examined for possible scratches or filler dislocations.

Statistical analysis

Statistical software (SPSS Statistics 25.0 from IBM, SPSS Incorporated, IBM Cooperation, NY, United States) was used to perform the analysis. Surface roughness and gloss values were analyzed using ANOVA, Tukey tests and Pearson correlation tests. The changes in ΔE and ΔE00 were evaluated using T tests, multivariate ANOVA, and Dunnett's post-hoc tests. The P-value of <0.05 was considered significant for all tests.

Results

Surface roughness and gloss

The smoothest surface that can be produced on a resin composite was achieved with a Mylar strip for all groups ($p<0.05$). TWD and NOV were able to polish all the tested single-shaded resin composites and the control group ($p>0.05$). In the TWD groups, the material with the smoothest surface was Omnichroma, and the difference between this material and the others was significant ($p<0.05$). In the NOV groups, the smoothest surfaces were obtained with Omnichroma and Zenchroma, and the difference between these groups and the others was significant ($p<0.05$) (Table 3).

The highest gloss level was observed for all materials in the Mylar strip groups ($p<0.05$). Regardless of the polishing system used, Omnichroma was the glossiest material, while Charisma Diamond One was the least glossy group. In the TWD groups, Omnichroma was glossier than all the other groups tested ($p<0.05$). In the NOV groups, Omnichroma and NeoSpectra ST HV were the glossiest

Table 3 Surface roughness values (Ra) and gloss measurements of the Mylar strip (M), TWD, and NOV polished groups for different resin composites. Different superscript letters in the same columns indicate statistically significant differences ($p<0.05$)

Surface roughness	TWD (Ra, µm)	NOV (Ra, µm)	Gloss	TWD	NOV
CDO	**0,21417**^{a}	**0,23028**^{A}	CDO	**22,48411**^{a}	**16,14272**^{C}
	0,05528 (M)	0,05639 (M)		71,68373 (M)	73,39890 (M)
EU	**0,21722**^{a}	**0,22000**^{A}	EU	**20,95029**^{a}	**24,40058**^{A}
	0,06056 (M)	0,06056 (M)		74,08772 (M)	74,31871 (M)
ZEN	**0,21611**^{a}	**0,19778**^{B}	ZEN	**25,65428**^{a}	**23,49341**^{A}
	0,05639 (M)	0,05833 (M)		73,79075 (M)	67,89840 (M)
OMN	**0,14278**^{b}	**0,15361**^{B}	OMN	**32,60157**^{b}	**32,89242**$^{B, D}$
	0,04750 (M)	0,06667 (M)		69,89228 (M)	65,67313 (M)
NS (control)	**0,21083**^{a}	**0,23917**^{A}	NS (control)	**25,65720**^{a}	**27,03205**$^{A, D}$
	0,06389 (M)	0,06417 (M)		75,24828 (M)	74,47132 (M)

Table 4 Pearson correlation p values of surface roughness and gloss of the tested resin composites according to the polishing systems

Groups	Twist Dia (TWD)	Nova Twist (NOV)
Charisma Diamond One	0,990	0,334
Essentia Universal	0,534	0,185
Zenchroma	**0,003***	0,984
Omnichroma	0,677	0,729
NeoSpectra ST HV	0,282	0,469

samples, while Charisma Diamond One was the least glossy group ($p=0.000$ for OMN and $p=0.006$ for NS) (Table 3).

There was no correlation between smoothness and gloss for any of the NOV and TWD groups, except for the TWD polished Zenchroma group ($p=0.003$)(Table 4).

Discolorations after coffee immersion

Results according to the CIELab system

Regardless of the materials and polishing systems used, the groups with Mylar strips were the most discolored ($p<0.05$). The amount of coffee discoloration that occurred was above the clinically acceptable level of $\Delta E=2$.

For TWD groups, Charisma Diamond One ($\Delta E=6.45$) and Essentia Universal ($\Delta E=5.61$) were the most discolored groups ($p=0.085$), while Zenchroma ($\Delta E=3.06$) and Omnichroma ($\Delta E=2.96$) were the least discolored ($p=1.000$). In NOV polished groups, Essentia Universal ($\Delta E=5.85$) and Charisma Diamond One ($\Delta E=5.68$) were the most discolored groups ($p=0.999$), while NeoSpectra ST HV, Omnichroma and Zenchroma were the least discolored ($\Delta E=3.48$; 3.70; 3.79, respectively) ($p=1.000$). The polishing wheel system used affected the ΔE values after storage in coffee for Charisma Diamond One ($p=0.015$), Omnichroma ($p=0.000$) and Zenchroma ($p=0.011$), with the NOV groups being the most discolored (Fig. 4).

After repolishing, Charisma Diamond One failed to reach the $\Delta E<2$ level, regardless of the polishing system used, while the other groups showed values well below this level ($p<0.05$). The polishing wheel system used influenced the recovery of the ΔE value after repolishing only for Omnichroma ($p=0.001$), where TWD recovered the color better than NOV (Fig. 4).

Results according to the CIEDE2000 system

Regardless of the materials and polishing systems used, the groups with Mylar strips were the most discolored ($p<0.05$). Coffee discoloration, which occurred in all groups, was above the clinically acceptable level of $\Delta E_{00}=1.8$.

In the TWD groups, Charisma Diamond One ($\Delta E_{00}=4.69$; SD=0.568) was the most discolored group ($p=0.000$), while Zenchroma ($\Delta E_{00}=2.16$; SD=0.326) and Omnichroma ($\Delta E_{00}=2.12$; SD=0.223) were the least discolored ($p=1.000$). Similarly, in the polished NOV groups, Charisma Diamond One ($\Delta E_{00}=4.06$; SD=0.438) and Essentia Universal ($\Delta E_{00}=3.62$; SD=0.517) were the most discolored groups ($p=0.266$), while NeoSpectra ST HV ($\Delta E_{00}=1.99$; SD=0.503) was significantly less discolored ($p=0.000$).

The polishing wheel system used affected ΔE_{00} values after storage in coffee for Charisma Diamond One ($p=0.006$), NeoSpectra ST HV ($p=0.008$), Omnichroma ($p=0.002$) and Zenchroma ($p=0.011$). Compared with the TWD group, the NOV group was more discoloured for Essentia Universal, Omnichroma and Zenchroma, while the degree of discoloration was lower for Charisma Diamond One and NeoSpectra ST HV (Fig. 5).

After repolishing, Charisma Diamond One failed to achieve $\Delta E_{00}=1.8$, regardless of the polishing system used, while the other groups had values well below this point ($p<0.05$). The polishing wheel system used influenced the recovery of the ΔE_{00} value after repolishing in Essentia Universal ($p=0.022$) and Omnichroma ($p=0.000$), where it was observed that TWD recovered the color better than NOV, except for the Essentia Universal group (Fig. 5).

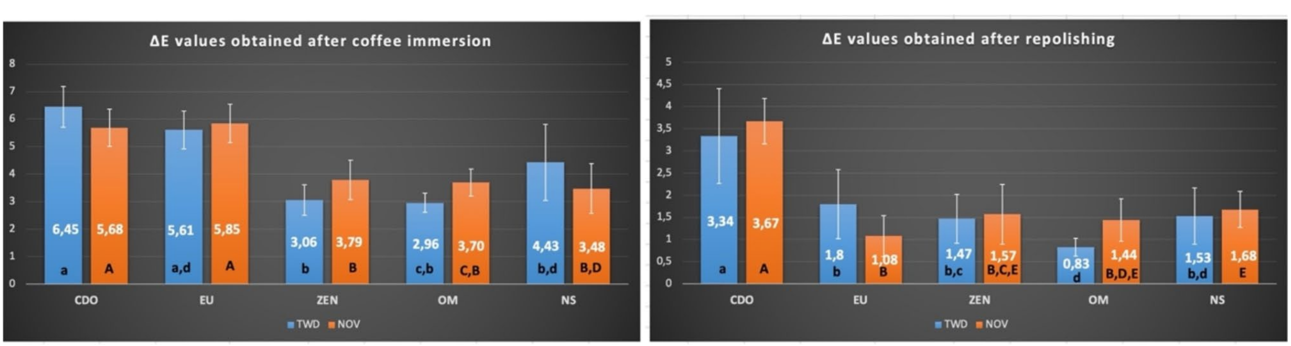

Fig. 4 ΔE values and SDs obtained after coffee immersion and after repolishing all the resin composites. Different letters in the columns indicate statistical significance according to multivariate ANOVA and Dunnett's T3 test

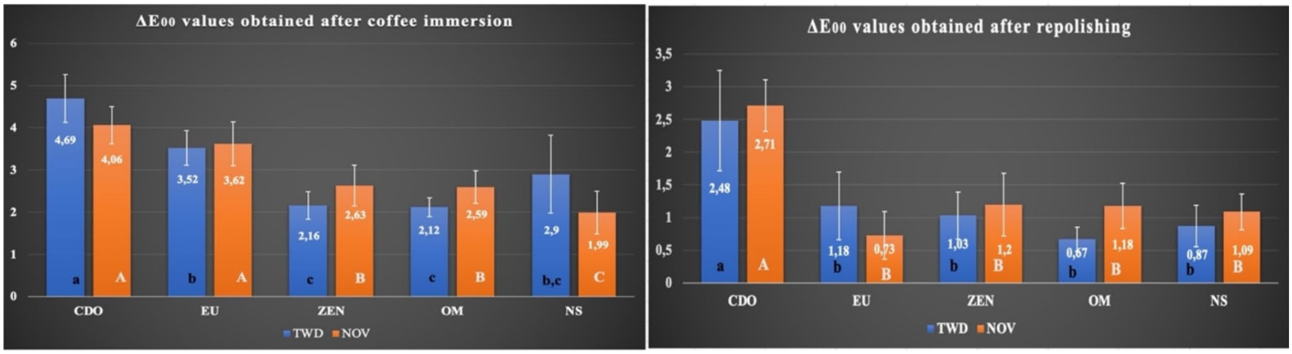

Fig. 5 ΔE00 values and SDs obtained after coffee immersion and repolishing of all the resin composites. Different letters in the columns indicate statistical significance according to multivariate ANOVA and Dunnett's T3 test

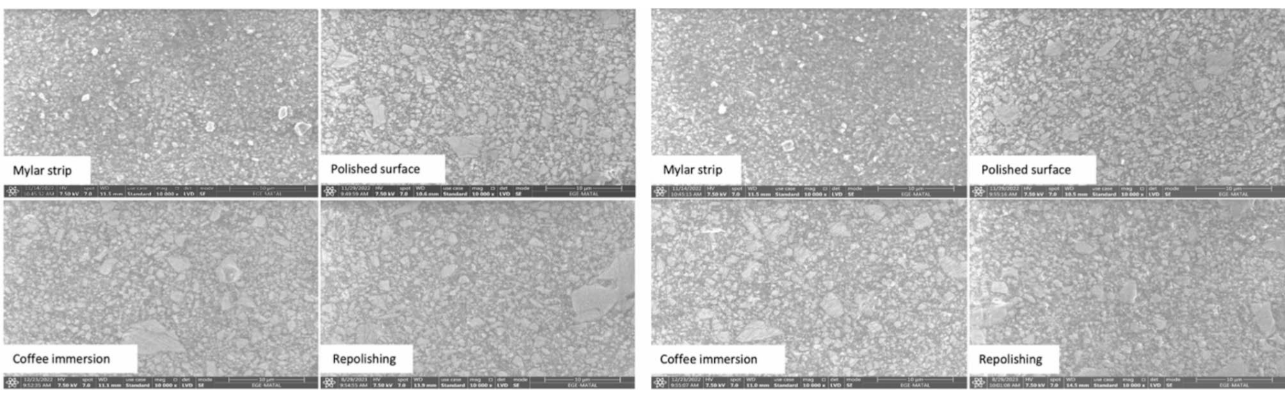

Fig. 6 SEM images after different applications on a Charisma Diamond One sample polished with a Twist Dia on the left side and a Nova Twist on the right side (1000x magnification)

Comparison between the CIELab and CIEDE2000 systems

Although the calculation method and color values were different for the two systems compared, the ranking of coffee discoloration among materials was similar for the TWD groups and almost the same for the NOV groups.

The repolishing values were lower for the CIEDE2000 evaluation system, but the rankings between the tested resin composites were almost the same for TWD and NOV (except for NeoSpectra ST HV) and for the CIELab values.

Scanning electron microscopy results

According to the SEM images, the composition of all the resin composites was clearly visible on the Mylar strip and polished surface. Moreover, high-quality polished surfaces with polishing wheels could be observed in all the groups. Twist Dia and Nova Twist, similar to the control group, produced smooth surfaces with only very shallow or no scratches on the surfaces of the resin composites, and repolishing of the specimens did not remove the particles on any of the materials tested. Consistent surfaces were obtained with both polishing systems, although the roughness values were identical for each resin composite. It was also found that the profilometric measurements were confirmed by SEM analysis.

The SEM images of Charisma Diamond One clearly show the presence of nanohybrid fillers in the material. The surface of the material remained unchanged after polishing, coffee immersion and repolishing (Fig. 6). Essentia Universal contains prepolymerized fillers, which can be clearly seen in Fig. 7. Immersion in coffee resulted in a bubbled smear-like layer on the surface, which was easily removed with repolishing. Zenchroma contains microhybrid and ultrafine fillers, as shown in Fig. 8, and Omnichroma has supraneopherical fillers that look like nanofillers, as shown in Fig. 9. Neither material was affected by the repolishing procedures, and no scratches or particle pull-outs were observed. NeoSpectra ST HV contains spherical, prepolymerized SphereTEC fillers, which make the material surfaces homogeneous and stable throughout the process (Fig. 10).

Discussion

The purpose of this in vitro study was to evaluate the surface roughness, gloss and color change of single-shaded resin composites polished with simplified systems after one week of coffee immersion and repolishing.

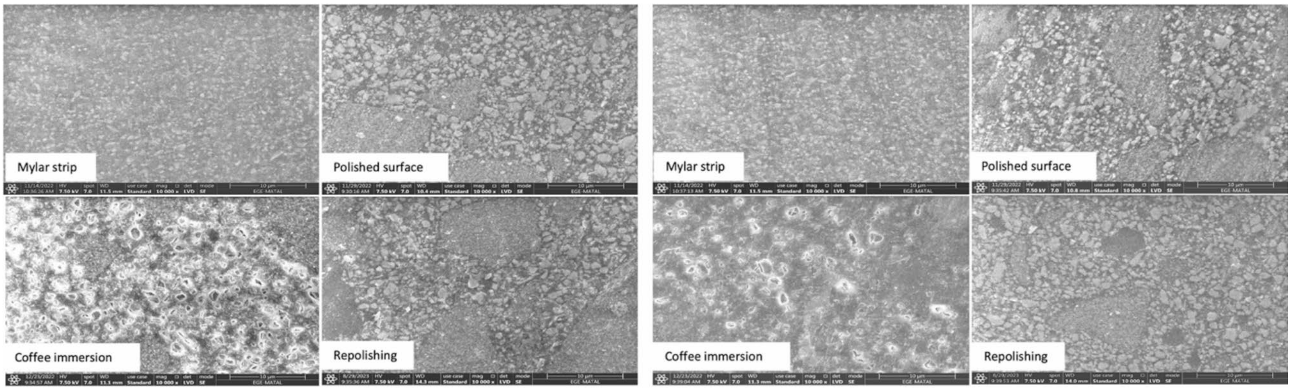

Fig. 7 SEM images after different applications on Essentia Universal samples polished with Twist Dia on the left side and Nova Twist on the right side (1000x magnification)

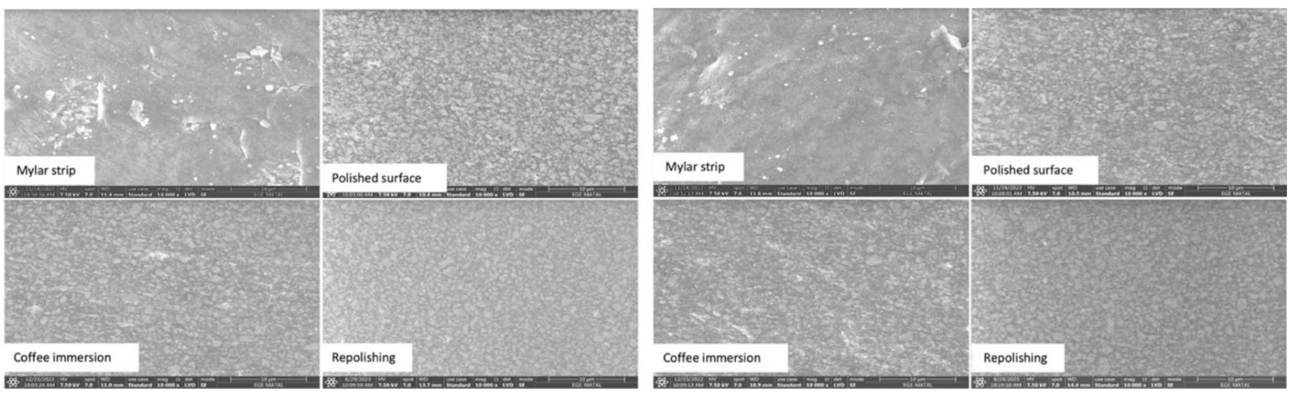

Fig. 8 SEM images after different applications on Zenchroma samples polished with Twist Dia on the left side and Nova Twist on the right side (1000x magnification)

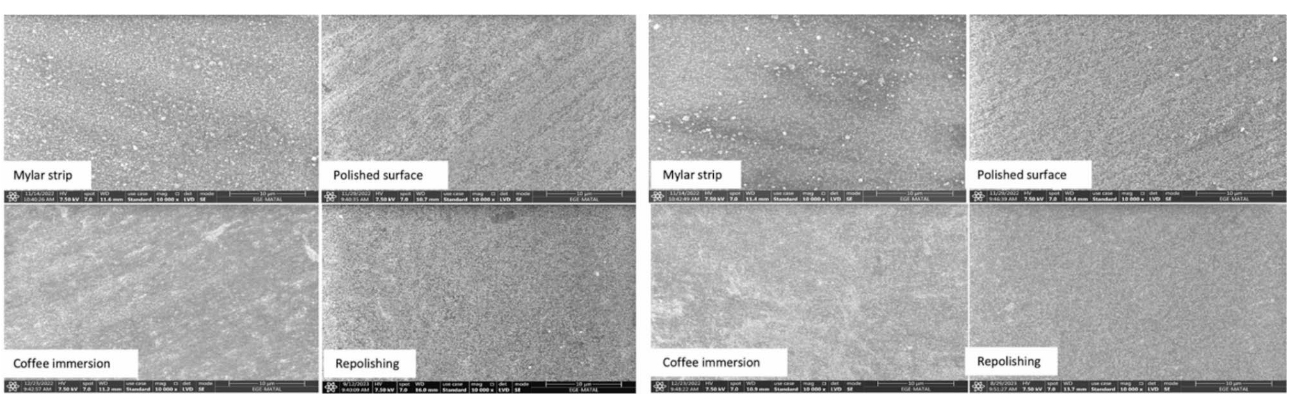

Fig. 9 SEM images after different applications on Omnichroma samples polished with Twist Dia on the left side and Nova Twist on the right side (1000x magnification)

Our first hypothesis stating that the surface roughness and gloss of single-shaded resin composites do not differ from those of the nanohybrid composites tested was rejected. Our second hypothesis, which states that prolonged immersion in coffee will not affect the color of the single-shaded resin composites compared to that of the nanohybrid composite tested, was rejected. Our third hypothesis, that the original color of the single-shaded resin composites cannot be restored by repolishing compared to that of the control group, was rejected.

Currently, for the finishing and polishing of esthetic restorations, the focus is on reduced systems that combine some of the F/P processes in one or two steps. The advantage of these systems is the ease and efficiency of producing a smooth surface without having to switch to finer polishing tools or having to wash/dry between each

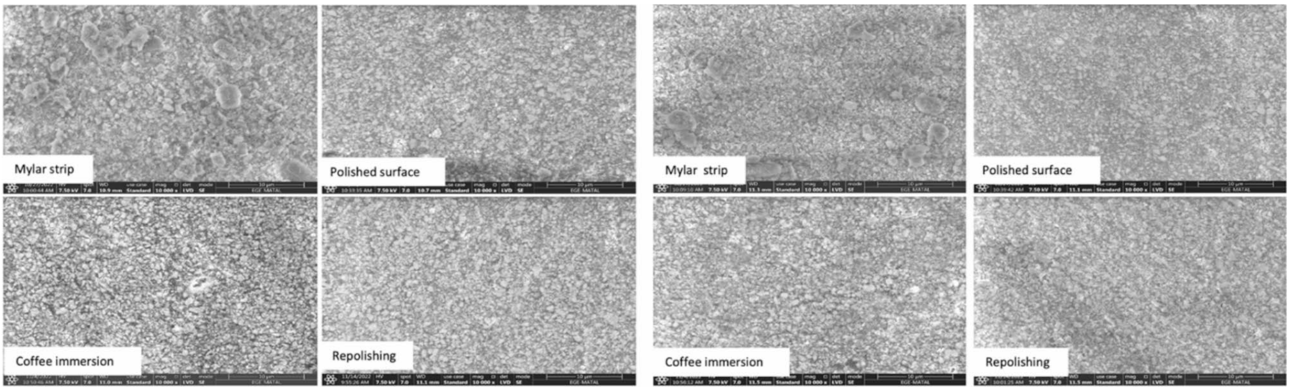

Fig. 10 SEM images after different applications on NeoSpectra ST HV samples polished with Twist Dia on the left side and Nova Twist on the right side (1000x magnification)

step [20, 35]. For that purpose, Sof-Lex spirals, Clearfil Twist Dia and Nova Twist wheels have been introduced as reduced two-step polishers. These flexible wheel designs with elastomeric bristles containing aluminum oxide and pure diamond particles impregnated in rubber can adapt to most surfaces of the restorations resulting in reduced surface roughness [35] Many studies in the past have investigated the effectiveness of multiple-step and reduced-step F/P instruments, with positive results for reduced-step wheel systems [14, 19, 20, 35]. It was concluded by Dennis et al. [35] that clinicians have today the choice of a wide range of reduced step polishers that could achieve similar or even superior outcomes than the multi-step systems. According to a recent study [36], Twist Dia polisher and other diamond-containing polishing systems could produce acceptable smooth, glossy surfaces and could be considered one of the preferable polishing systems for resin composite restorations. In the present study, no significant difference was found between the surface smoothness of the Clearfil Twist Dia and Nova Twist wheels on any of the single-shaded resin composites tested, except for Omnichroma, which had smoother surfaces than the others. This was attributed to the filler matrix of the material containing supra-nano-spherical fillers.

Profilometers have been used for years to measure the surface roughness of esthetic resin-based materials. They provide 2D information and an arithmetic mean roughness value, which is used to represent different material/polishing system combinations and helps clinicians in treatment selection [16, 20]. One study [15] reported that restorations appear visually smooth and clinically acceptable when their surface roughness is less than 1 µm (Ra value). Since the results of the specimens treated with the simplified wheel F/P systems in this study were in the range of 0.14–0.23 µm, the initial effects of both systems were accepted as "visibly smooth." In addition, as the limit for patients to detect surface roughness is 0.3 µm [15, 21], we can say that all these surfaces remained undetectable to the patients as well. Furthermore, according to our results, there was no significant difference between the surface smoothness achieved with the Twist Dia and Nova Twist wheels on all the single-shaded resin composite materials tested.

Gloss (GU) is used to quantify the shininess of a surface and is based on specular reflectance measured with a glossmeter at a specific angle through a specific aperture. Gloss is a complex phenomenon that is difficult to objectively evaluate because it is affected by the observer's perception [37]. Highly polished, plane black glass with a refractive index of 1.567 is defined as having a gloss of 100 GUs [20]. In restorative dentistry, the goal is to achieve a level of gloss that is comparable to that of enamel, with 40 through 60 GUs as the desired gloss [13, 38]. According to a recent study [39], specimens with GUs of 0 through 40 were considered low to moderate and therefore unacceptable, values of 50 through 80 were considered high and clinically acceptable, and values of 90 through 100 were considered superior. According to our results, the glossiness of our samples was quite low, with Mylar strip surfaces being glossy, with a GU ranging from 70 to 75. The highest gloss values that we obtained were from the Omnichroma group, with 32 GUs being very low in comparison to a previous study [39]. We did not evaluate the gloss of the materials after discoloration and repolishing, as our baseline values were already very low, and as a recent review on the subject revealed no correlation between surface roughness and gloss after toothbrushing abrasion [40]. A surface with scratches will show highlights emanating from the difference in topography from the peak to the trough of the scratches. Moreover, as the surface is rotated, these highlights will be displaced or incongruent with their surroundings, which will cause a reduced perception of gloss [41]. Antonson et al. [13], showed that the improvement of surface roughness may not directly result in similar improvement of surface gloss which can differ from material to material. Supporting these results, our SEM picture evaluations and our profilometer results were in accordance and the polished surfaces evaluated had very shallow or no scratches on their surfaces and the lower level of gloss could not be attributed to this phenomenon.

Increased surface gloss and smoothness are important for obtaining superior results and maintaining the marginal integrity of restorations. It is generally assumed that a reduced surface roughness will provide a higher gloss value. According to the study of Suzuki et al. [42], the GU values of resin composites evaluated after 80.000 toothbrushing strokes showed a significant decrease while their surfaces were getting rough. On the contrary, the CAD/CAM blocks containing smaller fillers retained higher GU values and smoother surfaces after the test period. According to their study, a negative correlation between GU and Ra was observed. On the other hand, it is very well known that the gloss of resin composite materials depends on the type of filler, its content in the material and the polishing systems used by the dentist [14, 19, 40, 43].

According to a recent review performed by Amaya-Pajares et al. [40] on the subject evaluating various dental composites after polishing and toothbrushing; suprananofill/nanofill/microfill resin composites tended to have smooth and glossy surfaces due to smaller particle sizes. Moreover, they showed that toothbrush abrasion resulted in surface roughness and reduction in gloss. On the other hand, 26% of the included studies showed an inverse correlation between surface smoothness and gloss, while 37% showed no significant correlation. Therefore, it was assumed that the relationship between gloss and roughness was different, but these parameters were mutually interacting and were not always related [40]. Our results show that this is true only for Zenchroma polished with the TWD system, while we did not find any correlations between surface smoothness and gloss for the other single-shade resin composites according to Pearson correlation test analysis.

According to a study performed by Tessarin et al. [44], the type of light in dental offices may be determinant for optimal esthetic treatment, since illuminants directly influence the optical perception of restorative materials and the surface gloss perception. Furthermore, the type of clinical illumination might influence the mimicking of a restoration outside the clinical setting under different lighting, as gloss perception under incandescent light is higher than under a fluorescent source. They found also that the incandescent and fluorescent lights differed, with the fluorescent light being the illuminant under which the observers perceived less difference in gloss. However, as the patient will be exposed to various illuminants, the dentist must ensure that the finishing and polishing protocol provides the optimal gloss match under all conditions and not only in fluorescent light. If a restoration loses gloss and becomes dull over time due to patient eating habits, the abrasiveness of toothpaste or an acidic diet, it can be easily repolished as part of a refurbishment treatment rather than being replaced. According to Rodrigues-Junior et al. [43], the surface roughness and gloss of restorations are affected by finishing and polishing procedures. According to the polishing system used, the resulting surface gloss may differ, meaning that a single polishing system will not behave similarly for all resin composites. In contrast to our results, they found that multistep F/P systems produced more gloss, while reduced-step systems produced more surface roughness and less gloss for all the materials tested. The reduced step that they used was Enhance, which is an aluminum oxide pre-polisher (40 µm) and not a polisher, which may have affected the roughness and gloss of the material tested.

When SEM images showing surface topographies of these two polishing wheel systems on monochromatic resin composites were evaluated, supporting findings were observed with the profilometric findings amongst all materials/wheel systems tested. It was evident that both two-step F/P systems showed homogeneous uniform surfaces across all resin composite groups with very shallow scratches on some surfaces. All the resin composites evaluated had mainly rounded and very small filler sizes making their polishing very easy, without scratching the surfaces or protruding any filler particles. This was also observed after the repolishing performed after the coffee discoloration process. Our findings are in accordance with Dennis et al.'s study [35] and Antonson et al.'s study [13].

Resin composites tend to discolor in the mouth after long-term use. Most of the water absorption of resin composites occurs during the first week [25]. Since stain absorption seems to be closely related to water absorption [18, 32], the discoloration of the restorations tended to follow the evolution of water. The staining effect of various beverages (coffee, tea, cola, red wine, chocolate drink, and food dye) on resin composites has been widely studied [14, 18, 19, 24–26, 32, 33]. In the present study, coffee, which is consumed daily in modern society and has proved to have a high capacity of staining resin composites [34, 45, 46], was selected as a weekly discoloring agent. In this process, staining agents may penetrate or remain on the surface of the resin composite restorations. Surface discoloration is closely related to the oral hygiene, diet, and smoking habits of patients. On the other hand, the nature of the resin itself may also be responsible for the different staining potentials of the resin composites. According to Sideridu et al. [45], resin materials containing urethane di-methacrylate (UDMA) appeared to be more stain resistant than materials containing di-methacrylate as an organic matrix. The current results of this study were consistent with this assumption, as all the single-shaded resin composites we tested, except for Charisma Diamond One, contained UDMA in their organic matrix and were less discolored than the control group containing methacrylate after one week of coffee storage. A possible explanation for the stronger discoloration observed in the Charisma Diamond One group, irrespective of the polishing system used, could be its lower filler content compared to the other single-shaded resin composites tested, leading to stronger water/colorant absorption.

According to a research group [29], the CIEDE2000 formula better reflects the color differences perceived by the human eye than does the CIELab formula and thus should be considered for use in clinical color analysis. In contrast to these findings, in another study, the data obtained showed a high correlation between the CIELab and CIEDE2000 formulas, and it was concluded that both color formulas can be used interchangeably for evaluation [47]. In accordance with these results, in the current study, both the CIELab and CIEDE2000 formulas (ΔE and ΔE_{00}) were calculated, and no statistically significant difference between them was found.

In the present study, the acceptable clinical limits for ΔE values were set at 2 as the threshold for the CIELab system and as $\Delta E_{00}=1.8$ for the CIEDE2000 system. According to our results, the color changes after 7 days of coffee immersion were perceptible in all the single-shaded composite resins and in the control group. These results are consistent with those of previous research [48–51]. However, repolishing restored the color of all the single-shaded resins to an imperceptible ΔE value of less than 2 and less than 1.8 for ΔE_{00} values, except for the Charisma Diamond One group.

After discoloration, tooth brushing with toothpaste, repolishing, and bleaching can remove all or part of this discoloration non-invasively and are alternatives to total replacement [11, 18, 19]. Moreover, repolishing an old restoration will not only restitute its original color but will eliminate the imperfections and make its surface smooth and glossy again, extending its in situ longevity by providing esthetic superiority [19]. Therefore, repolishing was chosen as a non-invasive treatment option in the present study to restitute all the baseline properties of the restorations. After polishing with the same system used before staining, all resin composites except Charisma Diamond One showed a decrease in ΔE and ΔE_{00} values to an imperceptible level (2 and 1.8, respectively). However, we believe that resin composite restorations in clinical situations cannot regain their original color after polishing alone, probably because of the penetration of staining substances into the materials [11, 18, 19], and that fine finishing followed by polishing may be more appropriate in these cases.

This in vitro research has several limitations. First, a profilometer was used to identify the form of the surface along particular routes during the roughness test. Using new technologies based on optical techniques would have helped to evaluate roughness not only on routes but also on entire regions, providing a significant escalation in the number of sampled points. Second, the gloss of the samples could have been evaluated by a more sophisticated device capable of detecting higher GUs. Further investigations, especially on the color matching ability of single-shaded resin composites, need to be performed in the future.

Conclusions

Within the limits of this in vitro study, the following conclusions were drawn:

- Smooth and glossy surfaces were achieved with the reduced-step Twist Dia and Nova Twist polishing wheel systems, regardless of the single-shaded composite resins used. The smoothest and shiniest surfaces were achieved with Omnichroma.
- Surface smoothness and gloss do not correlate with each other, except for Zenchroma.
- Immersion in coffee affects the color of the resin composites; however, Charisma Diamond One and Essentia Universal reacted more strongly to the discoloration process.
- The repolishing procedures ensure that the color recovery is below the acceptable limit for all the resin composites tested, except for Charisma Diamond One.
- The color evaluations with CIELab and CIEDE2000 gave similar results in the ranking of the materials, so using only one system to evaluate the color would be sufficient in further studies.

Abbreviations

TWD	Twist Dia
NOV	Nova Twist
OMN	Omnichroma
ZEN	Zenchroma
EU	Essentia Universal
CDO	Charisma Diamond One
NS	NeoSpectra ST HV
RC	Resin composites
F/P	Finishing and polishing
AFM	Atomic force microscope
PT	Perceptual threshold
AT	Acceptance threshold
GU	Gloss units
SEM	Scanning electron microscope
UDMA	Urethane di-methacrylate

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Author contributions
Conceptualization, LST, CC, AD and HB; methodology, LST, CC and AD; validation, LST, CC, AD and HB; formal analysis, LST and HB; investigation, LST, CC, AD and HB; writing—original draft preparation, LST, CC; writing—review and editing, LST, CC, AD and HB; supervision, LST, CC, AD and HB; project administration, LST, CC, AD and HB. All authors have read and agreed to the final manuscript version before submission and agreed to be accountable for all aspects of the study.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

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Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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