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Questioning the effectiveness of composite Polishing systems by crosschecking profilometer and dental microscope outcomes

Bora Korkut✉, Elif Alkan, Ezgi Kızıl Öztürk, Cafer Türkmen & Dilek Tağtekin

To investigate the clinical efficiency of the composite polishing systems and procedures by comparing device-based quantitative and visual inspections. Six composite polishing groups were prepared as per polishing discs (fine and super-fine, Sof-Lex), spiral wheels (prepolisher & high-shine-polisher, DiacompPlus), silicone cup (Enhance & Pogo), polishing paste (Lucida), rubber cup (Kenda), and sandpaper (1000 & 1500-grits). All were performed in three steps (3 × 30s), and paste was used for each. Surface roughness (Ra) was measured by a profilometer, and the Surface Roughness Index (SRI) was evaluated using a dental operating microscope (DOM). ANOVA, Kruskal-Wallis H, and Friedman tests were used (< 0.050). The first polishing step significantly increased Ra scores ($P < 0.05$) except for the paste group. The second step decreased Ra for all ($P < 0.05$). The best results were obtained after using polishing paste as the third step. A weak correlation was found between the SRI and Ra scores (rho = 0.287)($P < 0.001$). A weak correlation in the second (rho = 0.460)($P = 0.002$) and a moderate correlation in the third step were observed (rho = 0.549)($P < 0.001$). Outcomes were different for profilometer Ra and DOM SRI assessments. High SRI scores for the mylar strip corresponded to the low Ra scores. Therefore, Ra measurements may be misleading without DOM confirmation. Crosschecking device-based roughness scores with visual evaluations under magnification might be recommended. Lucida paste enhanced the polishing effectiveness for all systems. Different outcomes may be obtained in vitro through the device-based and visually driven surface roughness analyses, which are important for proper composite polishing system selection clinically. The polishing system and application procedure may affect not only the surface roughness but also the surface morphology of a restoration.

Keywords Polishing, SRI, Roughness, Profilometer, Magnification, Dental microscope

The quality of a restoration's surface is crucial for ensuring its clinical success and durability[1]. Advances in resin-based composite restorations and polishing materials have led to more effective restoration surface polishing with simpler techniques[2–4]. Achieving a smooth restoration surface with high gloss is essential for the optimal esthetic outcome, better soft tissue health, and maintaining the integrity of the restoration margins[5–7]. Rough restoration surfaces can compromise esthetics by diminishing light reflection, increasing susceptibility to external staining, and promoting plaque accumulation[6,8]. As the surface quality of the restoration is significantly influenced by the type of finishing and polishing system, the proper selection is critical to avoid these and prolong the longevity of the restoration[6,7,9]. Moreover, the size, shape, and abrasiveness of the finishing/polishing materials are important[2]. A wide range of single-step or multi-step composite polishing systems are available in the market, such as polyurethane-based discs, aluminum oxide discs, abrasive rubber cups, spiral diamond-embedded wheels, and polishing pastes[7,10–12]. Typically, the procedure involves using these materials with progressively decreasing abrasiveness from coarse to fine grits[11]. Clinically, it is crucial to select a polishing system that provides the smoothest surface in the shortest time with the fewest instruments[13].

The patients are often able to perceive surface roughness more than 0.3 µ with their tongue[7]. Clinical studies have determined that the threshold for bacterial plaque retention typically occurs at a surface roughness above 0.2 µ, which is generally accepted as the maximum roughness threshold for dental restorations[7,8]. Surface roughness can be evaluated both qualitatively and quantitatively[11]. Optical and mechanical profilometers, atomic force microscopes (AFM), and scanning electron microscopes (SEM) can be used for quantitative surface roughness

Department of Restorative Dentistry, Dentistry Faculty, Marmara University, Istanbul, Turkey. ✉email: bora.korkut@marmara.edu.tr

assessments[14]. Qualitative roughness assessments can be performed visually using the Surface Roughness Index[10] scores by direct inspection or through standardized macro photographs[2]. However, the effectiveness and quality of a composite polishing system can't be evaluated only by assessing the surface roughness[6,7]. Smoothening the surface by abrading minimum restorative material and maintaining the remaining surface morphology should be the goals of the procedure[6]. Regarding in vitro investigations, the standardization of the initial sample surface is also an important step to achieve an accurate outcome, which is usually disregarded in the literature[6,7]. To overcome this problem and provide more accurate information, clinicians and researchers can cross-check the statistical outcomes with magnified direct visual observations[15].

This in vitro study aimed to investigate the effect of various composite finishing and polishing systems on the surface roughness of disc-shaped composite samples by cross-checking the profilometer outcomes (Ra) with dental operating microscope (DOM) outcomes. The null hypotheses of the study were: (I) different polishing systems presented similar surface roughness scores, (II) device-based and visual assessments had similar outcomes regarding the roughness scores.

Materials and methods

Preparation of samples

The sample size calculated using G*Power 3.1.9.7 software based on a previous study[16] with an effect size of f = 0.675; α = 0.05; 1-β = 0.85 resulted in $n = 7$ for each group[17].

Forty disc-shaped samples were prepared by placing a universal nanohybrid resin composite (G-aenial A'chord, GC, Japan) into disc-shaped silicon molds with a 10 × 2 mm diameter. To obtain standardized initial sample surfaces, the composite material in the silicon mold was covered with a mylar strip (Hawe Stop-Strip, Kerr, USA) on the top and the bottom surface, then compressed between two glass slides to create smooth sample surfaces[18–22]. The oxygen inhibition layers on the top surfaces were avoided using a high-viscosity glycerine gel (Air Barrier, GC), and the samples were polymerized using a polywave LED curing unit (Valo Grand, Ultradent, USA) at a radiant power of 1000 mW for 20 s on each side and removed from the mold. The radiant power of the unit was checked before the sample preparation. The samples were then immersed in distilled water at room temperature, stored for 24 h, and subjected to 10.000 thermal cycles with 20 s dwell time at 5–55 °C temperature (corresponding to 1-year of clinical use) in a thermal cycle device (SD Mechatronik, Germany) before the surface polishing procedures[23].

Polishing groups and application protocols

The samples were randomly divided into six groups ($n = 7$ for each) based on the selected polishing system. The polishing disc group included two Al_2O_3 embedded discs (fine [24 µ] and superfine [8 µ]; Sof-Lex; 3 M) and a polishing paste (Lucida, Diashine USA) applied with a star-shaped felt (Lucida Click, DiaShine) as the third step. The spiral wheel group included two spiral-shaped, diamond-embedded spiral wheels (pre-polisher [40–50 µ] and high-shine polisher [3–6 µ]; Diacomp Twist Plus, EVE, Germany) and the polishing paste and the star-shaped felt as the third step. The silicone cup group included two Al_2O_3 embedded silicone cups (Enhance [40 µ] and Pogo [7 µ]; Dentsply, USA) and the polishing paste as the third step. The rubber cup group included a blue rubber polishing cup (Kenda [30–40 µ], Liechtenstein) and the polishing paste, and the star-shaped felt as the third step. The sandpaper group included two sandpapers (1000 and 1500 grits; Atlas) and the polishing paste and the star-shaped felt as the third step. A separate polishing paste group included the application of a diamond-embedded paste (Lucida) and star-shaped felt (Lucida) three times consequently (Fig. 1).

After 24 h of storage in distilled water, one side was polished for each sample as per the manufacturers' recommendations using the polishing systems presented in Table 1. All the polishing procedures were performed under 24X magnification by a dental microscope (OMS 2000, Zumax, China), in dry conditions. A latch-type slow-speed handpiece (Kavo, Bismarckring) was used in dry conditions for the polishing at 10.000 rpm. Each polishing step was used continuously for 30 s (90 s in total) for each system by rotating the sample a quarter turn every 5 s to a homogenous surface polishing (Figs. 2, 3, 4, 5, 6 and 7). Only the sandpaper application was done manually under wet conditions. After each step, the samples were rinsed with a water spray for 10 s to remove debris and air-dried. The press-on force was not calibrated in this study, but all the procedures were performed by a single, experienced restorative dentistry instructor under high magnification and illumination.

The data collection

The surface roughness of all samples was investigated using a contact profilometer (MarSurf PS10, Mahr), and surface roughness values (Ra) were recorded with 0.25 mm cut-off length, 4 mm tracing length, and 1 mm/s of stylus speed[24]. The initial Ra of each sample was measured before the polishing procedures. The Ra measurements were also performed after each step of the polishing procedures. To minimize the bias, nine measurements were performed on the sample surface. Three were obtained in the same position, then the sample was rotated by 60 degrees (in a clockwise direction) to perform three more measurements, and it was rotated again to perform another three measurements[24].

Additionally, 30° inclined surface images of all samples were captured at baseline, and after each polishing step to investigate the surface roughness through the light reflections. A full-frame mirrorless DSLR camera-integrated (Alpha 7III, Sony) dental operating microscope (DOM) (OMS 2000, Zumax) was used to obtain the standardized, 24X magnified, inclined images. On the collected images, the surfaces of the samples were evaluated by the operator using the Surface Roughness Index (SRI)[10] scores in a range between 1-to-4) (Table 2)[25]. To avoid misinterpretation due to the fingerprints on the samples, the surfaces were wiped using a glass cloth before the image capturing.

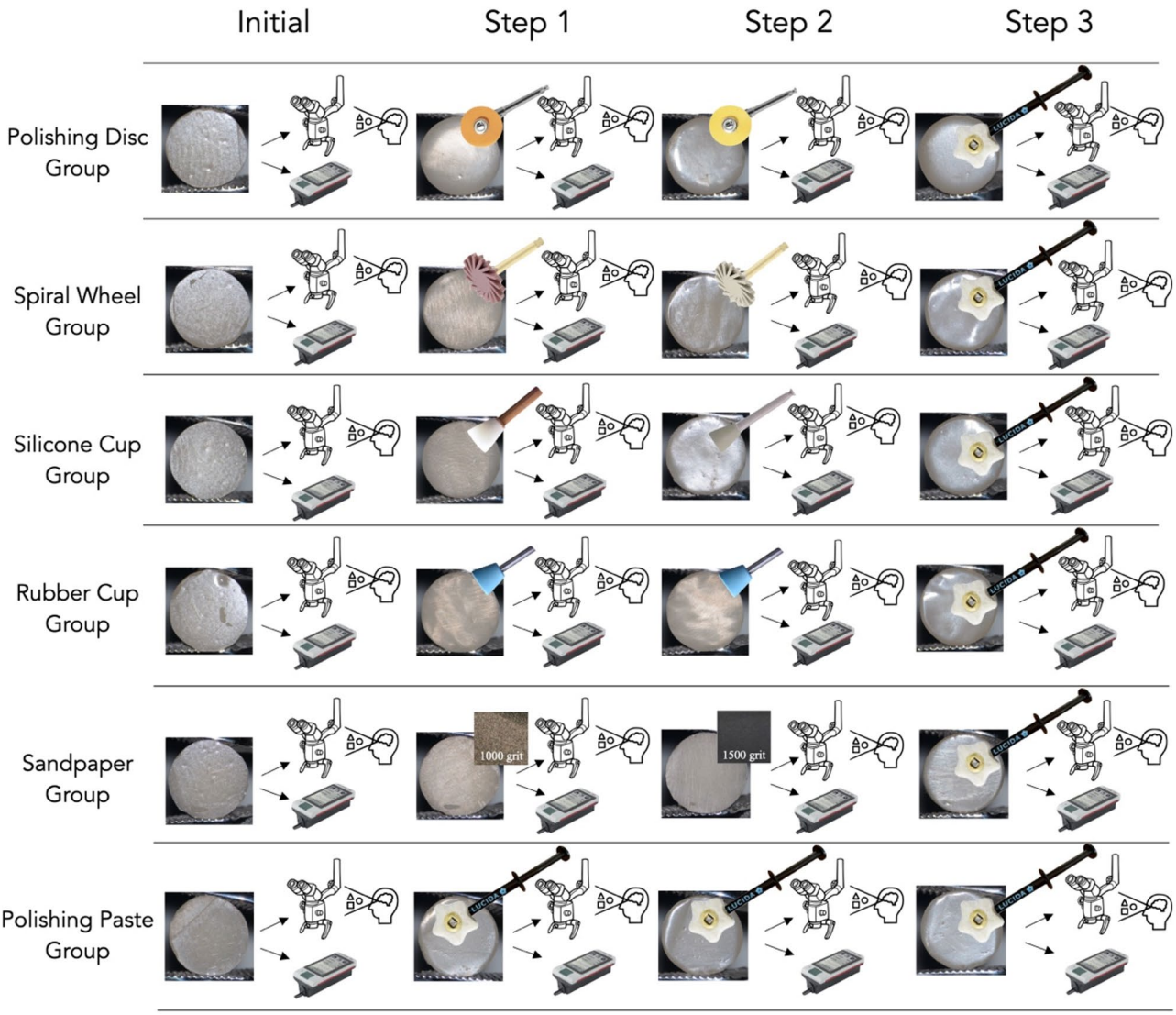

Fig. 1. The workflow chart of the study.

Material	Manufacturer	Content	Application Technique
Sof-Lex XT discs	3 M, USA	2-step aluminium oxide embedded flexible disc system. Fine (24 µ), and super fine (8 µ).	Step 1: Fine-grit (light orange) disc was used for 30 s. Step 2: Super-fine-grit (yellow) disc was used for 30 s. Step 3: Lucida paste with a star-shaped felt additionally for 30 s.
Diacomp Plus Twist Polishing Spiral Wheels	Eve, Germany	2-step polishing system with spiral wheels including diamond particles. Pre-polishing (pink, 40–50 µ), High-shine polishing (grey, 3–6 µ).	Step 1: Pre-polishing (pink) spiral wheel was used for 30 s. Step 2: High-shine polishing (grey) spiral wheel was used for 30 s. Step 3: Lucida paste with a star-shaped felt additionally for 30 s.
Enhance/Pogo	Dentsply Sirona, Germany	2-step aluminium oxide and diamond-embedded rubber cup system. Enhance (40 µ), Pogo (7 µ).	Step 1: Enhance cup was used for 30 s. Step 2: Pogo cup was used for 30 s. Step 3: Lucida paste with a star-shaped felt additionally for 30 s.
Rubber polishing cup	Kenda, Liechtenstein	Traditional medium grit blue rubber cup (30–40 µ).	Step 1: The rubber cup was used for 30 s. Step 2: The rubber cup was used for 30 s. Step 3: Lucida paste with a star-shaped felt additionally for 30 s.
Sandpaper	Atlas, Turkiye	1000-, 1500-grit sandpaper.	Step 1: 1000-grit sandpaper was used for 30 s. Step 2: 1500-grit sandpaper was used for 30 s. Step 3: Lucida paste with a star-shaped felt additionally for 30 s.
Lucida polishing paste	DiaShine, USA	One-step polishing paste used with star-shaped felt and mandrel. (n/a)	Step 1: Lucida paste with a star-shaped felt for 30 s. Step 2: Lucida paste with a star-shaped felt for an additional 30 s. Step 3: Lucida paste with a star-shaped felt for an additional 30 s.

Table 1. Contents and manufacturers of the selected composite Polishing systems.

SofLex

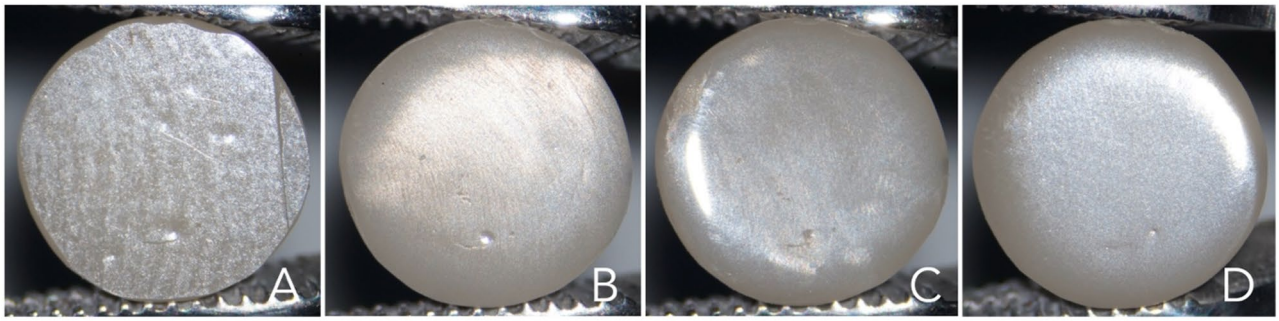

Fig. 2. DOM images of a composite sample in the polishing disc (Sof-Lex) group. (**A**) Initial, (**B**) 30 s of application with the fine disc, (**C**) 30 s of application with the superfine disc, (**D**) 30 s of application with the Lucida polishing paste with a star-shaped felt.

Eve Spiral

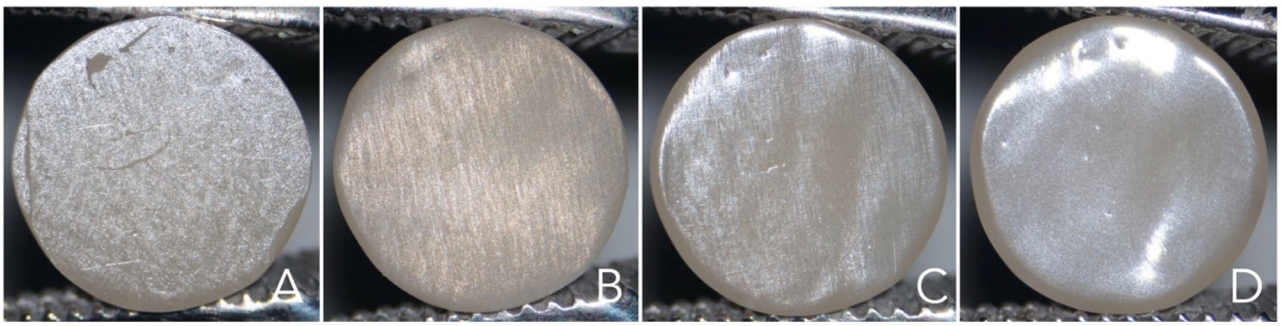

Fig. 3. DOM images of a composite sample in the spiral wheel (Diacomp Plus Twist) group. (**A**) Initial, (**B**) 30 s of application with the prepolisher, (**C**) 30 s of application with the high shine polisher, (**D**) 30 s of application with the Lucida polishing paste with a star-shaped felt.

Enhance Pogo

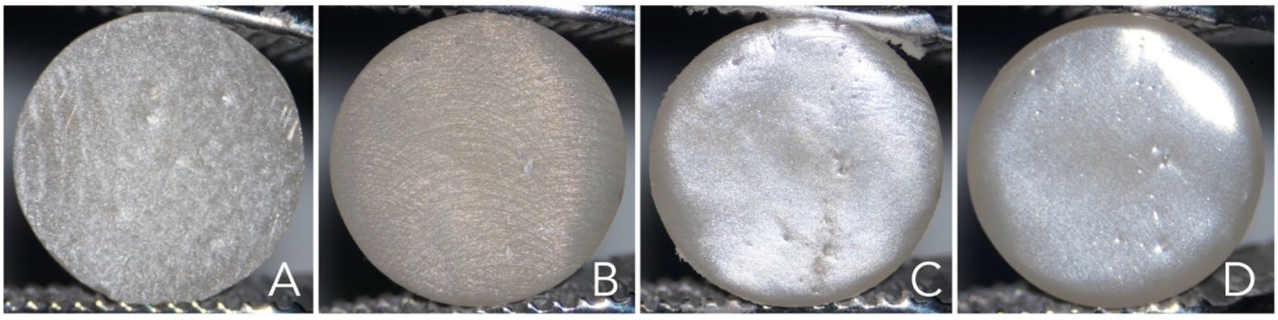

Fig. 4. DOM images of a composite sample in the silicone cups (Enhance & PoGo) group. (**A**) Initial, (**B**) 30 s of application with the Enhance cup, (**C**) 30 s of application with the PoGo cup, (**D**) 30 s of application with the Lucida polishing paste with a star-shaped felt.

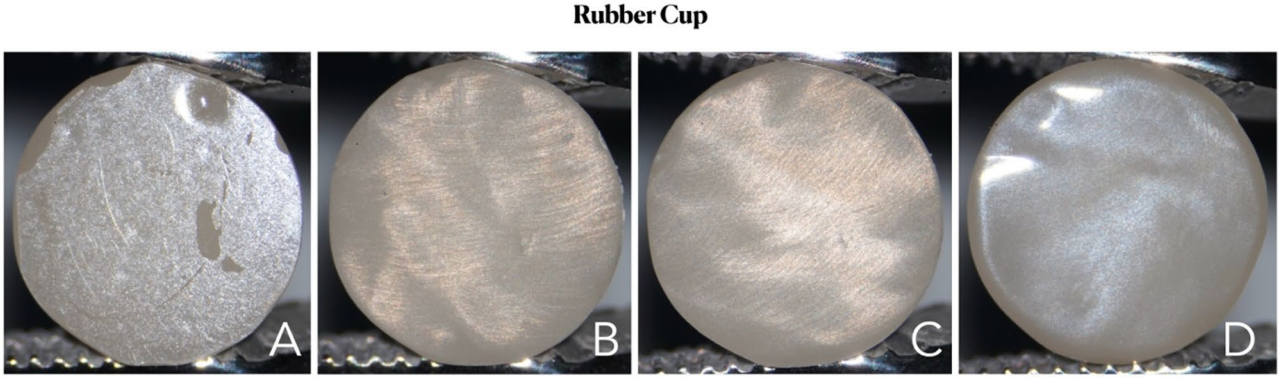

Fig. 5. DOM images of a composite sample in the rubber cup (Kenda) group. (**A**) Initial, (**B**) 30 s of application with the rubber cup, (**C**) Another 30 s of application with the rubber cup, (**D**) 30 s of application with the Lucida polishing paste with a star-shaped felt.

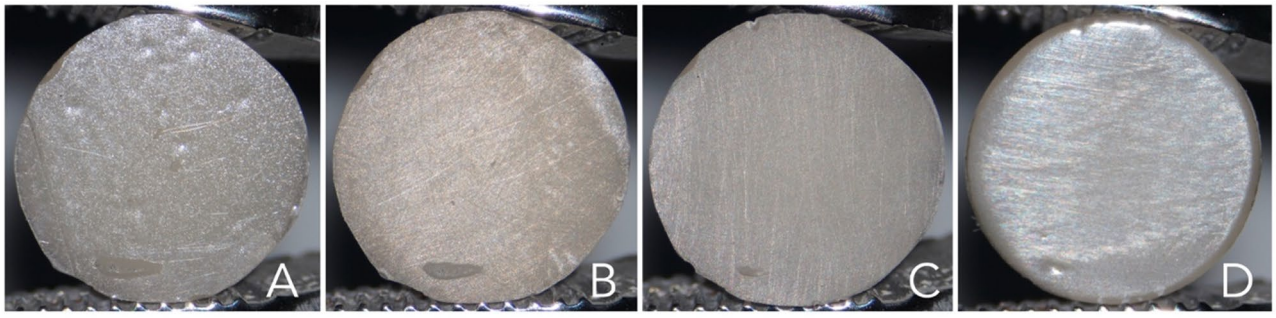

Fig. 6. DOM images of a composite sample in the sandpaper group. (**A**) Initial, (**B**) 30 s of application with the 1000-grit sandpaper, (**C**) 30 s of application with the 1500-grit sandpaper, (**D**) 30 s of application with the Lucida polishing paste with a star-shaped felt.

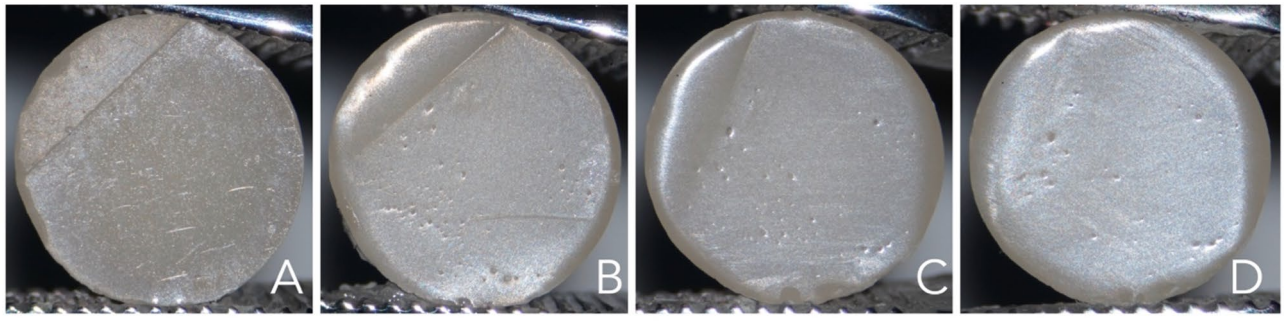

Fig. 7. DOM images of a composite sample in the polishing paste group. (**A**) Initial, (**B**-**D**) 3 × 30 s of consequent application with the Lucida polishing paste with a star-shaped felt.

Statistical analysis

Data were analyzed with IBM SPSS V25. The conformity to the normal distribution was observed with the Shapiro-Wilk test. One-way Analysis of Variance (ANOVA) was used to compare normally distributed data according to finishing and polishing groups. The Welch test was used for non-homogeneous variances. Multiple comparisons were analyzed with Tamhane and Tukey HSD tests. The Kruskal Wallis H test was used to compare the data that were not normally distributed according to the groups. Repeated Analysis of Variance was used to analyze within-group comparisons for normally distributed data, and the Friedman Test was used for not

Score	Description
0	Ideal surface with no scratches or damage
1	Acceptable smoothness with sporadic scratches
2	Fine, relatively shallow scratches over much of the surface
3	Rough surface, deep scratches over the whole of the surface
4	Very uneven surface, with very deep scratches over the whole of the surface

Table 2. SRI score chart according to Howell & Weeks[25].

Polishing system	Initial	Step 1	Step 2	Step 3	Test Stat.	*p****
Polishing Disc group	0.16 ± 0.015 ^{A}	0.21 ± 0.01 ^{cB}	0.17 ± 0.01 ^{dA}	0.16 ± 0.01 ^{bcA}	33.863	**< 0.001**
Spiral Wheel Group	0.17 ± 0.03 ^{AC}	0.40 ± 0.04 ^{abB}	0.19 ± 0.01 ^{bcA}	0.16 ± 0.01 ^{bC}	130.199	**< 0.001**
Silicone Cup Group	0.17 ± 0.04 ^{AC}	0.38 ± 0.06 ^{abB}	0.18 ± 0.05 ^{cdA}	0.15 ± 0.03 ^{cC}	226.308	**< 0.001**
Rubber Cup Group	0.22 ± 0.06 ^{B}	0.51 ± 0.21^{aC}	0.35 ± 0.04 ^{aA}	0.28 ± 0.03 ^{aB}	13.575	**0.007**
Sandpaper Group	0.16 ± 0.03 ^{B}	0.33 ± 0.02 ^{bcC}	0.26 ± 0.03 ^{bC}	0.15 ± 0.02 ^{cB}	118.367	**< 0.001**
Polishing Paste Group	0.29 ± 0.13 ^{A}	0.20 ± 0.07 ^{cA}	0.15 ± 0.04 ^{dB}	0.14 ± 0.04 ^{cC}	16.312	**0.006**
Test Stat.	2.357	14.387	26.147	26.470		
p	0.088*	**< 0.001***	**< 0.001****	**< 0.001****		

Table 3. Comparison of Polishing systems regarding the Ra values in each step. *Welch test; **One Way Analysis of Variance; ***Repeated measures analysis of variance; same letter codes (a-d in columns; A-C in rows) have no significant difference.

normally distributed data. Analysis results are presented as mean ± standard deviation for normally distributed data and median (minimum-maximum) for not normally distributed data. The significance level was set at < 0.05.

Results

Regarding the assessments of the surface roughness (Ra) values, the initial Ra values were similar for all the polishing systems ($P = 0.088$). However, the minimum obtained Ra value was 0.16 ± 0.015 (Table 3). After the first polishing step, the Ra values of all the polishing systems significantly increased ($P < 0.05$) except the polishing paste group, which remained the same. After the second polishing step, the Ra values of all the polishing systems significantly decreased ($P < 0.05$) except the sandpaper group, which remained the same. After the second step, the Ra values of the polishing disc, spiral wheel, and silicone cup groups were similar to the initial values ($P < 0.001$ for each). Whereas significantly higher Ra values for the rubber cup ($P = 0.007$) and sandpaper groups ($P < 0.001$) and lower Ra values for the polishing paste group ($P = 0.006$) were obtained. The third polishing step significantly decreased the Ra values for all the polishing systems ($P < 0.05$) except the polishing disc group, which remained the same.

At the end of the second polishing step, the polishing paste (0.15 ± 0.04 ^{d}), polishing disc (0.17 ± 0.01^{d}), and silicone cup (0.18 ± 0.05^{cd}) groups presented significantly lower Ra values than the other systems, while the rubber cup (0.35 ± 0.04^{a}) presented the highest Table 3). At the end of the third polishing step, the polishing paste (0.14 ± 0.04^{c}), sandpaper (0.15 ± 0.02^{c}), polishing disc (0.16 ± 0.01^{bc}), and silicone cup (0.15 ± 0.03^{c}) groups presented significantly lower Ra values than the other systems, while the rubber cup (0.28 ± 0.03^{a}) remained to show the highest.

Regarding the assessments of the Surface Roughness Index scores, the initial SRI scores were similar for all the polishing systems ($P = 0.018$). However, the minimum obtained Ra value was 4 (3–4) (Table 4). After the first polishing step, the SRI scores of all the polishing systems significantly decreased ($P < 0.001$). After the second polishing step, the SRI scores of all the polishing systems also significantly decreased ($P < 0.001$). After the third polishing step, the SRI scores of the sandpaper, spiral wheel, and silicone cup groups significantly decreased ($P < 0.001$ for each).

At the end of the second polishing step, the polishing paste [1 (1–1)^{b}] and polishing disc [1 (1–1)^{b}] groups presented significantly lower SRI scores among all ($P < 0.001$)(Table 4). At the end of the third polishing step, only the rubber cup group presented significantly higher SRI scores among all ($P < 0.001$) and other polishing systems presented similar SRI scores.

A weak correlation was found between the total Ra values and the SRI scores (rho = 0.287) ($P < 0.001$). Although a weak correlation was observed in the second step (rho = 0.460) ($P = 0.002$), a moderate correlation was observed in the third step (rho = 0.549) ($P < 0.001$).

Discussion

Both hypotheses of the study were rejected due to the different surface roughness levels obtained for different polishing systems and the weak correlation between the device-based and visual assessment outcomes.

Polishing system	Initial	Step 1	Step 2	Step 3	Test Stat.	p^{**}
Polishing Disc group	4 (3–4)^{A}	2 (1–2)^{dB}	1 (1–1)^{bC}	1 (1–1)^{bC}	19.000	< **0.001**
Spiral Wheel Group	4 (4–4)^{A}	3 (2–3)^{bcB}	2 (1–2)^{aC}	1 (1–1)^{bD}	19.453	< **0.001**
Silicone Cup Group	4 (4–4)^{A}	3 (3–3)^{abB}	2 (2–2)^{aC}	1 (1–1)^{bD}	21.000	< **0.001**
Rubber Cup Group	4 (4–4)^{A}	3 (3–4)^{aB}	2 (2–2)^{aC}	2 (1–2)^{aC}	19.935	< **0.001**
Sandpaper Group	4 (4–4)^{A}	3 (2–3)^{bcB}	2 (1–2)^{aC}	1 (1–1)^{bD}	20.194	< **0.001**
Polishing Paste Group	4 (3–4)^{A}	2 (2–2)^{cdB}	1 (1–1)^{bC}	1 (1–1)^{bC}	21.000	< **0.001**
Test Stat.	13.667	29.228	28.616	27.703		
p*	0.018	< **0.001**	< **0.001**	< **0.001**		

Table 4. Comparison of Polishing systems regarding the SRI scores in each step. * Kruskal Wallis H test; ** Friedman's test; same letter codes (a-d in columns; A-C in rows) have no significant difference.

Lower surface roughness of a restoration decreases plaque accumulation, secondary caries, and discoloration[26]. Bollen et al. stated that surface roughness values over 0.2 μ considered a potential bacterial plaque retention area[8]. Accordingly, the characteristic features of a resin-based composite material, such as surface roughness, gloss, translucency, and color stability, determine the optical properties of a restoration[27–29]. However, this in vitro study compared the polishing systems through a single-type resin composite, and therefore, the restorative material was not a variable. Instead, it searched for an answer to the following question: Is the device-based roughness (Ra) always compatible with the visually assessed roughness?

Regarding the composite restorations, the surfaces of the restoration should first be finished and then polished[30]. However, these procedures could not be isolated well in the literature due to the inclusion of both the finishing and polishing materials in some of the kits[30]. This study focused only on the finished composite surfaces' polishing procedure. Accordingly, the samples were produced by the mylar strip and glass setup, which was considered the best method to achieve smooth sample surfaces[30–32]. Therefore, the finishing procedure could be skipped in this study. Glycerine gel was used to avoid the oxygen inhibition layer, as previously suggested[9]. According to the results, the obtained Ra values of the initial sample surfaces were found to be similar in all groups. Thus, the surfaces were considered initially standardized (Table 3). Additionally, this standardization was supported by the SRI scores (Table 4). However, the observed weak correlation between the Ra values and the SRI scores revealed that the device-based roughness and the visually assessed roughness may not always be compatible. The lowest Ra value was 0.16 ± 0.03 in the present study, which corresponded to the highest 4 (4–4) visual SRI value[15,33]. The contact-type profilometer indicated very low surface roughness values at the initial and the second steps, while they were quite rough when scored visually under the DOM. This incompatibility might be due to the selected route[34] of the contact-type profilometer's tip on the sample surfaces. Even though the measurements were performed three times for each sample by rotating it 60 degrees, the small tip only contacted some specific areas on the surface, which might not exhibit the entire roughness. Therefore, it might be wise to question the trueness of the contact-type profilometer results for such studies. Also, regarding the incompatibility at the initial step, the visual SRI scores by the mylar strip were the highest compared to the other steps, and it was inconsistent with the results of various previous studies[30–32]. It might be possible for the studies that did not investigate the sample surfaces under a DOM to provide false positive outcomes regarding the level of surface roughness. Even though our Ra results revealed that the smoothest surfaces were generated with the mylar strip supporting Janus et al.[33] and Alfawaz[33] it seems not possible to reach the Ra value (0.20) of Janus et al. or Alfawaz (0.30) every time for all the samples (Table 3). Therefore, these results supported the previous studies recommending applying a standard finishing procedure to the sample surfaces before applying the polishing steps to better simulate the clinical situations[15,16]. Additionally, consistent with Vinagre et al.[35] considering no universally accepted gold standard polishing system is available, the polishing system and related steps should be selected depending on the initial roughness of the composite sample surface in vitro and restoration surface *in vivo*.

The number of polishing steps is controversial in the literature, which is especially important for polishing discs and polishing cups. Janus et al. and Korkut B. used four grits of Sof-Lex discs in their study[30,38], while Dennis et al.[32] used four grits of Sof-Lex discs from coarse to ultrafine, followed by Enhance Polishing Cup and DiaPolisher diamond paste (GC Corp.). Costa et al.[15] used a one-step silicone cup PoGo without using the Enhance step. Atash et al.[21] used two steps of Sof-Lex discs, while Jung et al. used the last three grits of Sof-Lex discs for the composite surface polishing. Moreover, almost all the previous research in the literature focused on the assessment of the surface roughness rather than the volumetric loss during the polishing procedures[6,7]. However, an optimal surface polishing system should create a smooth surface without changing the established surface morphology[36]. Aluminum oxide particles are harder than the majority of the fillers used in resin composites. Therefore, they can remove equal amounts from both inorganic filler particles and the resin matrix and thereby may change the surface texture[37]. Korkut and Unal. reported that the surface abrasiveness of the four grits of Sof-Lex discs (coarse, medium, fine, and superfine) was the highest (91 μ on average) among the investigated polishing systems[6]. Accordingly, the shape and design of the polishing discs may affect the outcome. Thus, discs with elastomeric bristles or spirals that are uniformly impregnated with abrasives can tolerate the press-on force during the application and minimize the unwanted pressure[12]. Consistently, in the present study, the round light reflections in the DOM images of the Sof-Lex disc group at the second and third steps revealed

that these aluminum oxide-embedded discs changed the macro surface morphology of the samples (Fig. 2). Whereas the macro surface structures in the other groups remained (Figs.3,4,5,6 and 7).

Several studies considered the aluminum oxide involving Sof-Lex Discs the best polishing tool for removing surface irregularities and providing smoothness[9,32,38,39]. In this study, only two grits (fine and superfine) of the Sof-Lex discs were used for 30 s each. According to the Ra results of the second step (after 60 s of use), smoother surfaces were provided than the spiral wheel, rubber cup, and sandpaper groups, consistent with the results of Uctasli et al.[31] Moreover, other than the Sof-Lex discs and silicone cup groups, the spiral wheel also presented a surface roughness (Ra) below 0.20, but the rubber cup group, which was partially consistent with Dennis et al. mentioning similar surface roughness below 0.2 μ for the two-step rubber cups (Polishettes, Kenda) and spiral wheels (Daitech Shapeguard, Coltene)[32]. Costa et al. considered the one-step use of silicone cup PoGo (Ra = 0.16) superior to the three-grit of the Sof-Lex disc (Ra = 0.21) with no statistical difference between them[15]. Alfawaz agreed with lower Ra values of 0.10 and 0.08 for the three grits of Sof-Lex discs and 0.04 and 0.06 for the PoGo[33]. These results are inconsistent with our results as the SofLex discs provided lower Ra values (0.17 ± 0.01) after the second step than the Enhance & PoGo (0.18 ± 0.05). This disagreement might be due to the different number of steps used for the polishing systems and the polishing time spent for each step as well. Such in vitro studies investigate the polishing effectiveness of composite samples with plane surfaces that were not rough at all, as mentioned in the initial results of Table 3. Moreover, probably depending on the grit of the first step of the polishing system, surface roughness is first increased and then decreased again by the further steps. Inconsistent with our results, Atash et al. mentioned that the spiral wheels (Diacomp plus, EVE) presented better Ra outcomes (0.58) than two grits of the Sof-Lex discs (0.70)[16]. Whereas, Korkut B. considered four grits of Sof-Lex disc application for 120 s and two steps of the spiral wheel (Twist Dia, Kuraray) application for 60 s, the most effective polishing systems among the other systems involving the Enhance & PoGo[38]. The differences in polishing steps and polishing durations might be the reasons for the controversial outcomes mentioned above. Even 1000 and 1500 grits of sandpaper, which is a common material to standardize the composite sample surface initially[39], created a rougher surface (Ra = 0.33 ± 0.02) than the initial surface by the mylar strip in the present study after 30 s of use (Table 3). Therefore, it might be wise to select the starting grit of a polishing system depending on the surface roughness of the sample. However, even with similar polishing durations and number of steps, Sarac et al. reported higher mean Ra values (0.79) for the Sof-Lex polishing discs (medium, fine, and superfine) and rubber cups (0.96) (Astropol, Ivoclar) compared to our results[39]. This might be due to the effect of the press-on force variable by the operator during the polishing procedure[6,7,12]. Also, the particle sizes in the resin matrix of the composite might influence the outcomes[31].

Besides the device-based Ra outcomes, the visual SRI scores under the DOM indicated a weak correlation in the second step. This was due to the difference in the silicone cup group, where lower visual scores were collected compared to the device-based scores (Tables 3 and 4). Even though weak correlation, it might be interpreted that the device-based and visual scores seemed relatively compatible after the second step of polishing, unlike the initial step.

Various researchers investigated the influence of the polishing paste as an additional step after a single- or multi-step polishing system. Yet, some authors think that the use of additional polishing paste is optional[2,7]. Aydın et al. stated that the use of additional polishing paste reduces the composite surface roughness[40]. In agreement with this, Atash et al. determined that the use of polishing paste (Diamond Polish Paste, Ultradent) for 20 s improved the surface roughness for both the spiral wheels and two-step Sof-Lex discs[16]. The results of the present study were also consistent with these results. All investigated polishing systems' effectiveness was enhanced with the additional use of the polishing paste for 30 s, and all systems except the rubber cup presented surface roughness within acceptable limits (Ra < 0.02) after the use. Even though a weak correlation between the SRI and Ra scores in the third step, the device-based and visual scores seemed relatively compatible, consistent with Jaramillo-Cartagena et al. considering multi-step systems more efficient than single-step systems[41]. Therefore, the use of Lucida polishing paste as an additional last step might be recommended clinically for a more effective polishing. Additionally, in this study, the best Ra and SRI scores were obtained by the single use of the polishing paste for a prolonged time, like 90 s. This outcome might also be useful clinically if the initial surface of the restoration was finished priorly to and had an initial surface roughness (Ra) level < 0.20 (Table 3).

This in vitro study might have some limitations. Only a nanohybrid, paste-type resin composite from a single brand was used, while other composite types and brands may influence the outcomes[16,31]. Also, the shape of the polishing material can be an influencing factor. The more the polishing material touches the surface, the more effective the polishing will be[7]. However, polishing procedures were only performed on flat surfaces, which might have influenced the outcome. Additionally, even though the polishing procedures were performed by a single operator, the press-on force was neither standardized nor monitored during the applications. This might have caused operator bias due to the various polishing pressures and influenced the outcomes of this study[6].

Conclusion

Within the limitations of the current study, it was concluded that:

I. Sof-Lex and Enhance & PoGo systems were considered more effective when no additional polishing paste was used. The rubber cup was considered the least effective among all. The application of Lucida polishing paste with felt as a third step for composite polishing may enhance the effectiveness of all the polishing systems. It might be beneficial to select the polishing system and related steps depending on the initial roughness of the composite surface.
II. The surface roughness outcomes were not the same for the device-based profilometer and visually driven dental operating microscope assessments, especially at the initial step. Very high SRI scores observed for the mylar strip corresponded to the very low Ra values. Therefore, Ra measurements may be misleading

without DOM confirmation. Cross-checking the quantitative device-based roughness scores with the visual evaluations under magnification might be recommended in this regard.

Data availability

The statistical data can be obtained from www.eistatistik.com.

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Author contributions

Conception and Design: BK and DTData Acquisition and Analysis: BK and DT Statistical Analysis: EAData Interpretation and Writing of the Original Draft: BK, EA, and EKÖManuscript Review and Revisions: DT and CT.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to B.K.

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