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Effect of magnification and press-on force on resin composite polishing

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Abstract

Objective To evaluate surface roughness (Ra) and gloss (GU) of two resin composites after polishing with two systems, using a novel press-on force guided (PFG) polishing simulator.

Materials and methods Eighty specimens were prepared using Essentia Universal (EU) and G-aenial Universal Injectable (GUI) composites. Surface roughness and gloss were assessed by a profilometer (Marsurf Ps10), and a glossmeter (Novo-Curve). They were polished with Sof-Lex and Twist Dia systems with or without magnification and PFG. Each polishing material was used for 30 s. Ra_1 and GU_1 measurements were repeated by the same operator. Data were analyzed using One-way ANOVA, Three-way ANOVA, and Robust ANOVA with Bonferroni Correction for multiple comparisons and Spearman's rho Correlation Coefficient (< 0.050).

Results Higher Ra values were observed in GUI group for Twist Dia (0.33 ± 0.05^z) compared to SofLex (0.22 ± 0.08^y). Roughness was higher when PFG was uncontrolled (0.31 ± 0.07^x), compared to the controlled (0.25 ± 0.09^w). No Ra difference was observed in EU group between SofLex (0.33 ± 0.04) and Twist Dia (0.29 ± 0.04)($P = .440$). Uncontrolled PFG provided higher gloss for GUI and EU composites (69.7 ± 2.91^x, 54.63 ± 18.68^x, respectively). Twist Dia presented higher gloss for GUI and EU composites (72.3 ± 2.57^z, 58.88 ± 13.73^z, respectively). Magnification did not affect the roughness or gloss for both composites ($P \geq .05$). A moderate negative correlation was found between roughness and gloss in GUI (r=-.546)($P < .001$), while no correlation was observed in EU (r=-.110)($P = .449$).

Conclusion Higher surface roughness and gloss were observed with uncontrolled (not constant) press-on force. Even though SofLex may provide a lower surface roughness, Twist Dia can generate a greater surface gloss regardless of the composite type. 3.5X loupe magnification was not effective on surface roughness and gloss within a limited polishing time.

Clinical Relevance Press-on force is an important factor affecting the composite polishing quality. Spiral polishing wheels can be advantageous for composite restoration polishing, as they better preserve the secondary and tertiary anatomies and provide a higher gloss. The effect of magnification on composite polishing can be related to the time spent using it.

Keywords Press-on force, Loupe magnification, Composite, Roughness, Resin composite gloss, Polishing simulator

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Introduction

The surface roughness of a direct resin composite restoration is one of the most important factors determining its clinical success and longevity [1, 2]. It is directly related to the gloss, color stability, and thus the esthetics, mechanical properties, and wear kinetics of a restoration. The patients can perceive surface roughness of more than 0.3 µm with the tongue [3]. In addition, increased surface roughness can increase biofilm adhesion and maturation, gingival irritation, and the recurrence of caries lesions [4]. A surface roughness of more than 0.2 µm was determined to be perceived by the patient's tongue, which was generally accepted as the maximum roughness threshold for dental restorations [3]. Therefore, surface roughness is also related to tactile perception and, thus, patient comfort [5]. Regarding the composite restorations, finishing and polishing procedures are mandatory after layering to eliminate the surface roughness [3]. Finishing is defined as rough contouring or reduction to obtain the desired morphology of the restoration, while polishing refers to the reduction of roughness and scratches typically caused by the finishing instruments and to provide a glossy surface [6]. The structure of the resin composite materials was improved to enhance the surface polishability and, thereby, the color stability in the long term [7, 8]. The major change was in the modification of inorganic filler content, such as reduction in the filler size, alterations in the filler shape, and an increase in the filler ratio [9].

Various finishing and polishing materials in different sizes and shapes have been introduced for the effectiveness of the materials for different anatomical forms of the tooth. The shapes consist of cups, tips, points, flames, coated abrasive disks and strips, brushes, wheels, and spiral wheels [3, 6]. In addition, different types of particles were embedded in the finishing and polishing materials, such as aluminum oxide, silicon carbide, polyurethane, or diamond particles, to reinforce the efficacy of the polishing [3, 10]. Also, materials for polishing both resin composites and ceramic surfaces were recently introduced [3]. Additionally, different levels of surface abrasiveness from different finishing and polishing materials and steps were previously reported, and the possible effect of the press-on force on this during the application was indicated [10]. Thus, the finishing and polishing were considered a highly material-dependent and technique-sensitive procedure [6, 10, 11].

The press-on force is another variable that determines the effectiveness of the finishing and polishing procedure in terms of gloss and surface roughness, depending on the resin-based material [10, 12]. Heintze et al. and Yu et al. pointed out that in most of the in vitro studies, the press-on force is not controlled or stabilized, and this aspect was not even mentioned in the studies [12, 13]. The press-on force of ≤ 2 N was considered a critical value by some manufacturers, such as Kenda (USA) and Shofu (Japan) [3]. However, it is not always possible to standardize it and maintain the exact level of pressure clinically for the operator. Various previous in vitro studies used unidirectional forces, whereas the force vector is also an important parameter [12]. It is clinically irrelevant to apply unidirectional force, especially when considering the anatomy of the tooth [10]. Krejci et al. evaluated the abrasiveness of bristles in vitro using a unidirectional force of 2.5 N, but they provided no information about standardizing the press-on force [14]. The shape of the polishing material and the contact angle to the corresponding tooth surface were also considered influencing parameters for the press-on force [3]. In this context, large flames and cups have been reported to conduct larger forces compared to small flames and lenses [3, 12]. Consequently, the quality of the polishing cannot be evaluated only by the level of surface smoothening but also by assessing the gloss and the remaining surface morphology [3].

Working under magnification allows a more conservative and precise approach to the restorative procedures [15]. In addition, magnification can improve the quality of finishing and polishing procedures when it comes to assessing and correcting rough restoration surfaces that cannot be visible to the naked eye [16]. Operating movements with a precision of 1–2 mm were previously reported for dentists working without magnification, whereas it was approximately 10–20 µm under 20X magnification [17]. The limit to the precision of the treatment was therefore considered not in the hands but in the eyes.

There is a lack of simulation of correct clinical conditions for finishing and polishing procedures in the literature [12]. A proper polishing simulator must address issues such as standardization, accuracy, and reliability through multi-directional press-on force guidance [10, 12]. Moreover, it might be more reliable to investigate the effect of magnification in this regard. Therefore, the present study aimed to assess the surface roughness (Ra) and surface gloss of micro- and nano-hybrid composite specimens after finishing and polishing procedures with two polishing systems using a novel Press-on Force-Guided (PFG) Polishing Simulator, with and without magnification. The null hypotheses of the study were: (I) The press-on force guidance did not affect the surface roughness and gloss, and (II) Magnification did not affect the surface roughness and gloss. (III) There will be no difference in surface roughness and gloss for the investigated finishing/polishing systems.

Materials and methods

The sample size was calculated using G*Power 3.1.9.7 software based on an ANOVA test with an effect size of f = 0.4; α = 0.15; 1-β = 0.80, *n* = 5 for each subgroup [18].

Eighty disc-shaped composite samples from two types of resin composites were prepared using disc-shaped silicon molds with a 10 mm diameter and 2 mm thickness. To obtain standardized initial specimen surfaces, the composite in the mold was covered using a mylar strip on the top and the bottom surface, then compressed between two glass slides [19]. The polymerization was performed using a polywave LED curing unit (Valo Grand, Ultradent, USA) at 1000 mW of radiant exitance for 20 s on each side. Two main groups were created as per the selected two composites. A micro-hybrid (Essentia Universal, GC Corp., EU) and a nano-hybrid (G-aenial Universal Injectable A2 shade, GC Corp., GUI) were used. The samples in each composite group were randomly divided into two subgroups as per the polishing systems: Sof-Lex (medium [40], fine [24µ], and superfine [8µ], 3 M, USA) and Twist Dia (pre-polisher [40–50µ] and high-shine polisher [3–6µ], Kuraray, Japan). The types of resin composites and polishing systems are listed in Table 1.

The specimens in each polishing group were further subdivided according to the use or no use of 3.5X magnification and the press-on force guidance, respectively (*n* = 5). The workflow chart is presented in Fig. 1. A single, experienced (5 years of experience) restorative dentistry instructor performed the polishing procedures. The 3.5X loupes were used under constant 5500 K° illumination. To avoid eye fatigue, the operator looked at a blue colored surface before polishing every specimen's surface. The specimen flat surfaces were also standardized by the operator using silicon carbide abrasive papers in 600, 800, and 1000 grits. The abrasive papers were renewed for each specimen. Then, before the initial assessments, the thickness of each specimen was calculated (three times for each specimen) by the operator using an industrial digital screw-type micrometer (0.001 mm) with 25–50 mm measuring range (ME-DI-MIC-25- 50-LD Digital Micrometer, Allendale Group Ltd., UK) [10]. The average hickness values were used for statistical analysis, and following the observation of no significant difference between the initial thicknesses, the assessments of the study were initiated.

Table 1 The type of resin composites and Polishing systems

Material	Type	Content	Manufacturer
Essentia Universal Shade (EU)	Microhybrid Composite	Resin matrix: UDMA, Bis-MEPP, Bis-EMA, Bis-GMA, TEGDMA. Inorganic filler: pre-polymerised fillers (17 µm): strontium glass (400 nm), lanthanide flüoride (100 nm), fumed silica (16 nm) FAlSi glass (850 nm), 81% wt	GC Corp., Japan
G-aenial Universal Injectable (GUI)	Nano-hybrid Composite	Resin matrix: UDMA, Bis-MEPP, TEGDMA, pigment, photoinitiator. Inorganic filler: Silicon dioxide, strontium glass (10–200 nm), 69% wt, 50% vol	GC Corp., Japan
Sof-Lex Disc	Polishing Discs	Medium (40µ), Fine (24µ), and SuperFine (8µ) grits	3 M ESPE, USA
Twist Dia	Polishing Spiral Wheels	Pre-polisher (14µ) and High-shine polisher (10µ) grits	Kuraray Noritake, Japan

Bis-GMA bisphenol A diglycidil dimethacrylate, *Bis-EMA* bisphenol A glycol methacrylate ethoxylated, *TEGDMA* triethylene glycol dimethacrylate, *UDMA* urethane dimethacrylate, *Bis-MPEPP* 2,2-bis[(4-methacryloxy polyethoxy) phenyl]propane

The initial surface roughness was measured (baseline, Ra_0) using a contact-type profilometer (Marsurf Ps10, Mahr, Germany), and the surface gloss values were measured (baseline, GU_0) using a gloss meter (Novo-Curve, Rhopoint, UK). Glossmeter measurements were performed three times by a single operator to minimize the bias, and the average values were used for the statistical analyses. The profilometer measurements were performed 6 times by moving the device tip in two directions (3 times for each), which were perpendicular to each other. This was done to avoid false assessments due to possible unidirectional minor surface scratches and to evaluate the surface texture more accurately. Following baseline measurements, the specimens were stored in distilled water for 24 h. Then, one side of the specimens was polished as per the manufacturer's recommendations using the polishing systems. A latch-type slow-speed handpiece (Kavo, Bismarckring) was used in dry conditions for the polishing at a constant 10.000 rpm. Each polishing step was used continuously for 30 s (thereby a total of 60 s for the two-step and 90 s for the three-step systems) for the selected polishing system under dry conditions by rotating the specimen a quarter turn in a clockwise direction every 5 s to achieve a homogenous surface polishing. The polishing procedure was performed by a single, experienced restorative dentistry instructor. A novel PFG Polishing Simulator device, including a force sensor, was manufactured to monitor the press-on force during the polishing procedures (Fig. 2). The same force sensor was previously used by Heinze et al. and Yu et al. to quantitatively assess the vertical press-on forces during the polishing procedures [12, 13]. However, rather than reading the instant press-on force value, the PFG Polishing Simulator used in this study can generate a computer-based output of the press-on force range during the whole polishing period. Although it was used previously for monitoring the press-on force during the

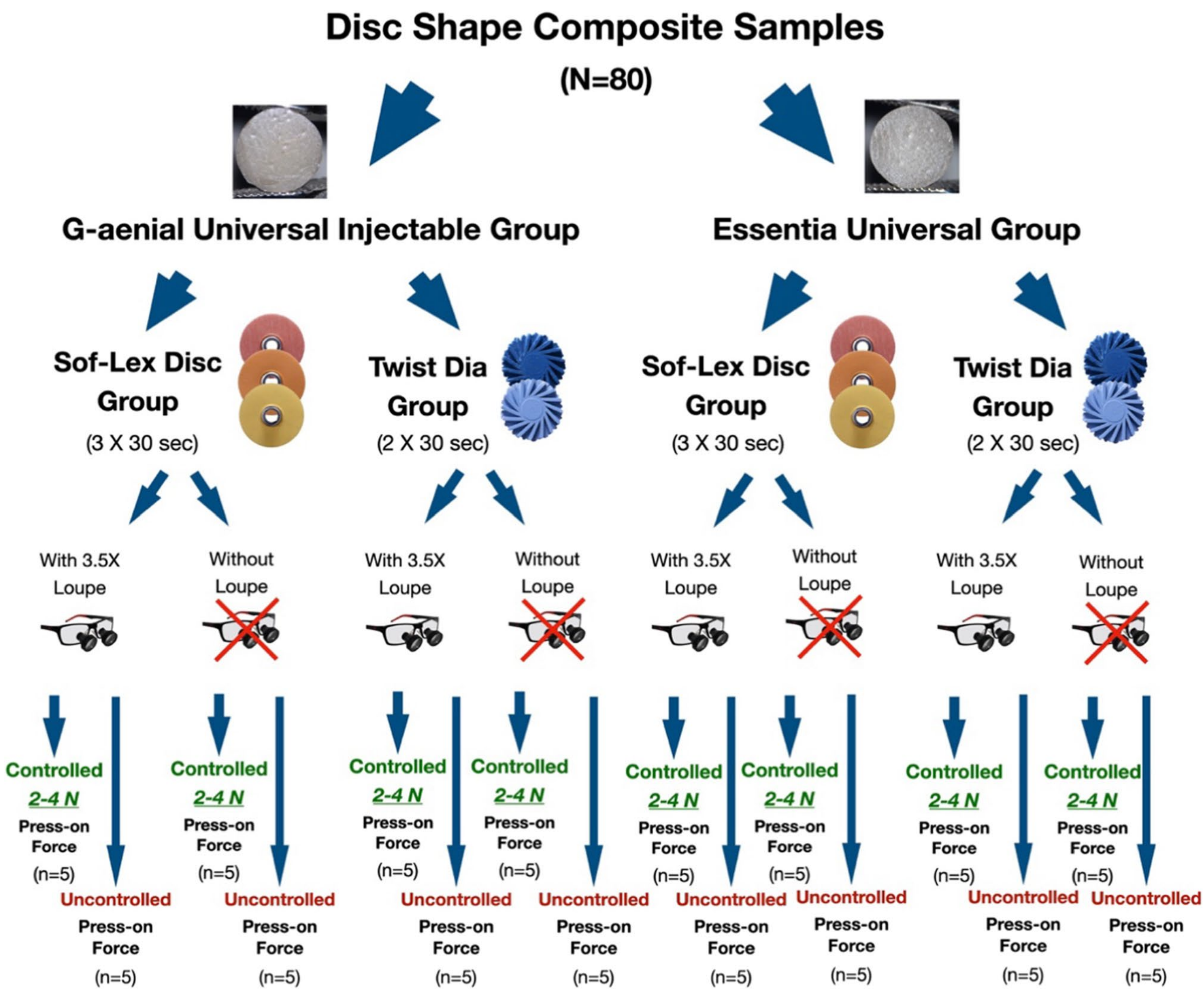

Fig. 1 The workflow chart of the study. Two composite groups of the study were G-aeniel Universal Injectable (GUI) and Essentia Universal (EU). Two polishing systems of the study were SofLex Disc and Twist Dia. The magnification used in some groups of the study was the 3.5X loupe. The polishing procedures were performed with controlled (2–4 N) and uncontrolled (free-force) press-on force

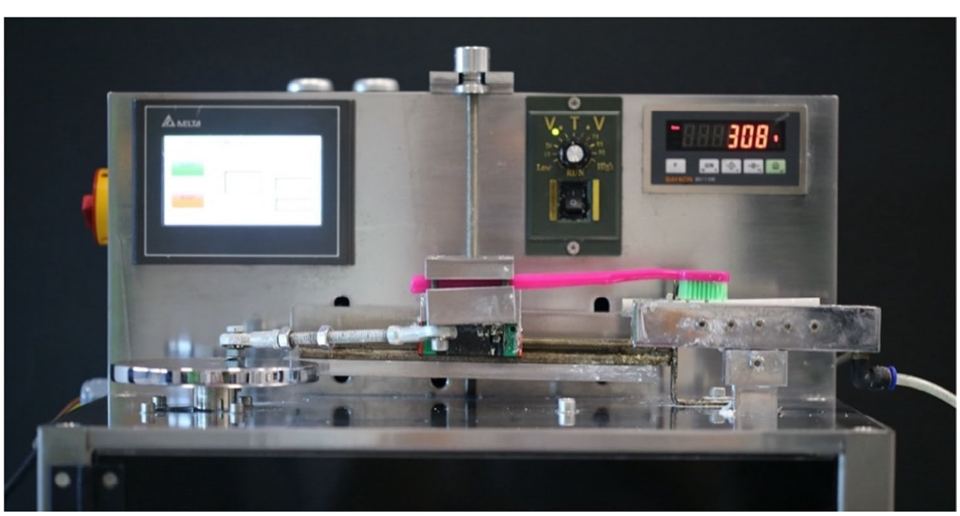

Fig. 2 The Press-on Force-Guided (PFG) Polishing/Brushing Simulator

tooth brushing procedure, this is the first time that this novel simulator was used for a composite polishing procedure [20]. The handpiece, including a polishing material, was held free-hand by the operator on the PFG Polishing Simulator so that the operator could perform the polishing procedure while monitoring the applied press-on force simultaneously. The handpiece was not fixed in order to assess the press-on force alterations during the application, thus, to simulate the real clinical scenario. The related quantitative data could be read by the observer directly from the device's screen by using a data cable and a computer. In the controlled force group, the observer applied the press-on force between just 2–4 N by simultaneously checking the device's screen. Therefore, the small press-on force range output data of the entire polishing procedure was recorded for each polishing system. In the uncontrolled force group, the specimens were polished without simultaneously reading the data from the screen; in other words, it was a free-hand, blind force application. At the end of the procedure, the press-on force range of the output data was read. Thus, a wider press-on force range of the entire polishing procedure was extracted and collected. The recordings were performed for each of the polishing systems for both composite types. Following the polishing procedures, surface roughness (Ra_1) and gloss measurements (GU_1) were performed by the same operator again.

The data were analyzed using the Minitab V14 and Jamovi V2.3.28 software programs. The normality was checked using the Shapiro-Wilk test. One-way ANOVA, Three-way ANOVA, and Robust ANOVA with Bonferroni Correction were used for the multiple comparisons. Correlation between the roughness and gloss was analyzed using Spearman's rho Correlation Coefficient. The deemed significance was set at < 0.05.

Results

Regarding the surface roughness (Ra) values of the injectable composite group, press-on force stability and polishing system type affected the results (Table 2). Significantly higher Ra values were observed for the Twist Dia (0.33 ± 0.05^z) polishing system compared to the SofLex Disc (0.22 ± 0.08^y) (Fig. 3c and a, respectively). The use of magnification did not affect the roughness level (P = .250). Regardless of the polishing system (in total), the Ra values were significantly higher when the press-on force was uncontrolled (0.31 ± 0.07^x), compared to the stable force (0.25 ± 0.09^w). Whereas the interaction of the polishing systems and the press-on force variable did not affect the surface roughness (P = .163).

Table 2 Multiple comparisons for the surface roughness (Ra) of the injectable composite

Polishing System	Magnification	Press-on Force		Overall Comparison
		Controlled	Uncontrolled	
SofLex Disc	No	0.21 ± 0.10	0.28 ± 0.08	0.25 ± 0.09
	Yes	0.16 ± 0.04	0.25 ± 0.06	0.20 ± 0.07
	Overall	0.18 ± 0.08	0.27 ± 0.07	0.22 ± 0.08^y
Twist Dia	No	0.31 ± 0.06	0.35 ± 0.06	0.33 ± 0.06
	Yes	0.32 ± 0.04	0.34 ± 0.03	0.33 ± 0.03
	Overall	0.32 ± 0.05	0.34 ± 0.05	0.33 ± 0.05^z
Overall Comparison	No	0.26 ± 0.10	0.32 ± 0.07	0.29 ± 0.09
	Yes	0.24 ± 0.09	0.29 ± 0.07	0.27 ± 0.08
	Overall	0.25 ± 0.09^w	0.31 ± 0.07^x	0.28 ± 0.09

	Test stat.	*P*
Press-on force	**8.150**	**0.007**
Polishing system	**29.760**	**< 0.001**
Magnification	**1.370**	**0.250**
Press-on force ✻Polishing system	2.040	0.163
Press-on force ✻Magnification	0.010	0.919
Polishing system ✻Magnification	1.150	0.292
Press-on force✻ Polishing system ✻Magnification	0.260	0.614

no difference between the groups with the same letters

*Three-way ANOVA, R^2 = 57.18%, corrected R^2 = 47.82%, average ± sd, (w-z)

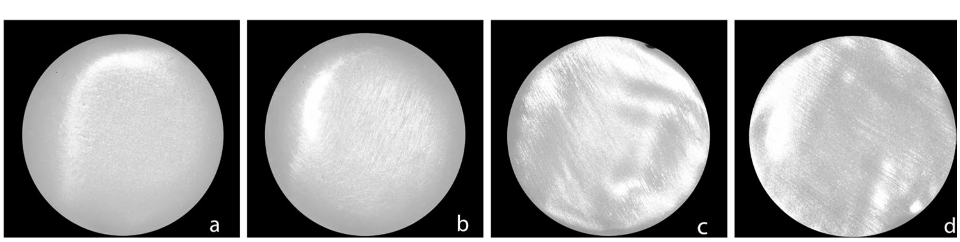

Fig. 3 Images of specimens' surface structure under 22X of dental operating microscope magnification. **(a)** GUI composite surface structure after polishing with the SofLex system. **(b)** EU composite surface structure after polishing with the SofLex system. **(c)** GUI composite surface structure after polishing with the Twist Dia system. **(d)** EU composite surface structure after polishing with the Twist Dia system

As for the surface roughness values of the paste-type composite group, the results were not influenced by any of the variables or interactions (Table 3). There were no significant differences in the surface roughness between the SofLex Disc (0.33 ± 0.04) and Twist Dia (0.29 ± 0.04) polishing systems (P=.440) (Fig. 3b and d, respectively). The use of magnification did not affect the roughness level (P=.715). Regardless of the polishing system, the Ra values were higher for the uncontrolled press-on force, but the difference was not significant (P=.140).

Regarding the gloss (GU) values of the injectable composite group, press-on force and the type of polishing system significantly affected the results (Table 4). Significantly higher gloss values were observed for the Twist Dia (72.3 ± 2.57^{z}) polishing system compared to the SofLex Disc (42.2 ± 5.52^{y}) (Fig. 3c and a, respectively). The use of magnification did not affect the level of gloss regardless of the polishing system (P=.160). The gloss level was significantly higher when the press-on force was uncontrolled (69.7 ± 2.91^{x}), compared to the stable force (45.2 ± 6.2^{w}). Significantly higher gloss values were also obtained for the uncontrolled press-on force in the SofLex Disc (60.2 ± 3.21^{a}) and Twist Dia (78.5 ± 3.54^{c}) polishing systems individually (P=.001).

Regarding the gloss values of the paste-type composite group, the press-on force control and the type of polishing system significantly affected the results (Table 5). The gloss level for the paste-type composite groups was quantitatively lower than the injectable composite groups. Significantly higher gloss values were observed for the Twist Dia (58.88 ± 13.73^{z}) polishing system compared to the SofLex Disc (32.73 ± 9.99^{y}) (Fig. 3d and b, respectively).

Table 3 Multiple comparisons for the surface roughness (Ra) of paste-type composite

Polishing System	**Magnification**	**Press-on Force**		**Overall Comparison**
		Controlled	**Uncontrolled**	
SofLex Disc	No	0.37 ± 0.12	0.35 ± 0.13	0.36 ± 0.09
	Yes	0.29 ± 0.05	0.37 ± 0.08	0.33 ± 0.04
	Overall	0.33 ± 0.06	0.36 ± 0.07	0.33 ± 0.04
Twist Dia	No	0.26 ± 0.09	0.33 ± 0.09	0.30 ± 0.06
	Yes	0.11 ± 0.16	0.44 ± 0.15	0.27 ± 0.12
	Overall	0.19 ± 0.09	0.38 ± 0.08	0.29 ± 0.04
Overall Comparison	No	0.32 ± 0.07	0.34 ± 0.08	0.31 ± 0.05
	Yes	0.20 ± 0.08	0.40 ± 0.08	0.30 ± 0.03
	Overall	0.27 ± 0.04	0.35 ± 0.05	0.31 ± 0.04

	Test stat.	***P***
Press-on force	**2.402**	**0.140**
Polishing system	**0.633**	**0.440**
Magnification	**0.137**	**0.715**
Press-on force ✻ Polishing system	1.234	0.278
Press-on force ✻Magnification	1.524	0.229
Polishing system ✻Magnification	0.005	0.946
Press-on force ✻ Polishing system ✻Magnification	0.301	0.589

*Robust ANOVA, trimmed mean was used for the comparisons (Trim ratio: %5), trimmed mean average ± sd

Table 4 Multiple comparisons for the surface gloss (GU) of the injectable composite

Polishing System	**Magnification**	**Press-on Force**		**Overall Comparison**
		Controlled	**Uncontrolled**	
SofLex Disc	No	36.1 ± 4.07	57.9 ± 5.51	47 ± 5.17^{a}
	Yes	10.7 ± 2.16	62.6 ± 3.55	36.7 ± 9.8^{a}
	Overall	23.4 ± 5.18^{b}	60.2 ± 3.21^{a}	42.2 ± 5.52^{y}
Twist Dia	No	69.9 ± 5.38	72.6 ± 5	71.2 ± 3.5b
	Yes	63.9 ± 1.4	84.4 ± 3.15	74.1 ± 4.13^{b}
	Overall	66.9 ± 2.84^{a}	78.5 ± 3.54^{c}	72.3 ± 2.57^{z}
Overall Comparison	No	53 ± 7.01^{ab}	65.2 ± 4.44^{ab}	59.2 ± 4.29
	Yes	37.3 ± 9.92^{a}	73.5 ± 4.61^{b}	56.1 ± 6.97
	Overall	45.2 ± 6.2^{w}	69.7 ± 2.91^{x}	57.6 ± 2.43

	Test stat.	***P***
Press-on force	**89.220**	**< 0.001**
Polishing system	**144.700**	**< 0.001**
Magnification	**2.110**	**0.160**
Press-on force ✻ Polishing system	24.140	0.001
Press-on force ✻Magnification	21.780	0.001
Polishing system ✻Magnification	6.640	0.001
Press-on force ✻ Polishing system ✻Magnification	1.440	0.242

no difference between the groups with the same letters

*Robust ANOVA, trimmed mean was used for the comparisons (Trim ratio: 5%), trimmed mean average ± sd., (a, b, w, x, y, z)

Table 5 Multiple comparisons for the surface gloss of paste-type composite

Polishing System	Magnification	Press-on Force		Overall Comparison
		Controlled	Uncontrolled	
SofLex Disc	No	31.86 ± 7.33	34.71 ± 8.41	33.29 ± 7.59
	Yes	23.25 ± 8.05	41.09 ± 8.88	32.17 ± 12.34
	Overall	27.56 ± 8.56^a	37.90 ± 8.82^c	32.73 ± 9.99^y
Twist Dia	No	46.23 ± 3.45	71.08 ± 8.42	58.66 ± 14.44
	Yes	46.57 ± 4.69	71.64 ± 3.44	59.11 ± 13.77
	Overall	46.40 ± 3.89^b	71.36 ± 6.07^d	58.88 ± 13.73^z
Overall Comparison	No	39.05 ± 9.30	52.90 ± 20.75	45.97 ± 17.19
	Yes	34.91 ± 13.77	56.37 ± 17.31	45.64 ± 18.79
	Overall	36.98 ± 11.63^w	54.63 ± 18.68^x	45.81 ± 17.77

	Test stat.	*P*
Press-on force	**64.770**	**< 0.001**
Polishing system	**142.190**	**< 0.001**
Magnification	**0.020**	**0.881**
Press-on force ✻Polishing system	11.100	0.002
Press-on force ✻Magnification	3.000	0.093
Polishing system ✻Magnification	0.130	0.724
Press-on force ✻ Polishing system ✻Magnification	2.830	0.102

no difference between the groups with the same letters

*Three-way ANOVA, R^2 = 87.5%, corrected R^2 = 84.77%, average ± sd, (a, b, w, x, y, z)

The use of magnification did not affect the level of gloss (*P* =.881). In total, the gloss level was significantly higher with an uncontrolled press-on force (54.63 ± 18.68x) than with a stable press-on force (36.98 ± 11.63^w). In addition, the press-on force significantly affected the gloss for both the SofLex and Twist Dia groups, as the uncontrolled force showed a significantly higher gloss in each group (*P* =.002).

Regarding the comparison between the composite types, GUI composite presented significantly higher surface gloss and lower surface roughness than the EU composite (p <.001 for each) (Table 6). A moderate negative correlation was found between surface roughness and gloss in the GUI composite group (r =-.546; P <.001), whereas there was no correlation between the two variables in the EU composite group (r =-.110; P =.449) (Table 7).

Table 6 Comparison between the composite types regarding surface roughness(Ra) and gloss (GU).

	Composite Type		F	P*
	Flowable Composite (GIU)	Paste-Type Composite (EU)		
Surface Gloss (GU)	34.74 ± 32.97	28.04 ± 26.37	67.26	< 0.001
Surface Roughness (Ra)	0.231 ± 0.150	0.304 ± 0.226	13.85	< 0.001

Table 7 Correlation between the surface roughness (Ra) and gloss (GU) values.

Composite Type		Surface Gloss (GU)	
		r	P
Injectable Composite (GUI)	Surface Roughness (Ra)	-0.546	<0.001
Paste-Type Composite (EU)	Surface Roughness (Ra)	-0.11	0.499

Discussion

The first hypothesis of the study was rejected because the controlled press-on force decreased the surface roughness and the surface gloss for both composites. However, only the decrease in roughness in the EU group was not considered statistically significant. The second hypothesis of the study was accepted because the use of magnification did not affect the roughness level significantly for all groups. The third hypothesis of the study was partially rejected because a significant difference in surface roughness was observed between the two polishing systems for the flowable composite group but not the paste-type composite group.

The impact of press-on force

The importance of the press-on force during composite polishing was previously mentioned by Heintze et al., who considered not monitoring it as a critical limitation of many studies [12]. This study used a novel PFG Polishing Simulator during the entire polishing procedure that possesses a 3D force sensor to evaluate the vertical press-on forces and thereby simulate clinical scenarios. A similar monitoring and standardization in press-on force was performed using this device recently by Meseli et al., for the tooth brushing procedure [20]. Heintz et al. concluded that although many manufacturers recommend the press-on force of 2 N as an optimal value for composite polishing procedures, it can be beyond 2 N during the application [12]. Accordingly, in the present study, 2 N was selected as the control threshold during the press-on force monitoring. However, since it was not possible to keep 2 N constantly in clinical conditions due to the multidirectional forces, a more realistic range for the control threshold was set as 2–4 N, based on the pilot studies. Moreover, in clinical practice, the exact press-on forces used by clinicians cannot be foreseen due to the different types, shapes, and hardness of the chosen polishing system and the anatomical form of the tooth [3, 10]. Therefore, polishing with the uncontrolled press-on force was also evaluated as a separate group in this study.

The surface roughness decreased in the present study when the press-on force was limited between 2 and 4 N during the polishing. This result was valid for both composite materials, yet it was only significant for the polishing of GUI (Tables 2 and 3). Since the uncontrolled press-on force could be randomly lower or higher than 2–4 N, it is not possible to compare the load of press-on forces applied. However, it can be interpreted that the controlled press-on force during polishing was likely more effective in reducing roughness compared to free-force polishing. In agreement with Heintze et al. [12], the results of the present study revealed that the results of various previous studies might not simulate real clinical conditions, as the reported results could be even worse due to the unstable polishing press-on force. The reason for the insignificant difference in the roughness of the paste-type composite can be attributed to the structural difference in terms of size, quantity, and silanization of the inorganic fillers, which leads to a low polishability of the microhybrid EU composite. In other words, the effect of the press-on-force control was more evident when a composite has a higher polishability, such as the nanohybrid GUI composite [21]. In addition, the obtained surface gloss was higher for both the EU and GUI composites when the press-on force was not controlled (Tables 4 and 5). Therefore, in the present study, the surfaces resulting from the uncontrolled press-on force were considered glossier, and the opposite was also valid.

The relation between gloss and roughness

The nanohybrid, highly-filled flowable GUI composite presented higher surface gloss and lower surface roughness than the microhybrid EU (Table 6). Moreover, as expected, a moderately negative correlation was observed between roughness and gloss in nanohybrid flowable composite GUI, while no correlation was found in microhybrid paste-type composite EU. However, when the results were examined in detail, the results of the present study revealed that surface gloss may not only be related to surface smoothness. Because even though the Twist Dia system produced a rougher surface for the nanohybrid flowable GUI composite, it also produced higher gloss compared to the SofLex (Fig. 3c and a, respectively). Also, when there was no significant difference in roughness, the Twist Dia system still presented a higher gloss than the SofLex system (Fig. 3d and b, respectively). These results were in agreement previous outcomes of Korkut B [3] and Korkut et al. [19]. Therefore, it might be interpreted that the surface gloss is more related to the selected polishing system rather than the composite type. Additionally, a very low level of surface roughness may not always be needed to achieve a high level of surface gloss [19]. The authors of this study believe that this relation between roughness and gloss provides very important clinical information and should be considered in clinical practice, especially when selecting the polishing system and polishing the restoration surfaces, including macro- and micro-surface textures [1, 3]. The higher gloss values for the highly filled flowable nanohybrid composite GUI than the paste-type microhybrid EU were also expected in agreement with the previous results [21, 22]. Because of the high polishability of the nano-sized filler particles, GUI had an important advantage compared to the micro-sized fillers of EU.

The impact of magnification

The use of magnification did not affect the surface roughness and gloss significantly within the limitations of the present study. Even though this statistical outcome was unexpected, the surfaces polished under magnification presented quantitatively lower Ra values (Tables 2 and 3). A loupe magnification of 3.5X was used in the present study, which can be considered a more time-demanding procedure compared to the naked-eye polishing [3]. With the magnified vision, the ability to see the surface in detail increases, and thus, it usually increases the chair time. Even though there is a lack of evidence regarding the effect of magnification in composite polishing, it might be interpreted that the ineffectiveness could be due to the limited time (30 s) spent on each polishing step in this study. Therefore, if the polishing time were not limited, a more effective surface polishing could be performed using the loupe compared to the naked eye. Another reason might be the magnification ratio, and a greater magnification, like a dental operating microscope, might have caused different outcomes [15, 16]. It might be useful to conduct further studies evaluating the operators' experience with the loupes and different magnification ratios, with no time limit for the polishing procedure.

Comparison between the polishing systems

When comparing the polishing systems, the SofLex Disc was found to be more effective than Twist Dia in reducing the surface roughness of the GUI due to its lower Ra values (Table 2). However, the two polishing systems showed similar roughness values when polishing the Essentia Universal (Table 3). The difference in the inorganic filler particles, the filler ratio, and the silanization of the two composites could be the reason for these different results in this study. It has been reported that the filler size, volume, weight, layering thickness, and degree of conversion are effective factors for the polishing quality of resin-based composites [23]. It has already been mentioned that the highly filled flowable nanohybrid composite GUI possesses the combination of strength, polishability, gloss retention, wear resistance, and translucency or opacity of a conventional paste-type composite [24, 25]. It was assumed that smoother restorative surfaces can be achieved by using composites with a smaller particle size, which leads to better distribution within the resin matrix [26]. In addition, the filler content of the GUI is 69 wt% by weight, which is relatively lower than the filler ratio of the microhybrid composite Essentia Universal, which is 81% by weight [1, 3]. Therefore, it was not surprising that a gold standard polishing system, the Sof-Lex Discs, presented better roughness results with a material with high polishability and a higher organic matrix content [21]. Furthermore, the polishing motion on the surface was cited as an influencing factor [27]. Fruits et al. [27], mentioned three crucial movements for developing an optimal surface texture: rotational (circular) motion, reciprocal motion, and planar motion. They concluded that planar motion produced the lowest roughness values, whereas the type and shape of the polishing material were not evaluated accordingly. In this study, the planar movement was used for both polishing systems. However, the effect of the disc and spiral shapes during this movement remains unclear. It is likely that the spiral shape of Twist Dia absorbed the high press-on forces during uncontrolled polishing, resulting in less effective smoothing but a more conservative approach to preserve the tertiary anatomical form and avoid excessive material removal from the surface, as previously mentioned by Korkut and Unal [10]. Moreover, the Sof-Lex system was used in 3 steps, resulting in a polishing time of 90 s, which was a longer period of time than the 60 s of the two-step Twist Dia. The gloss achieved with the Twist Dia system was higher than that of the Sof-Lex Discs system for both flowable and paste-type composites in the present study (Tables 4 and 5). The diamond particles and the flexible rubber spirals in Twist Dia probably resulted in a better gloss compared to the aluminum oxide particles in the Sof-Lex Discs, despite the mentioned shorter polishing time with Twist Dia [3, 10]. Therefore, it could be considered that the diamond-embedded spiral wheels can produce a glossy surface, even if it is considered rough, in agreement with Korkut et al. [19]. As mentioned above, this information could be useful for clinicians when polishing anterior composite restorations with macro- and micro-surface textures (secondary and tertiary anatomical forms) to avoid altering the surface texture produced [3]. Accordingly, for restorations where only surface smoothing is important and esthetic expectations are not very high, the three-step Sof-Lex System can be preferred. However, it should be borne in mind that it may significantly change the surface texture, and the gloss may be relatively low, while the two-step Twist Dia can easily bend and adapt to an irregular surface due to the rubber structure and spiral shape, thus preserve the surface texture (Tables 4 and 5) [3, 10]. Consequently, a successful composite polishing procedure should produce a smooth and glossy surface while maintaining the surface morphology with minimal volumetric material loss. However, the polishing material should be selected on a case-by-case basis.

Study limitations

To obtain more realistic results, clinical evaluations on the restorations should also be made. The surface roughness was investigated by the interaction of the two composites and the two polishing systems using disc-shaped composite samples without surface structures, whereby it could be more clinically relevant to work with tooth-shaped specimens [10]. In the clinic, however, the polishing procedure is a very dynamic task with considerable fluctuations in the press-on force according to the anatomical form changes of the surface. This study investigated the disc-shaped specimens with flat surfaces, like several previous studies, while it may not simulate the real restoration morphology. The type and shape of the polishing material might be more influential factors when polishing the occlusal surface of a posterior restoration or the labial/lingual surface curvatures of an anterior restoration [19]. Since the press-on force is highly dependent on the surface geometry of a restoration, it should be considered for further studies for more realistic outcomes. Both the glossmeter and contact profilometer results were selected area-dependent, and the non-uniform surfaces, because of the polishing procedure, might have affected the glossmeter outcomes. Different types of resin-based composites may influence the outcomes of the study. In addition, the amount of resin composite removed from the surface during the polishing procedure was not evaluated. Clinicians' experiences with magnification and higher magnification rates should also be evaluated in future studies.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- The press-on force affected the surface roughness and gloss. Higher surface roughness and gloss were observed when the uncontrolled press-on force was applied compared to controlled force between 2 and 4 N. Clinicians should consider this carefully when collecting information from the literature because, unlike the methodology of several previous research, the press-on force is generally not constant but applied uncontrolled free-force in clinical dental practice.

- Even though three-step (90s of polishing) SofLex system may provide a lower surface roughness, two-step (60s of polishing) Twist Dia could generate a greater surface gloss regardless of the composite type. Therefore, polishing with the diamond-embedded spiral wheels may generate high gloss on the surfaces, which are even considered relatively rough.
- The use of 3.5X loupe magnification was not considered effective on the surface roughness and gloss within a limited polishing time (30 s for each material).

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Authors' contributions
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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

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