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The Effect of Polishing Technique on 3-D Surface Roughness and Gloss of Dental Restorative Resin Composites

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Clinical Relevance

This article discusses the surface finish of different modern types of composites polished using different polishing protocols used in all dental practices.

SUMMARY

The aim of this study was to compare surface roughness and gloss of resin composites polished using different polishing systems.

Five resin composites were investigated: Filtek Silorane (FS), IPS Empress Direct (IP), Clearfil Majesty Posterior (CM), Premise (PM), and Estelite Sigma (ES). Twenty-five disk specimens were prepared from each material, divided into five groups, each polished with one of the following methods: Opti1Step (OS), OptiDisc (OD), Kenda CGI (KD), Pogo (PG), or metallurgical polishing (ML). Gloss and roughness parameters (Sa, Sz, Sq, and St) were evaluated by 60°-angle glossimetry and white-light interferometric profilometry. Two-way analysis of variance was used to detect differences in different materials and polishing techniques. Regression and correlation analyses were performed to examine correlations between roughness and gloss.

Significant differences in roughness parameters and gloss were found according to the material, type of polishing, and material/polishing technique (*p*< 0.05). The highest roughness was recorded when KD was used (Sa: 581.8 [62.1] for FS/KD, Sq: 748.7 [55.6] for FS/KD, Sz: 17.7 [2.7] for CM/KD, and St: 24.6 [6.8] for FS/KD), while the lowest was recorded after ML (Sa: 133.6 [68.9] for PM/ML, Sq: 256.5 [53.5] for ES/ML, Sz: 4.0 [1.3] for ES/ML, and St: 7.1 [0.7] for ES/ML). The

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highest gloss was recorded for PM/ML (88.4 [2.3]) and lowest for FS/KD (30.3 [5.7]). All roughness parameters were significantly correlated with gloss (*r*= 0.871, 0.846, 0.713, and 0.707 for Sa, Sq, Sz, St, and gloss, respectively). It was concluded that the polishing procedure and the type of composite can have significant impacts on surface roughness and gloss of resin composites.

INTRODUCTION

The clinical use of resin composites has considerably expanded over recent years because of the increasing esthetic demands and advances in composite technology.[1-3] The introduction of nanoparticle-filled composites with improved physical, mechanical, optical, and clinical performance made possible the use of such materials not only for the anterior region but also for posterior restorations.[1,3-6]

Surface roughness and gloss are recognized among the important properties affecting the appearance of composite material. A smooth surface improves esthetics; reduces plaque retention capacity, surface discoloration, tissue inflammation, and secondary caries;[1,3,4,7-10] and adds to the patient's comfort.[2,5,11]

The surface roughness of a resin-composite restoration depends on several factors, including filler content, size, shape, and interparticle spacing; monomer type; degree of cure; and efficient filler-matrix bonding.[9] Currently, surface roughness has been significantly improved by reducing the filler particle size and increasing filler loading.[9,12] For polishing media, the hardness, shape, and grit size of the abrasive components and the flexibility of the solid matrix, where the abrasive material is embedded, play a critical role.[3,9,12]

Efforts have been undertaken to determine which abrasive system provides the smoothest surface for commercially available composites.[2,3,6] Various methods have been introduced[2,13] with no consensus reached on the method providing the smoothest surface texture.[4,14] Sets of alumina particle–coated, highly flexible, polyurethane-based finishing and polishing disks have been shown to produce the smoothest surface topography.[6,15,16] Unfortunately, because of the difficult access to some restorations, various shapes of abrasive-impregnated rotary burs and handheld strips are alternatively used.[3] Recently, systems that utilize siloxane rubbers and diamond polishers were introduced to achieve a good surface polish using a single-step instrument.[10] These polishing systems were found either as good as or even superior to multistep polishers.[1,5,9,10,12,13]

Gloss is an important property used to measure surface shine and may be defined as a degree of approach to a mirror surface.[17] In resin composites, gloss is affected by the measuring angle, surface roughness, particle size, chemical heterogeneity, surface defects, and presence of other surface irregularities.[12,16,18,19]

A variety of methods have been introduced for measuring surface roughness of dental materials, including qualitative methods (optical and scanning electron microscopy and so on)[5,6,10,11,20] and quantitative methods (contact stylus profilometry, optical/laser noncontact profilometry, atomic force microscopy, and so on).[1,3,6,21] Optical profilometry techniques, based on various optical principles, such as interferometry, light scattering, and focus detection, have higher effective range for amplitude measurements,[22] and they are being increasingly used for the examination of surface roughness of dental materials.[11,16,20,23,24]

The aim of this study was to investigate the 3-D surface roughness and gloss properties of various types of modern composites polished with different polishing methods. The objectives to achieve this aim were to investigate the effect of polishing techniques on the 3-D amplitude surface roughness parameters and gloss of different restorative resin composites. The null hypotheses tested were 1) that there are no significant differences in surface roughness and gloss between composites polished using different polishing techniques and 2) that there is no correlation between surface roughness and gloss of the materials used in this investigation.

MATERIALS AND METHODS

Specimen Preparation

Five types of composites were investigated in this study (Table 1). Twenty-five disc specimens (Ø: 2 mm, h: 2 mm) were prepared of each material by injecting the resin-composite pastes into a Teflon mold. Two microscopic glass slides, covered with transparent Mylar strips, were used to compress the material in the mold. The samples were irradiated for 40 seconds from each surface with a halogen light-curing unit (Elipar Trilight, 3M-ESPE, Seefeld, Germany) operated in standard mode at 850 mW/cm^2 irradiance. The samples were stored dry at 23°C for 24 hours before processing.

Polishing Procedures

After polymerization, each of the five samples of the different materials was mounted on a glass slide and

Table 1: *The Composite Materials Investigated in This Study*

Material	Composition	Manufacturers
Filtek Silorane (FS)	Microhybrid composite,	3M ESPE, St. Paul, MN, USA
	Matrix: Silorane	
	Filler: quartz filler and YF_3 (76% wt)	
IPS Empress Direct (IP)	Nanohybrid composite	Ivoclar-Vivadent, Schaan, Liechtenstein.
	Matrix: Dimethacrylate monomer with reduced BisGMA,	
	Filler: Ba-Al-SiO_4 glass (0.4-0.7 μm), YtF_3 (0.1 μm), SiO_2/ZrO_2 mixed oxide (0.15 μm), prepolymers (4–5 μm) (77.5–79% wt, 52–59% vol).	
Clearfil Majesty Posterior (CM)	Nanohybrid composite	Kuraray, Tokyo, Japan
	Matrix: Bis GMA, TEGDMA, Hydrophobic aromatic dimethacrylate	
	Filler: Alumina nano filler (0.02 μm) and glass ceramic filler (1.5 μm) (92% wt, 82% vol)	
Premise (PM)	Nanohybrid composite	Kerr Corp, Orange, CA, USA
	Matrix: Ethoxylated bis-phenol-A-dimethacrylate, TEGDMA	
	Filler: Silica (0.02 μm), Ba-glass (0.4 μm) and prepolymers (30–50 μm) (84% wt, 69% vol)	
Estelite Sigma (ES)	Submicron resin composite	Tokuyama, Tokyo, Japan
	Matrix: BisGMA, TEGDMA	
	Filler: Spherical silico-zirconia produced by sol-gel method (0.2 μm), (82% wt, 71% vol)	

fixed in place using cyanoacrylate glue. After curing, all samples were subjected to sandpaper polishing (600 grit) under water cooling for 30 seconds for the purpose of standardization.[1,9,12,16] Samples of the different composites were subsequently divided into five groups according to the polishing procedure performed (Table 2). Finally, all specimens were ultrasonicated in a water bath for five minutes to remove any remaining polishing debris. A planar motion, which is a rotational movement with the axis of rotation of the abrasive device perpendicular to the surface being smoothed, was used during polishing, as it was reported to produce the lowest surface roughness.[1,2] As the load of the finishing device was reported to influence the polishing result, in the present study a single operator performed all the polishing procedures for standardization.[6] All polishing procedures were performed using a low-speed hand piece rotating at 12,000 rpm with a constant moving repetitive stroking action to prevent heat buildup or formation of surface grooves. A new polishing disc or set of discs (for multistep systems) was used for every sample.[2]

Surface Roughness Measurements

A noncontact optical interferometric profilometer (Wyko NT1100, Veeco, Santa Barbara, CA, USA) was used to measure surface roughness. The instru-

Table 2: *The Different Polishing Procedures Performed in This Study*

Group	Polishing Procedure
Opti1Step (OS)	One-step polishers (Kerr Corp, Orange, CA, USA). Polishing for 30 seconds using the flat broad surface of the disc.
OptiDisc (OD)	Three-step polishing system (Kerr). Polyester impregnated with aluminum oxide discs. Coarse/medium (dark blue) 40 μm, fine (light blue) 20 μm, extrafine (white) 10 μm, each used for 30 seconds.
Kenda (KD)	Kenda C.G.I three-step polishing system (Kenda AG, Vauz, Liechtenstein). Coarse (white), medium (green), ultrafine (pink). Polishing for 30 seconds each using the flat board surface of each disk.
Pogo (PG)	One-step diamond micropolishers (Dentsply/Caulk, Milford, CT, USA). Polymerized urethane dimethacylate resin, fine diamonod powder, silicon oxide (20 μm). The flat, broad surface of the disc was first applied using light hand pressure, followed by a gentle buffing motion for 30 seconds.
Control (ML)	Polished metallurgically in a grinding machine rotating at 200 rpm with a sequence of SiC papers of decreasing abrasiveness (320-, 400-, 600-, 800-, 1200- , 2000-, 3000-, and 4000-grit), 10 seconds each, under continuous water cooling.

ment was operated under the following conditions: vertical scan image mode, Mirau lens (5 × 2 FOV), 10× total magnification to include as much specimen area as possible in roughness calculations, 10-μm back-scan length, 30-μm scanning length, and a modulation length of 2. One scan was performed per specimen surface. The following amplitude roughness parameters were measured: Sa (the arithmetic mean of the absolute departures of the roughness profile from the mean line throughout the sampling length), Sq (the root mean square deviation of the assessed profile), Sz (the average value of the absolute height of the five highest peaks and the depth of the five deepest valleys over the sampling length), and St (the distance between the highest peak and the lowest valley of the profile within the evaluation length).

Surface Gloss Measurements

Surface gloss was measured with a gloss meter (Novo Curve, Rhopoint, Bexhill-on-Sea, UK) that was calibrated against a black-glass standard, provided by the manufacturer, with a reference value of 95.5 gloss units. The measurements were taken at the center of the specimens. Four measurements per specimen were performed at 60° light incidence and reflection angles, relative to the vertical axis, each time turning the specimen by 90°. The four readings were averaged to obtain a single value for each specimen. The measuring window was 2 mm × 1 mm, and the specimen was covered with a black shield to exclude ambient interferences.[11]

Statistical Analysis

A two-way analysis of variance (ANOVA) multiple comparison test was used for statistical analysis at a level of significance (α=0.05) to explore the influence of the independent variables, type of resin composite, and polishing technique as well as the interaction of surface roughness parameters and gloss between the types of composites and the polishing procedures. Series of one-way ANOVA followed by Games-Howell *post hoc* tests were performed to analyze the differences in roughness parameters and gloss between the different materials and different polishing techniques independently. Regression analyses were performed to determine any possible correlation between gloss and surface roughness parameters.

RESULTS

Figure 1 shows 3-D images of representative samples of each material and polishing system. Table 3

Table 3: *Two-Way Analysis of Variance Results in This Study*

Factor	Sa P Value	Sq	Sz	St	Gloss
Material	0.003	0.028	0.029	0.332	0.000
Polishing technique	0.000	0.000	0.000	0.000	0.000
Material/polishing	0.011	0.002	0.000	0.001	0.002

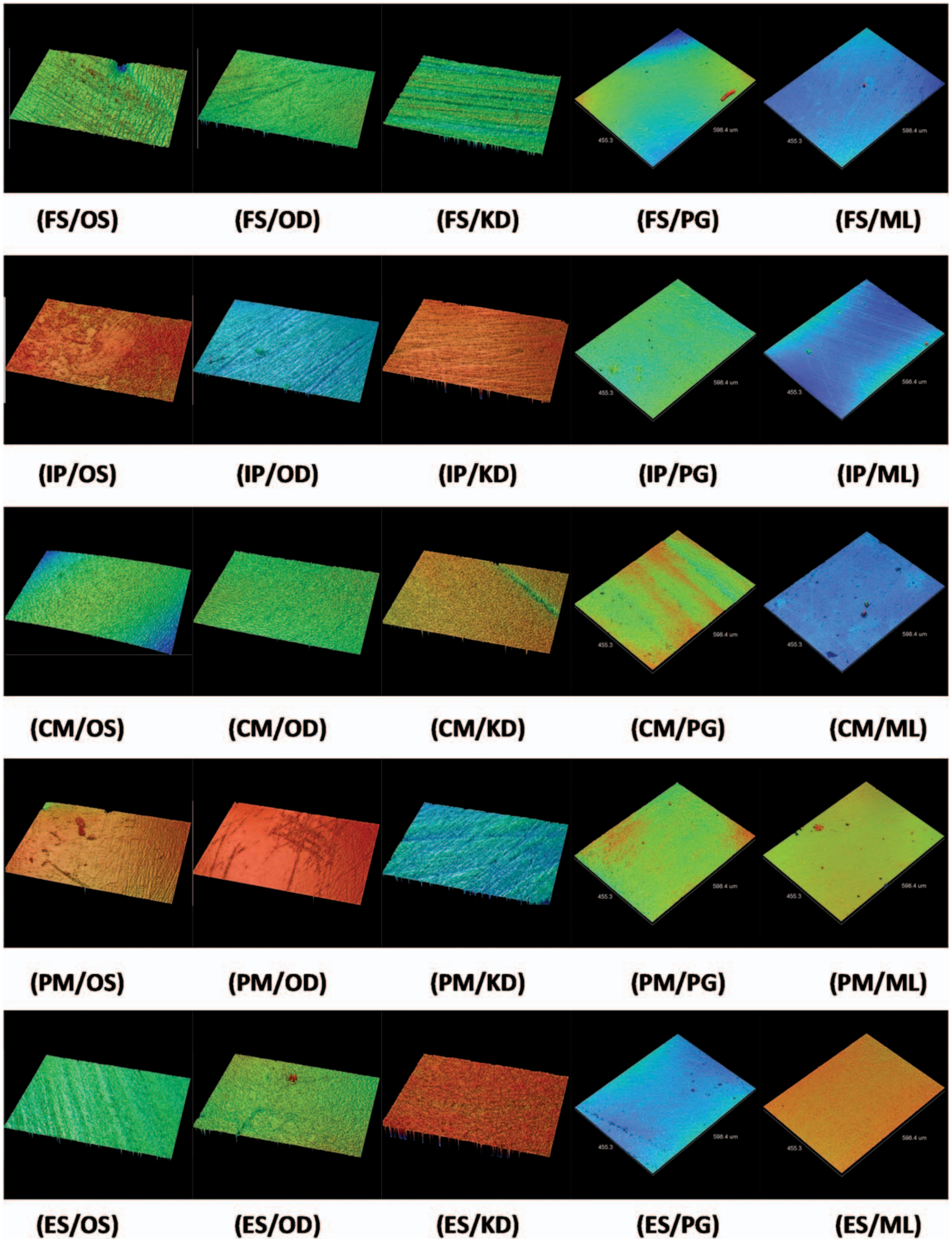

Figure 1. *3-D surface scans of representative samples of the different groups (10.3×; image size: 598.4 μm × 455.3 μm)*

Table 4: *Results of Sa (Means and SD/nm) for the Groups Tested*

Material	Polishing Technique				
	OS	OD	KD	PG	ML
FS	215.9 (62.3)[A/a]	287.5 (36.3)[A/b]	581.8 (62.1)[B/d]	316.0 (67.2)[A/f]	244.3 (96.9)[A/g]
IP	240.5 (29.4)[C/a]	388.9 (25.0)[D/c]	494.6 (113.8)[D/d]	250.9 (46.3)[C/f]	232.6 (66.1)[C/g]
CM	314.0 (103.8)[E/a]	262.2 (41.3)[E/b]	549.1 (111.6)[F/d]	324.6 (91.3)[E/f]	218.4 (61.8)[E/g]
PM	275.5 (61.7)[G/a]	267.3 (55.6)[G/b]	319.0 (55.6)[G/e]	280.1 (60.0)[G/f]	133.6 (68.9)[H/g]
ES	245.4 (67.4)[I/a]	253.3 (19.8)[I/b]	441.5 (40.7)[J/d]	256.3 (70.4)[I/f]	198.6 (42.3)[I/g]

[a] *Capital letters denote statistically similar groups in each material among the various polishing techniques (horizontal), while lowercase letters denote statistically similar groups in each polishing technique among the various materials (vertical).*

shows that there were significant differences in all roughness parameters and gloss among different materials and polishing techniques ($p < 0.05$), except for the effect of the material on St. The polishing technique was always a significant and a stronger factor than the type of the resin composite.

Tables 4 to 8 present the means and standard deviations of the surface roughness parameters and gloss measurements for the different groups investigated. Comparisons on the effect of different polishing treatments on the surface roughness and gloss measurements per resin-composite material revealed the following findings. For all the resin composites, the lowest roughness values were measured in the control polishing group (ML). When this group was excluded, the lowest roughness values were registered in OS or PG and the highest in KD treatment groups. The lowest gloss values were measured after KD and the highest after ML, followed by PG.

Fewer significant differences were recorded among the different materials under similar polishing techniques. The ranking of the materials also varied with different polishing methods and considering the different parameters. However, CM, FS, and IP had generally higher roughness and lower gloss than ES and PM. Nevertheless, some exceptions existed, as FS/OS had low roughness and high gloss, PM/OD had high roughness values, and ES gloss was not generally the highest.

Table 5: *Results of Sq (Means and SD/nm) for the Groups Tested*[a]

Material	Polishing Technique				
	OS	OD	KD	PG	ML
FS	293.1 (70.1)[A/a]	394.7 (89.6)[A/b]	748.7 (55.6)[B/d]	415.7(82.6)[A/f]	319.1(97.1)[A/g]
IP	314.9 (35.9)[C/a]	542.1(103.2)[D/c]	696.1(129.8)[D/d]	319.4(67.2)[C/f]	319.1 (54.7)[C/g]
CM	442.1(97.9)[E/a]	347.5 (43.6)[E/b]	671.1(105.0)[F/d]	411.5(126.2)[E/f]	355.0(108.4)[E/g]
PM	395.5(185.2)[G/a]	405.0 (98.0)[G/b]	401.0 (69.9)[G/e]	380.7 (85.2)[G/f]	346.5 (45.7)[G/g]
ES	322.8 (90.1)[H/a]	362.1(27.1)[H/b]	617.5(103.9)[I/d]	342.1 (71.2)[H/f]	256.5 (53.5)[H/g]

[a] *Capital letters denote statistically similar groups in each material among the various polishing techniques (horizontal), while lowercase letters denote statistically similar groups in each polishing technique among the various materials (vertical).*

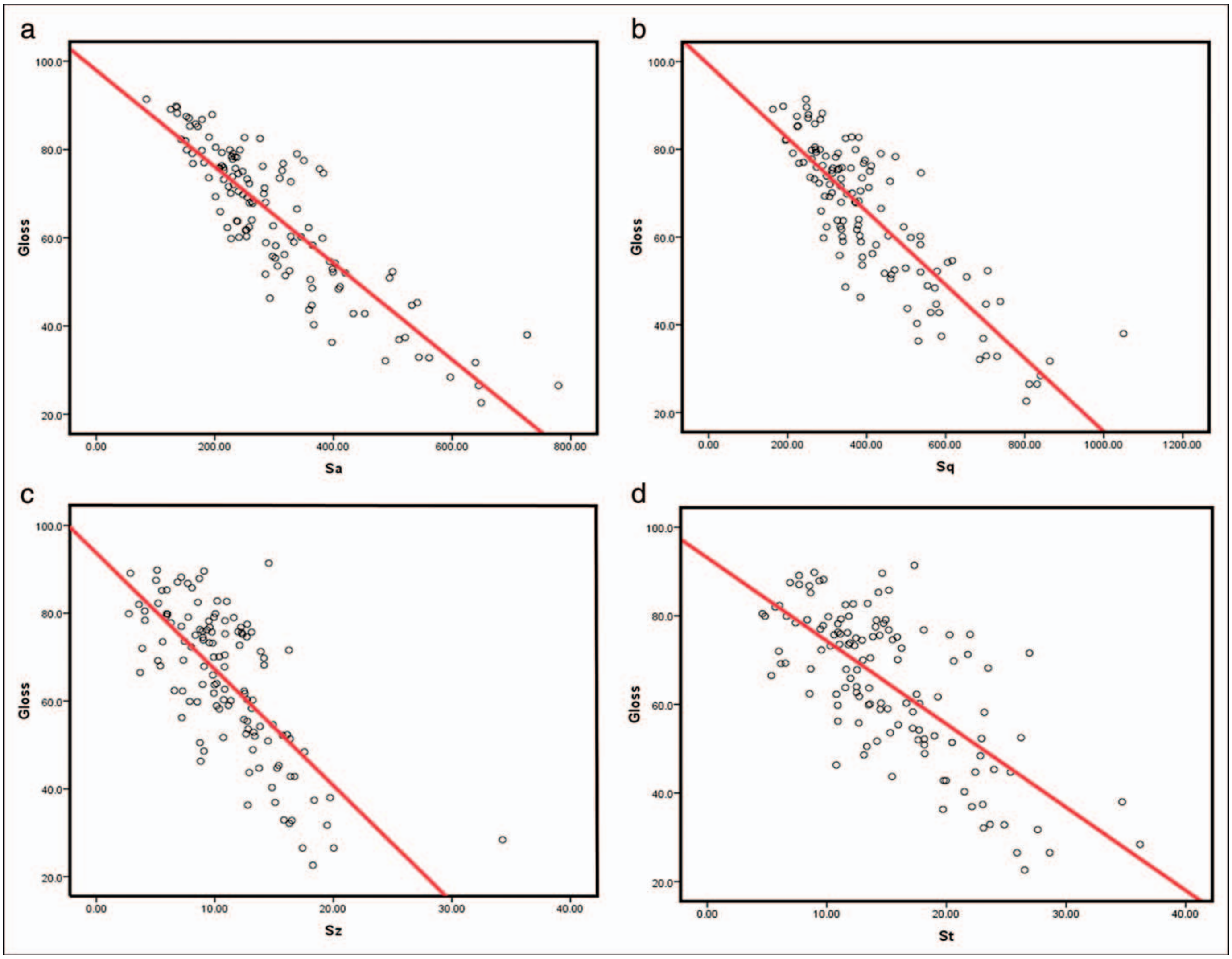

Figure 2. *The correlations between surface roughness and gloss. (2.a): Sa and gloss. (2.b): Sq and gloss. (2.c): Sz and gloss. (2.d): St and gloss*

Figure 2 shows the correlations between surface roughness parameters and gloss. For all materials, a significant linear correlation was found between the roughness parameters and gloss ($p<0.05$). The correlations between Sa/gloss ($r=0.871$) and Sq/gloss ($r=0.846$) were relatively strong, whereas those of Sz/gloss ($r=0.713$) and St/gloss ($r=0.707$) were weaker.

DISCUSSION

In this study, the surface roughness and gloss of five resin-composite restorative materials were investigated after being polished using five different polishing techniques. The metallographic polishing method was used as a control to point out the ultimate inherent polishing capacity of the materials, as it provided finer polishing, flat surfaces that were beneficial for gloss measurements and minimal influence from the operator's manipulations. Both the type of material and the polishing techniques significantly affected the surface roughness parameters and gloss of the materials, and hence the first null hypothesis was rejected. Except for St, in relation to material type, all surface roughness parameters and gloss were statistically different among the groups when considering material, polishing method, and material/polishing method factors. Furthermore, a significant moderately strong linear negative correlation was found between all surface roughness parameters and surface gloss, and therefore the second null hypothesis was also rejected.

Surface topography is 3-D in nature. Therefore, the measurement of 3-D surface topography can

Table 6: *Results of Sz (Means and SD/μm) for the Groups Tested*[a]

Material	Polishing Technique				
	OS	OD	KD	PG	ML
FS	7.7 (2.3)$^{A/a}$	9.7 (1.3)$^{A/b}$	16.6 (1.3)$^{B/d}$	11.6 (1.1)$^{A/f}$	8.6 (2.8)$^{A/h}$
IP	9.2 (0.5)$^{C/a}$	13.0 (0.7)$^{D/c}$	15.3 (2.8)$^{D/d}$	9.3 (1.0)$^{C/g}$	9.0 (2.1)$^{C/h}$
CM	12.4 (2.5)$^{E/a}$	11.3 (0.9)$^{E/b}$	17.7 (2.7)$^{F/d}$	12.2 (1.7)$^{E/f}$	9.3 (2.4)$^{E/h}$
PM	11.9 (1.0)$^{G/a}$	13.8 (2.0)$^{G/c}$	9.6 (1.0)$^{H/e}$	6.1 (2.9)$^{H/g}$	8.4 (2.0)$^{H/h}$
ES	10.5 (4.0)$^{I/a}$	10.5 (1.3)$^{I/b}$	18.2 (3.1)$^{J/d}$	7.5 (2.1)$^{I/g}$	4.0 (1.3)$^{K/i}$

[a] *Capital letters denote statistically similar groups in each material among the various polishing techniques (horizontal), while lowercase letters denote statistically similar groups in each polishing technique among the various materials (vertical).*

represent the natural characteristics of a surface.[17] Tactile profilometry is the most common measurement method, as it is widely available and relatively cheap but limited by the spatial dimension of the stylus, measuring force, sampling rate, and the calibration in the *z*-axis,[24] and they usually result in underestimation of the surface roughness.[17,24] In the current study, optical light profilometry, which has a much higher resolution than that of a mechanical stylus,[25] was used for assessing surface roughness of the composites. Moreover, a noncontact acquisition excludes possible surface damage caused by the mechanical sensor that could consequently create bias in the results.[6]

Although Ra is the most commonly used parameter for the quantitative description of roughness,[1,9,10] the use of different roughness parameters is recommended, as Ra does not fully describe the surface of the material,[12] and other amplitude or spacing parameters are also related to bacterial adhesion, optical features, or further properties.[6] Rq is sensitive to peaks and valleys on a surface,[24] and Rz can also minimize the chance of misinterpretation of the Ra parameter, as Rz is more sensitive to distribution of the peaks and valleys.[13]

High gloss for a resin composite gives a natural, esthetic appearance to a restoration. Smoother surfaces reflect light more efficiently and thus give a more glossy and lustrous appearance. According to

Table 7: *Results of St (Means and SD/μm) for the Groups Tested*[a]

Material	Polishing Technique				
	OS	OD	KD	PG	ML
FS	9.4 (3.9)$^{A/a}$	13.0 (2.3)$^{A/b}$	24.6 (6.8)$^{B/d}$	14.0 (2.0)$^{A/e}$	10.5 (2.1)$^{A/f}$
IP	12.1 (1.0)$^{C/a}$	16.6 (2.3)$^{D/b}$	23.1 (7.2)$^{D/d}$	11.5 (2.6)$^{C/e}$	10.8 (1.9)$^{C/f}$
CM	14.6 (3.3)$^{E/a}$	13.9 (1.7)$^{E/b}$	24.2 (5.9)$^{F/d}$	15.1 (2.8)$^{E/e}$	15.0 (1.1)$^{E/g}$
PM	17.5 (4.1)$^{G/a}$	22.0 (4.2)$^{G/c}$	15.9 (2.5)$^{G/d}$	9.3 (3.5)$^{H/e}$	12.6 (0.5)$^{H/f}$
ES	14.2 (3.0)$^{I/a}$	14.7 (2.8)$^{I/b}$	23.2 (4.8)$^{J/d}$	12.8 (2.3)$^{I/e}$	7.1 (0.7)$^{K/h}$

[a] *Capital letters denote statistically similar groups in each material among the various polishing techniques (horizontal), while lowercase letters denote statistically similar groups in each polishing technique among the various materials (vertical).*

Table 8: *Results of Gloss (Means and SD/Gloss Unit) for the Groups Tested*[a]

Material	Polishing Technique				
	OS	OD	KD	PG	ML
FS	72.4 (8.3)[A/a]	53.8 (6.9)[B/b]	30.3 (5.7)[C/c]	77.1 (4.1)[A/e]	78.5 (3.0)[A/g]
IP	74.0 (2.5)[D/a]	55.9 (5.3)[E/b]	49.7 (1.0)[E/d]	78.6 (5.3)[D/e]	82.3 (4.8)[D/g]
CM	61.1 (16.1)[F/a]	59.4 (5.0)[F/b]	39.4 (4.1)[G/c]	61.0 (4.5)[F/f]	77.6 (11.8)[F/g]
PM	72.0 (12.1)[H/a]	65.0 (11.4)[H/b]	55.6 (8.6)[H/d]	68.8 (2.7)[H/f]	88.4 (2.3)[I/g]
ES	64.0 (11.0)[J/a]	61.7 (11.1)[J/b]	36.2 (6.1)[K/c]	74.8 (2.1)[J/e]	81.4 (3.4)[L/g]

[a] *Capital letters denote statistically similar groups in each material among the various polishing techniques (horizontal), while lowercase letters denote statistically similar groups in each polishing technique among the various materials (vertical).*

ISO 2813, ASTHD 523 and 2457, and DIN 67530, semigloss surfaces should be measured with 60° angle of illumination, which was applied in the current study. This was found closer to the angle from which the average person will observe the surface.[17]

Although a threshold for unacceptable surface roughness has not yet been agreed on, it was reported that an Ra above 0.2 μm results in an increase of plaque accumulation and higher risk for caries and periodontal inflammation, compromising aesthetics and longevity of the restoration.[11,17] However, whether this holds true for all materials or dental hard tissues has not been systematically investigated in clinical trials.[11] Other reports found that when Ra was lower than 1 μm, the surfaces were visibly smooth.[5,26] Since most treated surfaces in this study presented Sa values higher than 0.2 μm and lower than 0.7 μm, the effect of the finishing/polishing systems on the finished surface of composite resins investigated is clinically relevant.[3,6]

Several studies showed that the polishing system influences the surface roughness, the gloss, and the color of a restoration.[25,27,28] Most of the published data show that many existing polishing systems provide sufficiently smooth surfaces, with Ra ranging from 0.02 μm to 0.56 μm.[7,17,26,29-32] The present results showed a significant change in the surface of the composites according to the polishing system used. This finding agrees with those reported in previous studies.[3] Although the type of material varied among the parameters, KD seemed to produce the highest roughness values, while ML produced the smoothest surfaces. Excluding the control group since it is not a clinically applicable technique, the lowest Sa and Sq were recorded with OS, the lowest Sz and St for PG, and the highest gloss with PG. In the current study, aluminum oxide discs used in the groups OD and KD resulted in poorer finish than one-step diamond polishers of OS and PG, which agrees with previous studies that PG system produced the smoothest finishing for composite resins compared to Soflex discs.[3,33] The smoother surface with PG is expected to be the result of the use of fine diamond powders instead of aluminum oxide and the cured urethane dimethacrylate resin delivery medium.[2] On the other hand, some studies showed that the more steps involved in polishing, the better the surface smoothness is.[16] Nevertheless, the use of one-step polishers is recommended to save time and costs.[9]

"Metallurgical" polishing produced the smoothest surfaces. Although this methodology is not clinically applicable, it proved that the inherent smoothness capacity of resin composites can be restored after contouring and that there is still room for improvement of the polishing systems to reach the ultimate material roughness characteristics as determined by their composition. Other polishing systems produced rougher surfaces than the ones obtained with ML. This is a reasonable finding since the fine discs, for example, correspond to highly abrasive SiC paper.[34] The gloss measurements were also lower for the specimens polished with noncontrol methods, as deep surface asperities with steep slopes and increased surface waviness, due to manual treatment, reflect light diffusely. However, the efficiency of the different polishing techniques varied among the different materials. For example, OD produced rough PM surfaces, while PG produced smoother PM surfaces (considering Sq, Sz, St, and gloss values). In the current study, the ranking of the polishing techniques varied according to the different materials and among the parameters investigated. Those findings might imply that the best polishing method is material dependent and that roughness parameters other than Sa should also be taken in consideration when evaluating surface roughness of composites.

An important factor in determining the surface roughness is the intrinsic roughness of a composite material, which is determined by the size, shape, and quantity of the filler particles.[5] In the present study, significant differences were observed between different composite resins. Resins with smaller filler particles usually have a smoother finish.[2,3] ES and PM had almost always the lowest roughness values, while CM, FS, and IP groups had generally higher roughness. ES is a nanocomposite. During polishing, these nanoparticles can be worn away rather than plucking. Eventually, the surfaces have smaller defects and better polish retention, unlike the rough texture with pits or craters expected in hybrid composites or microhybrids, such as FS and CM. For PM and IP, which are nanohybrids, better smoothness was generally observed, although it was poorer than ES. These results can be explained by the composition of these composites, as no particle dislodging is expected, while the large glass fillers of CM and FS can be plucked away, leaving voids or craters behind.[5] Furthermore, nanotechnology enables obtaining high filler loading, and hence ES, PM, and IP had higher filler content by volume. During polishing, higher filler content is expected to protect the resin matrix from excessive abrasion, resulting in smoother surfaces. In addition, because of strong filler-matrix integration, those composites wear by breaking off individual primary particles rather than by breaking off larger particles, as with hybrid composites, such as FS and CM, leaving shallower and narrower impressions and smoother surfaces.[12,16,27] The filler shape of ES is spherical, with a narrow range of 0.1- to 0.3-μm-size particles. Therefore, ES might reflect the light uniformly with lower diffusion/absorbance than CM, for example, which has irregular-shaped filler particles.[21] This also applies to FS, which is a microhybrid similar to CM, explaining the higher roughness parameters and lower gloss generally for those two.

To evaluate the polishing effect, the measurement of surface gloss is effective as an additional parameter. Values of gloss generally followed a similar trend to values of surface roughness parameters. With a 60° measuring angle, generally poor finish is considered below 60 gloss units (g.u.), acceptable finish between 60 and 70 g.u., good finish between 70 and 80 g.u., and excellent finish above 80 g.u.[35] The results of this study showed that KD produced poor finish; OD produced poor finish with FS, IP, and CM but acceptable finish with PM and ES; OS and PG produced acceptable to good finish; and ML produced good to excellent finish. Furthermore, a clear relationship was found between Sa, Sq, Sz, and St and gloss in each composite, agreeing with previous studies that found similar correlations.[17,21] The correlation of gloss with all roughness parameters revealed a trend of decreased gloss with increased roughness. Although some of the correlations between roughness parameters and gloss had moderately high coefficients, all were proven statistically significant. This might imply either that the correlations could have occurred by chance or possibly that further factors could have participated in the formation of the observed relations, including the hardness of the different fillers, the pattern of their abrasion, and their refractive indices. Furthermore, since it was found that surfaces with roughness as high as 1 μm can still be seen as smooth,[5,26] the dislodgement of nanoparticles ($<$400 nm) might not be visible by the eye, and therefore the surfaces still appear glossy.

CONCLUSIONS

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

1. The type of resin-composite and the polishing technique used are important factors affecting the surface roughness and gloss of these composites, the latter being the stronger factor.
2. For the composite materials used in this study, one-step polishers generally result in better surface finish of resin composites than multistep polishers.
3. The best polishing technique for resin composite is material dependent.
4. A significant negative correlation was found between gloss and all surface roughness parameters of resin-composite materials investigated, indicating that the better the surface finish of resin composites, the higher the gloss.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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