Influence of a new polishing system on changes in gloss and surface roughness of resin composites after polishing and brushing

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This study aimed to compare the change of surface roughness (Ra) and gloss units (GU) of five dental composites (Filtek Z250, Filtek Z350XT, Metafil CX, Ceram X one, and Venus Diamond) polished with three systems (Sof-Lex XT, Enhance/Pogo, and Sof-Lex Diamond) before/after simulated brushings and to determine the amount of time required to achieve maximum gloss. Ninety rectangular specimens ($n=18$ per composite) were prepared. Six specimens of each composite were assigned to one of the polishing systems. The Ra and GU of each specimen were measured after each polishing step. Five polished specimens per composite were brushed with a toothbrush machine, and the Ra and GU values were determined. Filtek Z350XT exhibited the most stable and lowest Ra during the brushing cycles regardless of polishing system. When using the Sof-Lex Diamond and Enhance/Pogo systems, the highest gloss and the smoothest surfaces were achieved after polishing and brushing.

Keywords: Dental composite, Polishing system, Gloss retention, Surface roughness

INTRODUCTION

Gloss is an attribute of visual appearance resulting from geometrical distribution of light reflected by the surface¹⁾, and high surface gloss is related to a smooth surface with low roughness of restoration²⁾. High surface gloss has been reported to positively affect the esthetic appearance of resin composite restorations³⁾. Resin composite material with high gloss will blend better with adjacent teeth than low-gloss materials^{3,4)}.

In vivo studies on threshold surface roughness (Ra) for bacterial plaque retention have shown that an average roughness greater than 0.2 μm is associated with a substantial increase in bacterial retention⁵⁾. A smooth surface reduces plaque accumulation and surface stain, improving the longevity and esthetics of restorations, allowing the restoration to maintain their natural appearance⁶⁾. Furthermore, initial surface microhardness generally increases with decreasing surface roughness for resin composites⁷⁾, and that increased surface roughness accelerates the wear of resin composites⁸⁾. A smooth surface adds to patient comfort because even a change of about 0.3 μm in surface roughness can be detected by the tip of the patient's tongue⁹⁾. Therefore, for these reasons, it is important to obtain glossy and smooth surfaces for resin composite restorations¹⁰⁾.

To achieve a desirable gloss level, finishing/polishing (F/P) is of the utmost importance to reduce surface roughness¹¹⁾. Finishing removes any scratches

caused by contouring instruments and results in a smooth surface¹²⁾. Polishing, the final step, provides the restoration a gloss-like enamel surface and reduces the surface energy¹²⁾. Commercially available F/P systems contain abrasives such as silicone oxide, aluminum oxide, and diamond dioxide that are impregnated in disks or rubber¹¹⁾. It has been recommended that a series of abrasive disks, from coarse to finer grits in multiple steps, should be used to achieve highly polished resin composite restorations¹³⁾. However, recent reduced-step systems combining some of the F/P procedures in 1 or 2 steps have shown similar results, with regards to surface roughness of resin composites compared to a multiple-step system even after a pre-polishing¹³⁾.

Some years ago, a two-step polishing system, Sof-Lex Diamond (SD), was introduced. It appears to have a similar composition to the Enhance/Pogo system but has spirals of either aluminum oxide or diamond particles impregnated in thermoplastic elastomers. However, to the best of the authors' knowledge, there are no published results comparing it with other F/P systems regarding its effects on gloss or surface roughness of dental resin composites or on the amount of time of F/P necessary to create the maximum gloss on resin composites.

The surface roughness of the resin composite is related to the composition of the material as well as the procedures and F/P systems used in polishing^{14,15)}. It was also reported that the different shapes and sizes of composite fillers, even in the same resin composite type, affected the surface morphology of resin composites subjected to finishing procedures¹⁶⁾. Nanofilled and

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nanohybrid resin composites were developed to create a material with high initial polishing combined with superior polish and gloss retention compared with the traditional microhybrid resin composites¹⁷. There have been studies on the effect of polishing system on surface roughness using different types of resin composites^{10,13,16,18-26}. However, no study has tested changes in surface roughness and gloss of nanofilled, nanohybrid, and microhybrid resin composite products currently available after using SD.

Toothbrushing after polishing with abrasive disks increases the surface roughness of the resin composite restorations to various degrees²⁷. A decrease in gloss caused by an increase in surface roughness leads to biofilm retention and staining, causing color instability and possibly resulting in higher rates of failure of the restoration over time²⁸. There have been studies on gloss retention after simulated toothbrushing^{2,29-32}. However, there have been few studies on the effect of polishing system on direct dental resin composite gloss retention over time after simulated brushing.

The purpose of this study was threefold: (1) to evaluate the changes of surface roughness and gloss of the three different resin composite F/P systems on five dental resin composites when polishing continuously to achieve maximum gloss; (2) to determine the amount of

time of F/P necessary to achieve maximum gloss; and (3) to compare surface roughness and gloss of the polished resin composites after three repeated simulated brushing cycles.

MATERIALS AND METHODS

Preparation of specimens

Five commercial resin composites with different particle sizes and compositions and three F/P systems were evaluated in this study (Tables 1 and 2). The resin composites evaluated were two microhybrid resin composites Filtek Z250 (Z2; 3M ESPE, St. Paul, MN, USA) and Metafil CX (ME; Sun Medical, Shiga, Japan), one nanofilled resin composite Filtek Z350XT (Z3; 3M ESPE), and two nanohybrid resin composites Ceram X one (CE; Dentsply, Milford, DE, USA), and Venus Diamond (VE; Heraeus Kulzer, Hanau, Germany). Unpolymerized resin composites (all A2 shade) were compacted into a polytetrafluoroethylene mold to create 90 rectangular specimens (width=5 mm, length=12 mm, thickness=2 mm, $n=18$ per resin composite). These specimens were placed on a pre-made acrylic ring (diameter=25 mm, height=8 mm) with a rectangular cavity the same shape of the mold and 0.5 mm in depth on the upper aspect to facilitate retention of the

Table 1 Resin composites (shade A2) tested in this study

Resin composite	Code	Type	Inorganic filler level (wt%)	Average particle size	Manufacturer	Lot #
Filtek Z250	Z2	Microhybrid	78	0.01–3.5 μm	3M ESPE, St. Paul, MN, USA	N703018
Filtek Z350XT	Z3	Nanofilled	78.5	Primary particle (0.005–0.02 μm)+ Nonagglomerated silica filler (0.02 μm)	3M ESPE	N751605
Metafil CX	ME	Microhybrid	54	Prepolymerized particle filler (5–10 μm)+ Spherical particle (<0.05 μm)	Sun Medical, Shiga, Japan	LW12
Ceram X one	CE	Nanohybrid	76	Nanoparticle (0.0023 μm)+ Nanofiller (0.01 μm)+ Glass filler (1.1–1.5 μm)	Dentsply, Milford, DE, USA	1504000378
Venus Diamond	VE	Nanohybrid	64	0.005–0.02 μm	Heraeus Kulzer, Hanau, Germany	010059A

Table 2 Finishing and polishing products tested in this study

Polishing system	Code	Average particle size	Manufacturer	Lot #
Sof-Lex XT	SX	Medium disk aluminum oxide (40 μm) Fine disk aluminum oxide (24 μm) Superfine disk aluminum oxide (8 μm)	3M ESPE, St. Paul, MN, USA	N695318 N716624 N701266
Enhance/Pogo	EP	Finisher disk aluminum oxide (40 μm) Diamond coated micro-polisher (10–15 μm)	Dentsply, Milford, DE, USA	140127 140930
Sof-Lex Diamond	SD	Pre-polishing spirals (Beige) Polishing spirals (Pink)	3M ESPE	N754057 N754058

specimens in the apparatus during the polishing and toothbrushing abrasion procedures. Mylar strips were placed over each surface of the unpolymerized resin composite to prevent formation of an oxygen inhibition layer, and a slide glass was lightly pressed using finger pressure for 30 s to extrude the excess resin composite. The specimens were then light cured for 40 s with a Valo LED curing unit (Ultradent, South Jordan, UT, USA) with a tip diameter of 12 ± 1 mm. The energy of the curing light ranged between 1,260 and 1,540 mW/cm² and was monitored with a dental radiometer (Light Meter-200; Rolence Enterprise, Chungli, Taiwan). The specimens were separated from the mold, and edge flashing was carefully removed. The specimens were dried for 24 h, and the surfaces were abraded on 600-grit silicon carbide paper (Struers, Cleveland, OH, USA) to produce a standard surface by a trained operator.

Measurement of surface roughness and surface gloss

At each polishing step, including baseline before polishing, the surface roughness and gloss unit of the specimens were measured ($n=6$, each group). The average surface roughness (R_a , μm) was measured with a surface profilometer (TR200; TIME Group, Pittsburgh, PA, USA) at four positions by rotating 90° between measurements with a cut-off value of 0.25 mm each for a tracing length measurement of 2 mm. The mean baseline surface roughness (R_a , μm) ranged from 0.696 to 0.845.

The gloss unit (GU) of the specimen surface was measured three times in the center of the specimen using a small-area gloss meter (Novo-Curve; Rhopoint Instruments, East Sussex, UK) with a square measurement area of 2×2 mm and 60° geometry. The influence of the overhead light was eliminated using a custom-made, 10-mm-thick, black polytetrafluoroethylene mold. One-way analysis of variance (ANOVA) results showed no statistically significant difference in R_a or GU at baseline between groups ($p=0.928$ for R_a , $p=0.727$ for GU).

Finishing and polishing

The specimens with the same resin composite product were randomly assigned to a group ($n=6$) to perform the F/P steps. A trained operator carried out the F/P procedures using the same low-speed handpiece (NSK, Tokyo, Japan; average 15,000 rpm) with light pressure for all experiments. Polishing was performed as follows.

1. Sof-Lex XT (SX; 3M ESPE)

Step 1: The surface was polished with a medium grit disk for 20 s, rinsed, and dried with a water/air syringe for a total of 10 s.

Step 2: The surface was polished cumulatively with a fine grit disk for 20 s, 40 s, and 60 s; rinsed; and dried with a water/air syringe for a total of 10 s.

Step 3: The surface was polished cumulatively with a superfine grit disk for 20 s, 40 s, and 60 s; rinsed; and dried with a water/air syringe

for a total of 10 s at each step.

2. Enhance/Pogo (EP; Dentsply)

Step 1: The surface was treated with Enhance under light intermittent pressure for 60 s, rinsed, and dried with a water/air syringe for a total of 10 s.

Step 2: The surface was treated with Pogo under light intermittent pressure for 20 s, 40 s, 60 s, 140 s, 160 s, and 180 s; rinsed; and dried with a water/air syringe for a total of 10 s at each step.

3. Sof-Lex Diamond (SD; 3M ESPE)

Step 1: The surface was treated with a coarse grit disk for 60 s, rinsed, and dried with a water/air syringe for a total of 10 s.

Step 2: The surface was treated cumulatively with a fine grit disk for 20 s, 40 s, 60 s, 140 s, 160 s, and 180 s; rinsed; and dried with a water/air syringe for a total of 10 s at each step.

The polishing motion was circular and constant and was performed under light pressure of each grinder only once. At each polishing step, the surface R_a and GU of the specimens were measured.

Atomic force microscopy (AFM) analysis

One sample from each group was selected randomly for AFM examination after all polishing procedures. Three-dimensional (3-D) images of each polished surface per material were obtained at 30 μm scan sizes (non-contact mode) using an XE-100 AFM (Park Systems, Suwon, Korea) equipped with a scanner with a maximum range of 100×100 μm .

Tooth brushing test

A commercial dentifrice (2080 Pro-Clinic; Aekyung, Seoul, Korea; radioactive relative abrasion [RDA]=90) was used to create a solution with a volume ratio of water to dentifrice of 2:1. A soft nylon toothbrush (Oral-B Soft) and the specimen were brought into contact in the dentifrice solution at room temperature (23°C). The specimens ($n=5$, each group) were mounted onto an acrylic case on the toothbrush machine. A uniform pressure of 150 g was applied to the toothbrush, and the toothbrush was used on the specimen with a linear back and forth brushing action at a frequency of 2.83 Hz. After brushing 5,760 strokes (complete forward and reverse movements) on each specimen, all specimens were ultrasonically cleaned for 5 min, rinsed in distilled water, and carefully wiped dry. The specimens were re-evaluated for surface roughness and gloss. A fresh slurry and toothbrush were used for every test. This brushing cycle was repeated three times, and the surface R_a and GU of the specimens were measured after each brushing cycle. One trained operator performed all steps and measured the values at every step. In addition, one randomly selected sample from each group was examined by AFM after all brushing cycles.

Statistical analysis

Statistical comparisons of Ra and GU on the specimens were performed between groups. The normality of the studied parameters was verified using the Kolmogorov-Smirnov test and Shapiro-Wilk test, and statistical analyses were performed based on parametric tests because all were normally distributed. The values of the studied parameters in each group at baseline, after all polishing procedures, and after each brushing cycle were compared by ANOVA, and homogeneity of variance was tested with Levene's test. According to the results of Levene's test, *post hoc* comparisons were performed using either Tukey's honestly significant difference (HSD) or Dunnett's T3. In addition, repeated measures ANOVA analysis was performed after the polishing procedure and after the first, second, and third brushing cycles to determine how Ra and GU changed with brushing after

polishing. All statistical analyses were performed with an alpha significance level of 0.05 using the Statistical Package for the Social Sciences (SPSS) 23 (IBM SPSS Statistics, Armonk, NY, USA).

RESULTS

Changes in gloss and surface roughness

The mean values and standard deviation of Ra and GU for each group are given in Table 3. The repeated measures ANOVA showed significant differences in Ra and GU between time points ($p < 0.05$). Z3 showed the most stable and lowest Ra value during brushing cycles regardless of polishing system. Compared with SX, EP and SD exhibited more stable and lower Ra values for each resin composite during brushing.

The changes of mean GU for the five dental resin

Table 3 Mean surface roughness (Ra) (μm) and gloss unit (GU) value with standard deviations (SD) of investigated composites

Group		Ra		GU	
		T1	T4	T1	T4
Z2	SX	0.077 (0.017)	0.113 (0.018) ^{cd}	58.1 (8.6)	14.5 (4.9) ^{ABC}
	EP	0.040 (0.024)	0.098 (0.019) ^{bc}	81.7 (4.5)	29.3 (12.5) ^{DE}
	SD	0.028 (0.005)	0.084 (0.020) ^{ab}	82.6 (1.0)	27.2 (10.5) ^{DE}
Z3	SX	0.067 (0.019)	0.054 (0.013) ^{ab}	55.9 (7.3)	54.1 (7.0) ^{EFG}
	EP	0.030 (0.005)	0.045 (0.010) ^a	86.7 (1.4)	82.3 (7.4) ^J
	SD	0.033 (0.003)	0.043 (0.005) ^a	80.6 (1.5)	80.6 (4.5) ^{IJ}
ME	SX	0.087 (0.011)	0.197 (0.011) ^f	56.9 (9.1)	28.0 (6.2) ^{BCD}
	EP	0.057 (0.012)	0.093 (0.021) ^{bc}	78.8 (3.0)	59.9 (5.1) ^{HI}
	SD	0.067 (0.003)	0.114 (0.020) ^{cd}	68.1 (1.6)	57.3 (10.1) ^{GH}
VE	SX	0.087 (0.004)	0.146 (0.021) ^e	48.6 (5.6)	19.0 (3.2) ^{AB}
	EP	0.057 (0.007)	0.101 (0.004) ^{bc}	81.0 (2.2)	53.6 (8.6) ^{FGH}
	SD	0.049 (0.004)	0.101 (0.007) ^{bc}	77.9 (2.9)	59.3 (8.3) ^{GH}
CE	SX	0.117 (0.011)	0.148 (0.052) ^e	31.4 (6.5)	16.5 (4.7) ^A
	EP	0.072 (0.009)	0.138 (0.041) ^{de}	65.9 (4.5)	33.1 (12.3) ^{CDE}
	SD	0.061 (0.004)	0.107 (0.021) ^{cd}	73.1 (1.7)	41.6 (13.4) ^{DEF}

Values with the same superscript are not significantly different ($p > 0.05$; repeated measures ANOVA between T1 through T4 with *post hoc* Tukey's HSD test).

Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; SX: Sof-Lex XT system; EP: Enhance-Pogo system; SD: Sof-Lex Diamond system; T1: after polishing; T4: after the 3rd brushing cycle.

Fig. 1 Mean gloss unit value changes for the 5 resin composites and 3 polishing systems tested. Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; M: Medium grit; F: Fine grit; SF: Superfine grit; B: Brushing; En: Enhance; Po: Pogo; C: Coarse grit.

composites depending on polishing system during polishing and brushing procedures are shown in Fig. 1. In EP and SD, GU increased with a high inclination until 120 s after polishing began but then gradually increased. Z3 polished with EP or SD maintained the most stable and highest GU during brushing cycles. EP and SD exhibited higher GU values especially for the Z3, ME, and VE groups during and after the brushing procedure.

The high value of GU and the low value of Ra did not always coincide. Z2 polished with SX, EP, and SD exhibited a lower Ra and lower GU values after the third brushing cycle compared to the other resin composite groups, except Ra in Z3 (Table 3).

Amount of time of F/P necessary to create maximum gloss
In the SX system, the GU of most resin composites increased after the third superfine disk was applied for 60 s (total of 140 s), while the Z3 resin composite achieved maximum GU after the third disk was applied for 40 s (total of 120 s). In the EP system, Z2, Z3, VE, and CE achieved maximum GU after the second disk, Pogo, was applied for 160 s (total of 220 s), while ME increased until the second disk was applied for 180 s (total of 240 s). In the SD system, Z2, Z3, VE, and CE achieved maximum GU after the second disk, polishing spirals, was applied for 160 s (total of 220 s), while ME increased until the second disk was applied for 180 s (total of 240 s) (Fig. 1). However, the GU for every resin composite was higher when using the SD or EP system

Fig. 2 Comparison of (A) mean surface roughness (Ra) (μm) and (B) gloss unit (GU) value for the resin composites tested after sequential polishing with different polishing systems.

Values with the same lowercase letter are not significantly different ($p>0.05$; one-way ANOVA between polishing systems with *post hoc* Tukey's HSD test). Vertical bars refer to the standard deviation. Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; SX: Sof-Lex XT system; EP: Enhance-Pogo system; SD: Sof-Lex Diamond system.

Fig. 3 Comparison of (A) mean surface roughness Ra (μm) and (B) gloss unit (GU) value for the polishing systems tested after sequential polishing with different resin composites.

Values with the same lowercase letter are not significantly different ($p>0.05$; one-way ANOVA between resin composites with *post hoc* Tukey's HSD test). Vertical bars refer to the standard deviation. Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; SX: Sof-Lex XT system; EP: Enhance-Pogo system; SD: Sof-Lex Diamond system.

compared to using SX after complete polishing.

Gloss and surface roughness after polishing procedures

The mean values and standard deviations of Ra and GU for each resin composite after polishing are shown in Fig. 2. There were significant differences in Ra between the SX group and the other groups ($p<0.001$, Tukey's HSD *post hoc* test with homogeneity of variance; Fig. 2A). In addition, the same result was obtained statistically for GU ($p<0.001$, Dunnett T3 *post hoc* test without homogeneity of variance; Fig. 2B).

The mean Ra and GU with standard deviations for each polishing system after polishing are given in Fig. 3. There were significant differences in Ra between Z3 with the lowest values and CE with the highest values ($p=0.023$, Tukey's HSD *post hoc* test with homogeneity

of variance; Fig. 3A). There was also a significant difference in GU between CE with the lowest values and the other groups ($p=0.033$, Tukey's HSD *post hoc* test with homogeneity of variance; Fig. 3B).

When the different dental resin composites for each F/P system were compared after polishing, Z2 with SD, Z3 with SD, Z2 with EP, and Z3 with EP exhibited the lowest Ras, while CE with SX exhibited the highest Ra ($p<0.001$, Tukey's HSD *post hoc* test with homogeneity of variance). In addition, Z2 with SD, Z3 with SD, Z2 with EP, and Z3 with EP produced the highest GU, while CE with SX produced the lowest GU ($p<0.001$, Tukey's HSD *post hoc* test with homogeneity of variance).

AFM analysis

Prior to the brushing procedures, the surface roughness

Fig. 4 AFM 3-dimensional images showing the polished surfaces of resin composites before brushing (scan size $30\times30\text{ }\mu\text{m}$).

Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; SX: Sof-Lex XT system; EP: Enhance-Pogo system; SD: Sof-Lex Diamond system.

Fig. 5 AFM 3-dimensional images showing the surfaces of resin composites after the third brushing cycle (scan size $30\times30\text{ }\mu\text{m}$).

Z2: Filtek Z250; Z3: Filtek Z350XT; ME: Metafil CX; VE: Venus Diamond; CE: Ceram X one; SX: Sof-Lex XT system; EP: Enhance-Pogo system; SD: Sof-Lex Diamond system.

of the specimens using the EP system and the SD system were lower than those using the SX system (Fig. 4). Z3 exhibited the lowest surface roughness, while VE and CE demonstrated a higher surface roughness compared to the other resin composites after the third brushing cycle (Fig. 5). When three brushing cycles, Z2, ME, VE, and CE polished with any F/P system showed rougher surfaces than before brushing, while the surface roughness of Z3 was less than or similar to that before brushing (Figs. 4 and 5).

DISCUSSION

In the present study, the SX system took less time than the two-step F/P systems for the Ra to decrease to less than 0.2 μm , known as the plaque accumulation threshold⁹. The SD system required less time to create smoother surfaces than did the EP system. However, even low Ra below 0.2 μm did not guarantee a high GU. A previous study on surface Ra and gloss of microhybrid and nanofilled resin composites after polishing reported that gloss of resin composites differed according to F/P system despite similar surface roughness for the resin composites¹⁰. Gloss can be affected by other factors such as difference in refractive indices of the resin matrix and filler, although the smoothness of the surface has a significant relationship with gloss of resin composites^{4,33}. It was reported that nanofilled composites would exhibit glossier surfaces than microhybrids after polishing because their diffusion reflection would be lower with smaller filler particles, making the surface appear glossy^{33,34}, corresponding well with our findings.

Filler particle technology is considered to influence the optical properties as well as the wear resistance of resin composite restorations³⁵. In the present study, CE exhibited higher Ra and lower GU than other resin composites after polishing, especially when using SX. CE is reported to represent an Ormocer containing inorganic-organic copolymers in addition to inorganic silanized filler particles³⁶. However, CE contains a relatively large size of glass filler, which may lead to premature wear of the resin matrix and loss of the filler particles from the resin matrix during polishing. Therefore, this factor may contribute negatively to a smooth, glossy surface even though it has been reported to have some advantages, including low shrinkage and biocompatibility³⁷. It was confirmed by AFM observation that the surfaces of CE with every F/P system were rougher than those of other resin composites before and after brushing.

After polishing with any F/P system, Z2 exhibited low Ra and GU as high as other resin composites before brushing even though Z2 is generally classified as a microhybrid because of its large filler range. However, a previous study reported that Z2 exhibited higher Ra compared with nanofilled or nanohybrid resin composites before and after toothbrushing when polishing with the SX system³⁸, which is different from our findings in that we were able to achieve low Ra and high GU immediately after polishing. This may be caused by the longer polishing time in the present study and the

strong matrix-filler integration of the resin composite, indicating that the filler particles may not be lost during the polishing procedure.

ME has large prepolymerized particle filler consisting of smaller fillers but has the lowest filler content³⁹, potentially leading to low wear resistance. However, the submicron filler particles in ME, which are larger than nanofilled particles, may contribute to rougher surfaces and lower gloss compared to other resin composites after polishing. VE is reported to contain a novel TCD-DI-HEA monomer that exhibits low contraction stress and shrinkage but in the presence of nanohybrid type fillers⁴⁰. However, in the present study, VE demonstrated no better surface roughness or gloss compared to other resin composites except for CE, which may imply that polished surface roughness may be related more to filler than to resin matrix.

The polishing efficacy of F/P materials is related to the hardness of the embedded abrasive particles, the flexibility of the backing material itself, and the shape of the instrument used²⁰. In the present study, the resin composite surface using SD and EP systems had statistically lower Ra and higher GU compared to those with SX for all the resin composites after complete polishing procedures. These findings are similar to the results of da Costa *et al.* in that the GU of the polished surface of Z2 and Filtek Supreme Plus was higher when using the EP system compared to the SX system¹⁶. The harder fine diamond particles embedded in the flexible disk with Pogo in the EP system and in the flexible spiral wheels with polishing spirals in the SD system, compared with the aluminum oxide particles in the SX system, may contribute to the higher GU of the polished resin composites.

The SD and EP systems exhibited more stable and lower Ra and higher GU for each resin composite during the brushing procedures compared with the SX system. Performing polishing for the maximum time may contribute to optimal Ra and GU of the resin composites, but it seems that the original mechanical properties of the resin composites remain after the brushing cycles. Z3, having a high concentration of nanoparticles, not only exhibited better polishing capabilities due to the small size of the particles, but also demonstrated excellent mechanical properties due to the high concentration of fillers¹¹. Z3 showed the most stable and lowest Ra and highest GU during the brushing cycles compared with other resin composites regardless of polishing system used, even though it had Ra and GU values similar to those of other resin composites when measured immediately after the polishing procedures. Therefore, the low Ra and high GU of Z3 were almost unchanged during the brushing process because the nano-sized filler particles in Z3 did not significantly affect the surface roughness, even though they may be removed during brushing. Z2 achieved low Ra and high GU values after the polishing procedures but exhibited higher Ra and lower GU values during the brushing cycles. It seems that the filler particles adhered well to the resin matrix in Z2 during the polishing process but were lost during

repeated and prolonged brushing, as demonstrated by the AFM images.

Da Costa *et al.*⁴¹⁾ suggested that a person may brush each tooth for four seconds twice a day, producing 16 strokes a day based on an estimated brushing stroke in the oral cavity of two strokes per second. Thus, 5,760 strokes, which is the equivalent of 16 strokes in 360 days, might represent one year of toothbrush abrasion. In the present study, the first, second, and third brushing cycles may represent 1, 2, and 3 years of toothbrush abrasion, respectively, which is still too short a period of time considering the average service year of resin composites. In addition, two-dimensional (2-D) tactile profilometry is reported to be linked to underestimation of dental resin composite surface roughness since surface topography is naturally three-dimensional⁴²⁾. Although we performed both 2-D contact methods and 3-D AFM examination to reduce errors in measurement and interpretation, there may be limits to the interpretation. In addition, we selected a soft bristle toothbrush because it is the most recommended toothbrush by general dentists. As a result, if a harder bristle toothbrush was used, the result after brushing would have been affected.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions may be drawn. The two-step F/P systems used in this study were able to achieve higher GU with the same polishing time compared to a multi-step F/P system. The SD F/P system was able to achieve higher GU and lower Ra for all resin composites in the study compared with those of the SX system but exhibited similar performance to the EP system after polishing. However, gloss retention of the polished surface after tooth brushing was dependent not on resin composite type or F/P system but on the resin composite product. In all F/P systems, Z3, which has a high proportion of nanoparticles, exhibited better gloss retention during simulated brushing cycles. Nevertheless, each resin composite product polished using an SD or EP system had higher GU compared to that using the SX system even after brushing.

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