

Influence of polishing systems and thermal aging on the surface gloss of microhybrid and nanohybrid resin composites

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Cite this article as: Gümüş Ayaz S. Influence of polishing systems and thermal aging on the surface gloss of microhybrid and nanohybrid resin composites. *J Dent Sci Educ.* 2026;4(4):150-157. doi:10.51271/JDSE-0091

Received: 20.08.2026

Accepted: 05.10.2026

Published: 28.10.2026

ABSTRACT

Aims: This study evaluated the effects of different polishing systems on the surface gloss of microhybrid and nanohybrid resin composites and the effect of thermal aging on gloss retention.

Methods: Ninety specimens of 3M™ Filtek™ Z250 and VOCO GrandioSO were assigned to Twist Dia (TD), Sof-Lex Disc (SD), or control groups (n=15). Thermal aging was performed for 15,000 cycles between 5°C and 55°C with a 30-second dwell time. Surface gloss was measured at baseline, after polishing, and after thermal cycling. Statistical significance was set at $p < 0.05$.

Results: Polishing significantly increased surface gloss in both composites (all $p < .001$), whereas thermal aging significantly reduced gloss (all $p < .001$; Cohen's $d = 2.32-4.24$). Immediately after polishing, TD and SD showed comparable gloss values ($p = 1.000$), and composite type had no significant overall effect [$F(1,84) = 3.02$, $p = .086$]. After thermal cycling, SD retained significantly higher gloss than TD ($p = .002$) and control ($p = .018$). Split-plot ANOVA showed significant effects of thermal cycling ($p < .001$, partial $\eta^2 = .908$) and polishing system ($p < .001$, partial $\eta^2 = .470$), with significant interactions between polishing system and thermal cycling and between composite type and thermal cycling (both $p < .001$).

Conclusion: Polishing increased surface gloss, whereas thermal aging substantially reduced it. SD demonstrated superior gloss retention after thermal aging, although TD and SD performed similarly immediately after polishing. Composite type did not significantly affect overall gloss but interacted with thermal aging.

Keywords: Composite resin, finishing and polishing, surface gloss, glossmeter, thermal aging

INTRODUCTION

Resin-based composites are widely used in direct restorative dentistry because of their favorable esthetic properties, adhesive potential, and versatility. The long-term esthetic performance of these materials, however, depends not only on their initial optical properties but also on their ability to maintain a smooth and glossy surface during service.^{1,2} Surface gloss is an important optical parameter associated with the perception of smoothness and restoration quality, while deterioration of surface characteristics may increase light scattering and compromise the esthetic appearance of restorations.¹⁻⁴ Therefore, achieving and maintaining a high-gloss surface is an important objective of finishing and polishing procedures.

Finishing and polishing procedures play a critical role in establishing the final surface characteristics of resin composites. The effectiveness of a polishing procedure is influenced by the abrasive material, particle size, number of polishing steps, application protocol, and intrinsic characteristics of the resin composite.^{3,4} In particular, filler size, morphology, distribution, hardness, and filler loading may affect the interaction between the abrasive and composite surface and consequently influence the final gloss. Recent

studies have demonstrated that the performance of polishing systems is material-dependent, with differences in surface gloss observed among resin composites following the use of one-step, two-step, and multi-step polishing protocols.⁵⁻⁸ These findings suggest that the classification of a composite alone may not adequately predict its response to a particular polishing system.

The maintenance of surface gloss following artificial aging is another clinically relevant consideration. Resin composites are exposed to repeated thermal fluctuations, moisture, mechanical stresses, and chemical challenges in the oral environment, which may induce degradation of the resin matrix-filler interface and alter surface characteristics over time. Thermocycling is therefore frequently used as an artificial aging method for evaluating the stability of restorative materials. Rocha et al.⁹ demonstrated that thermocycling between 5°C and 55°C reduced the surface gloss of several resin composites, although the magnitude of the effect varied according to the material. More recent investigations have similarly shown that gloss retention following finishing and polishing may vary according to both the composite formulation and the polishing protocol.^{8,9} Thus, a polishing



system that produces a high initial gloss may not necessarily provide optimal gloss retention after aging.

Despite increasing interest in the optical performance of polished resin composites, the combined effects of polishing system, composite filler characteristics, and subsequent thermal aging on surface gloss remain insufficiently characterized. In particular, direct comparisons between a two-step diamond-impregnated spiral system and a conventional multi-step aluminum oxide disc system in microhybrid and nanohybrid composites, followed by evaluation of gloss retention after extensive thermal cycling, are limited. This is relevant because Filtek Z250 and GrandioSO differ substantially in filler characteristics and resin matrix composition, potentially resulting in different responses to polishing and thermal aging. Therefore, this study aimed to evaluate the effects of Twist Dia and Sof-Lex Disc polishing systems on the surface gloss of a microhybrid resin composite (Filtek Z250) and a nanohybrid resin composite (GrandioSO), and to assess changes in gloss following 15,000 thermal cycles. The null hypotheses were that (1) polishing system would not significantly affect surface gloss, (2) resin composite type would not significantly affect surface gloss, and (3) thermal aging would not significantly alter surface gloss.

METHODS

Ethics

Ethics committee approval was not required because this was an in vitro laboratory study conducted exclusively using commercially available resin composite materials, without involving human participants, human-derived biological specimens, or animals. All procedures were carried out in accordance with the ethical rules and the principles.

Study Design and Specimen Preparation

This in vitro study was designed to evaluate the effects of different polishing systems on the surface gloss of microhybrid and nanohybrid resin composites and to assess gloss retention following thermal aging. Two commercially available resin composites were investigated: a microhybrid composite (Filtek™ Z250; 3M ESPE, St. Paul, MN, USA) and a nanohybrid composite (GrandioSO; VOCO GmbH, Cuxhaven, Germany). The compositions and characteristics of the resin composites are presented in [Table 1](#). The materials differed in filler type, filler loading, and resin matrix composition, allowing the influence of composite composition on surface gloss and gloss retention to be evaluated.

Specimen Size and Sample Size Calculation

A total of 90 resin composite specimens were prepared, consisting of 45 Filtek Z250 and 45 GrandioSO specimens. All specimens were fabricated using a standardized circular mold with an internal diameter of 8 mm and a thickness of 2 mm.

Sample size calculation was performed using G*Power software (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany). Based on a previous study with a similar methodology, an effect size of 3.608 was determined. With a statistical power of 95% and a significance level (α) of 0.05, the minimum required sample size was calculated as eight specimens per group.¹⁰ To increase the reliability and statistical power of the study, 15 specimens were included in each group, resulting in a total sample size of 90 specimens.

The specimens were randomly allocated according to resin composite type and surface treatment. For each composite, the specimens were divided into three groups ($n=15$): Twist Dia (TD), Sof-Lex Disc (SD), and an unpolished control group (K). Thus, six experimental subgroups were obtained, with 15 specimens in each subgroup.

Specimen Preparation

The specimens were prepared using a standardized procedure based on previously described methods. A circular plastic mold (8 mm in diameter and 2 mm in thickness) was placed on a glass slide and covered with a Mylar strip.¹¹ The resin composite was then placed into the mold and gently condensed to minimize the formation of voids. A second Mylar strip and a glass slide were placed over the uncured composite, and gentle pressure was applied to obtain a flat and uniform surface.

Polymerization was performed using a light-emitting diode (LED) curing unit (Valo X; Ultradent Products, South Jordan, UT, USA) with an irradiance of 1000 mW/cm². Each specimen was light-cured for 20 seconds from both the top and bottom surfaces. Following polymerization, the specimens were stored in distilled water at 37°C for 24 hours.

To standardize the initial surface conditions and remove the oxygen-inhibited layer, the upper surfaces of all specimens were roughened using the coarsest disc (80 μ m) of the OptiDisc system (Kerr Corporation, Orange, CA, USA). This procedure was performed under dry conditions at 9000 rpm for 30 seconds. The bottom surfaces were marked with a scalpel to ensure consistent specimen orientation throughout the subsequent procedures.

Polishing Protocol

All polishing procedures were performed by a single experienced and calibrated operator using a low-speed micromotor with a contra-angle handpiece (NSK, Japan). Polishing was performed according to the manufacturers' recommendations regarding rotational speed, application time and sequence. A new polishing instrument was used for each specimen, and gentle, consistent manual pressure was maintained throughout the polishing procedures; however, the applied pressure was not objectively quantified.¹²

Table 1. Resin composites used in this study

Resin composite	Manufacturer	Color	Classification	Filler (wt.%)	Filler type	Matrix
Filtek™ Z250	3M ESPE, St. Paul, MN, USA	A2	Microhybrid	82	Zirconia/silica; 0.01-3.5 μ m	Bis-GMA, UDMA, Bis-EMA, TEGDMA
GrandioSO	VOCO GmbH, Cuxhaven, Germany	A2	Nanohybrid	89	Glass ceramic filler (~1 μ m), functionalized silicon dioxide nanoparticles (20-40 nm), pigments	Bis-GMA, Bis-EMA, TEGDMA

wt. %: Weight percentage, MN: Minnesota, USA: United States of America, μ m: Micrometer, Bis-GMA: Bisphenol A-glycidyl methacrylate, UDMA: Urethane dimethacrylate, Bis-EMA: Ethoxylated bisphenol A dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate, nm: Nanometer



In the TD group, specimens were polished using a two-step diamond-impregnated spiral system (Twist Dia; Kuraray, Japan). The coarse spiral (14 μm) was operated at 5000 rpm for 20 seconds in a counterclockwise direction, followed by the fine spiral (10 μm), which was applied at 2000 rpm for 20 seconds in the same direction. Both polishing steps were carried out under dry conditions without water cooling.

In the SD group, specimens were polished with a four-step aluminum oxide (Al_2O_3)-coated polishing system (Sof-Lex Disc; 3M, USA). Coarse (55 μm), medium (40 μm), fine (24 μm), and superfine (8 μm) discs were applied sequentially for 20 seconds each at 5000 rpm under dry conditions.

Following polishing, the specimens were rinsed with distilled water to remove residual debris and dried with oil-free compressed air. The control group received no polishing procedure.

Surface Gloss Measurement

Surface gloss was measured using a glossmeter (PCE-SGM60 Plus; PCE Instruments, Germany) with a 60° measurement geometry. Gloss values were recorded in gloss units (GU). Gloss measurements were performed at three experimental stages: before polishing (baseline), immediately after polishing, and after thermal aging. Before each measurement, the specimens were rinsed with distilled water and dried to remove surface debris and moisture. The specimens were positioned in a standardized manner to ensure that the same surface area was evaluated at each measurement stage. A custom-made black polytetrafluoroethylene (PTFE) mold with a thickness of 10 mm was positioned over each specimen to ensure proper alignment and minimize the influence of ambient and reflected light. Each specimen was measured three times by a single experienced operator, and the mean of the three measurements was used for statistical analysis.¹³

Thermal Aging

Following the post-polishing gloss measurements, all specimens were subjected to thermal aging using a thermocycling device. The specimens underwent 15,000 thermal cycles between 5°C and 55°C, with a dwell time of 30 seconds in each bath. The transfer time between the two baths was kept as short as possible and was controlled by the thermocycling device.⁹ After completion of thermal cycling, the specimens were rinsed with distilled water and dried, and surface gloss was measured again using the same measurement protocol described above. The post-aging gloss values were compared with the baseline and post-polishing measurements to evaluate changes in surface gloss and gloss retention following thermal aging.

Statistical Analysis

All data analyses were performed using IBM SPSS Statistics, version 27.0 (IBM Corp., Armonk, NY, USA).

The gloss data obtained in this study were evaluated using a split-plot (mixed) three-way ANOVA, with composite type (GrandioSO/nanohybrid, Filtek Z250/microhybrid) and polishing system (Twist Dia, Sof-Lex Disc, unpolished control) treated as between-subjects factors, and thermal cycling (pre-thermal cycling/post-thermal cycling) treated as a two-level within-subjects (repeated-measures) factor because measurements were obtained from the same specimens. For

the polished groups, the pre-thermal-cycling value entered into the mixed ANOVA was the measurement obtained immediately after polishing; for the unpolished control groups, the corresponding pre-thermal-cycling value was the baseline measurement because no polishing procedure was performed. The initial baseline measurements of the polished groups were not included as a third level in the mixed ANOVA; they were used separately to evaluate the immediate effect of polishing relative to the pre-polishing condition. Main effects (composite type, polishing system, thermal cycling) and two- and three-way interactions (composite type $\times$ polishing system, composite type $\times$ thermal cycling, polishing system $\times$ thermal cycling, composite type $\times$ polishing system $\times$ thermal cycling) were examined; between-subjects effects were tested against the between-subjects error term, while within-subjects effects were tested against the residual error term. Effect sizes were reported as partial eta squared (partial η^2). Paired-samples t-tests were used to compare gloss values before and after thermal cycling within each composite-polishing system combination, with effect sizes expressed as Cohen's d. Pairwise comparisons between polishing systems were performed using independent-samples t-tests following one-way ANOVA. Bonferroni correction was applied to control for type I error arising from multiple comparisons. Statistical significance was set at $p < .05$.

RESULTS

Descriptive Statistics

As shown in Table 2, polishing markedly increased gloss values in both composite materials compared to the baseline (unpolished) surfaces. In the VOCO group, mean gloss increased from 54.95 ± 12.84 GU to 69.45 ± 11.32 GU with Twist Dia, and from 43.65 ± 16.38 GU to 66.32 ± 14.43 GU with Sof-Lex. In the Z250 group, this increase reached from 43.69 ± 10.63 GU to 81.04 ± 15.93 GU for Twist Dia, and from 46.20 ± 13.02 GU to 79.80 ± 18.91 GU for Sof-Lex. A one-way ANOVA performed before thermal cycling revealed a significant difference among polishing systems ($F(2,87)=39.30$; $p < .001$); however, pairwise comparisons showed no significant difference between Twist Dia and Sof-Lex ($p=1.000$), while both systems produced significantly higher gloss than the control group ($p < .001$ for both comparisons).

Following thermal cycling, a marked and statistically significant loss of gloss was observed in all groups (paired t-tests, $p < .001$ for all groups; Cohen's $d=2.32$ -4.24). According to the three-way split-plot ANOVA results, the main effect of thermal cycling was the most dominant finding of the study [$F(1,84)=829.70$; $p < .001$; partial $\eta^2=.908$], followed by the main effect of polishing system [$F(2,84)=37.29$; $p < .001$; partial $\eta^2=.470$]. The main effect of composite type alone did not reach significance [$F(1,84)=3.02$; $p=.086$].

The polishing system $\times$ thermal cycling interaction was significant [$F(2,84)=38.39$; $p < .001$], indicating that thermal cycling-induced gloss loss differed according to polishing system. Indeed, a one-way ANOVA performed after thermal cycling detected a significant difference among polishing systems [$F(2,87)=8.01$; $p < .001$], and the highest post-cycling gloss values in both composites were recorded in the Sof-Lex group (VOCO: 27.03 ± 7.37 GU; Z250: 21.11 ± 5.34 GU). In pairwise comparisons, Sof-Lex retained significantly more gloss than both Twist Dia ($p=.002$) and the control group ($p=.018$), whereas no significant difference was found



Table 2. Mean±SD, GU by composite, polishing system, and stage (n=15/cell)

Composite	Polishing system	Stage	Mean±SD (GU)	n
VOCO (nanohybrid)	Twist Dia	Baseline (pre-polish)	54.95±12.84	15
	Twist Dia	After polishing (pre-TC)	69.45±11.32	15
	Twist Dia	After thermal cycling	19.27±7.75	15
	Sof-Lex	Baseline (pre-polish)	43.65±16.38	15
	Sof-Lex	After polishing (pre-TC)	66.32±14.43	15
	Sof-Lex	After thermal cycling	27.03±7.37	15
	Control (unpolished)	Baseline (pre-TC)	45.33±9.99	15
	Control (unpolished)	After thermal cycling	18.52±4.44	15
Z250 (microhybrid)	Twist Dia	Baseline (pre-polish)	43.69±10.63	15
	Twist Dia	After polishing (pre-TC)	81.04±15.93	15
	Twist Dia	After thermal cycling	16.21±4.41	15
	Sof-Lex	Baseline (pre-polish)	46.20±13.02	15
	Sof-Lex	After polishing (pre-TC)	79.80±18.91	15
	Sof-Lex	After thermal cycling	21.11±5.34	15
	Control (unpolished)	Baseline (pre-TC)	44.99±10.86	15
	Control (unpolished)	After thermal cycling	20.26±6.64	15

SD: Standard deviation, GU: Gloss units, TC: Thermal cycling

between Twist Dia and the control group ($p=.876$). These findings indicate that Sof-Lex-polished surfaces were more resistant to thermal cycling-induced gloss loss compared to Twist Dia, whereas the initial gloss advantage achieved with Twist Dia was eliminated following thermal cycling. In addition, the composite type $\times$ thermal cycling interaction was also significant [$F(1.84)=12.12$; $p<.001$], suggesting that the two composites exhibited different patterns of gloss loss in response to thermal cycling (Figure; Table 3).

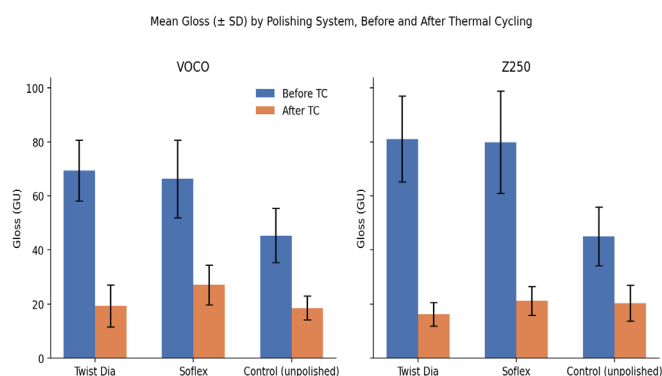


Figure. Mean gloss (±SD) before and after thermal cycling, by polishing system and composite

SD: Standard deviation

Key findings:

- **Thermal cycling (C):** Overwhelming main effect, $F(1.84)=829.70$, $p<.001$, partial $\eta^2=.91$ -gloss dropped sharply after thermal cycling in every group.
- **Polishing system (B):** Large main effect, $F(2.84)=37.29$, $p<.001$, partial $\eta^2=.47$ -polishing system materially affects gloss level.
- **Composite type (A):** Not significant on its own, $F(1.84)=3.02$, $p=.086$, partial $\eta^2=.035$.
- **Polishing $\times$ thermal cycling (B $\times$ C):** Significant, $F(2.84)=38.39$, $p<.001$ - the magnitude of gloss loss from thermal cycling differs by polishing system.
- **Composite $\times$ thermal cycling (A $\times$ C):** Significant, $F(1.84)=12.12$, $p<.001$ -the two composites lose gloss differently across thermal cycling.
- **Composite $\times$ polishing $\times$ thermal cycling (A $\times$ B $\times$ C):** Significant, $F(2.84)=4.53$, $p=.014$ - the polishing $\times$ thermal-cycling pattern itself differs somewhat between the two composites.
- **Composite $\times$ polishing (A $\times$ B):** Not significant, $F(2.84)=0.44$, $p=.643$.

Post-hoc comparisons: Thermal cycling effect within each composite $\times$ polishing group (Table 4).

Table 3. Three-way split-plot ANOVA results [composite (A) $\times$ polishing (B) $\times$ thermal cycling (C)]

Source	SS	df	MS	F	p	partial η^2
Composite type (A)	382.2	1	382.23	3.02	.086	.035
Polishing system (B)	9435.9	2	4717.97	37.29	<.001	.470
A $\times$ B	112.4	2	56.22	0.44	.643	.010
Subjects w/in cells (between-SS error)	10627.4	84	126.52	—	—	—
Thermal cycling (C)	87467.9	1	87467.95	829.70	<.001	.908
A $\times$ C	1277.3	1	1277.33	12.12	<.001	.126
B $\times$ C	8094.1	2	4047.05	38.39	<.001	.478
A $\times$ B $\times$ C	955.5	2	477.77	4.53	.014	.097
Residual (within-Ss error)	8855.4	84	105.42	—	—	—

*Between-subjects effects (A, B, A $\times$ B) tested against the subjects-within-cells error term; within-subjects effects (C, A $\times$ C, B $\times$ C, A $\times$ B $\times$ C) tested against the residual (within-subjects) error term. ANOVA: Analysis of variance, SS: Sum of squares, df: Degrees of freedom, MS: Mean square, F: F-statistic, η^2 : Eta squared, w/in: Within, Ss: Subjects

Table 4. Paired t-tests (before vs. after TC), Bonferroni-corrected $\alpha=.05/6=.0083$

Composite	Polishing system	Before TC	After TC	t(14)	p	Cohen's d
VOCO	Twist Dia	69.45±11.32	19.27±7.75	14.03	<.001*	3.62
VOCO	Sof-Lex	66.32±14.43	27.03±7.37	8.98	<.001*	2.32
VOCO	Control	45.33±9.99	18.52±4.44	9.70	<.001*	2.50
Z250	Twist Dia	81.04±15.93	16.21±4.41	16.41	<.001*	4.24
Z250	Sof-Lex	79.80±18.91	21.11±5.34	12.48	<.001*	3.22
Z250	Control	44.99±10.86	20.26±6.64	9.34	<.001*	2.41

*Significant after Bonferroni correction. Effect sizes are very large ($d=2.3-4.2$) in every group-thermal cycling produced a substantial, statistically robust loss of gloss regardless of composite or polishing system. TC: Thermal cycling

Polishing system comparisons, pooled across composite:

Before thermal cycling: one-way ANOVA $F(2,87)=39.30$, $p<.001$. Twist Dia and Sof-Lex produced statistically indistinguishable, high gloss; both were far glossier than the unpolished control (Table 5).

Table 5. Pairwise comparisons between groups using bonferroni correction

Comparison	Mean difference	t	p (Bonferroni)
Twist Dia vs Sof-Lex	2.18	0.52	1.000 (ns)
Twist Dia vs control	30.08	9.15	<.001*
Sof-Lex vs control	27.90	7.41	<.001*

*Significant after Bonferroni correction. vs: Versus, ns: Not significant

After thermal cycling: One-way ANOVA $F(2,87)=8.01$, $p<.001$. The ranking changes-Sof-Lex retains significantly more gloss than either Twist Dia or the control after cycling, while Twist Dia and the control become statistically indistinguishable (Table 6).

Table 6. Bonferroni-adjusted pairwise comparisons of mean values between the Twist Dia, Sof-Lex, and control groups

Comparison	Mean difference	t	p (Bonferroni)
Twist Dia vs Sof-Lex	-6.33	-3.66	.002*
Twist Dia vs control	-1.65	-1.06	.876 (ns)
Sof-Lex vs control	4.68	2.86	.018*

*Significant after Bonferroni correction. vs: Versus, ns: Not significant

Composite comparison, pooled across polishing system: Before TC: Z250 trended higher than VOCO (68.6 vs 60.4 GU), $t(88)=-1.99$, $p=.050$ (borderline). After TC: VOCO trended higher than Z250 (21.6 vs 19.2 GU), $t(88)=1.69$, $p=.095$ (n.s.). Neither simple effect reaches significance on its own, but the reversal in direction is consistent with the significant composite $\times$ thermal-cycling interaction reported above-Z250 starts glossier but loses relatively more gloss, ending on par with (or slightly below) VOCO.

DISCUSSION

In direct restorative dentistry, achieving an aesthetically pleasing result depends not only on color match and anatomical contouring but also on the initial surface gloss and its long-term retention.¹ Surface gloss directly influences light reflection and visual smoothness, which are critical parameters for the aesthetic success and lifespan of resin composite restorations.¹⁻³ The present study evaluated the immediate polishing effectiveness of a two-step diamond-impregnated spiral system (Twist Dia) and a four-step aluminum oxide disc system (Sof-Lex Disc) on a microhybrid (Filtek Z250) and a nanohybrid (GrandioSO) composite, as

well as the stability of the achieved gloss following 15,000 thermal cycles. Based on the findings, the first null hypothesis (that the polishing system would not affect surface gloss) was not rejected for the immediate post-polishing stage but was rejected following thermal aging. The second null hypothesis (that composite type would not affect gloss) was not rejected: the main effect of composite type did not reach statistical significance in the split-plot ANOVA [$F(1,84)=3.02$, $p=.086$], although a non-significant trend toward higher gloss in Z250 was observed before thermal cycling ($p=.050$). The third null hypothesis (that thermal aging would not alter gloss) was rejected across all experimental groups.^{9,14}

Immediately after polishing, both polishing systems provided a statistically significant increase in surface gloss compared with baseline values (all $p<.001$). However, no statistically significant difference in surface gloss was observed between Twist Dia and Sof-Lex Disc immediately after polishing ($p=1.000$, Bonferroni-corrected). This indicates that the two-step diamond-impregnated spiral system performed comparably to the multi-step aluminum oxide disc system in establishing initial surface gloss. Flexible aluminum oxide disc systems are widely used multi-step systems for achieving high surface smoothness and gloss due to their ability to sequentially reduce surface irregularities.^{1,3} However, multi-step systems are time-consuming and can be challenging to apply on complex occlusal topographies. Diamond-impregnated elastomeric spiral systems allow flexible adaptation to irregular contours while combining finishing and polishing into fewer steps.^{3,4} Our findings suggest that Twist Dia can achieve an initial surface gloss equivalent to Sof-Lex Disc, offering a clinically efficient alternative without compromising immediate aesthetic outcomes. Recent investigations by Ozaslan et al.¹⁵ and Altınışık & Özyurt.¹⁶ similarly demonstrated that multi-step disc systems and two-step diamond spiral polishing systems yield comparable initial surface smoothness, supporting the immediate efficacy of spiral polishing tools across various composite resin formulations.

Regarding the effect of composite formulation, Z250 showed a non-significant trend toward higher surface gloss than GrandioSO immediately after polishing ($p=.050$), and composite type did not reach significance as a main effect across the full model [$F(1,84)=3.02$, $p=.086$]. Although this trend did not reach conventional statistical significance, filler characteristics and matrix compositions may still explain the directional difference observed. Surface quality and gloss after polishing are strongly influenced by filler characteristics, such as filler size, morphology, loading, and the hardness contrast between inorganic fillers and the organic resin matrix.^{3,4} GrandioSO is classified as a nanohybrid composite



with a higher total filler loading (89 wt%) containing glass ceramic particles ($\sim 1 \mu\text{m}$) alongside functionalized silicon dioxide nanoparticles (20-40 nm). In contrast, Filtek Z250 is a microhybrid composite containing zirconia/silica particles ($0.01\text{-}3.5 \mu\text{m}$) embedded in a Bis-GMA/UDMA/Bis-EMA/TEGDMA matrix. During polishing, softer resin matrix components wear faster than hard inorganic filler particles. When abrasive instruments strike larger or harder filler agglomerates, protruding particles or micro-voids left by debonded fillers can increase diffuse light scattering, thereby reducing specular gloss. Furthermore, both polishing systems were applied under dry conditions without water cooling, as recommended by manufacturers for optimum visibility during finishing. However, dry polishing can generate localized frictional heat at the composite surface, potentially inducing micro-thermal degradation or plastic deformation of the organic matrix, particularly in composites with higher resin matrix ratios or specific monomer blends. The lower initial gloss trend observed in GrandioSO may be attributed to the selective wear and thermal friction around its larger glass ceramic filler particles, whereas the zirconia/silica filler distribution in Filtek Z250 allowed more uniform surface abrasability under the applied polishing protocols. This material-dependent polishing response aligns with the findings of Lippert et al.,¹⁷ who emphasized that the physical structure and filler composition of the resin composite dictate the maximum achievable gloss recovery after surface treatment.

Thermal aging represents a critical challenge to the intraoral stability of resin composite restorations. In the current study, all experimental groups experienced a marked and statistically significant reduction in surface gloss following 15,000 thermal cycles ($p < 0.001$), with large effect sizes (Cohen's d ranging from 2.32 to 4.24). Repeated thermal stress between 5°C and 55°C induces alternating expansion and contraction cycles between the organic matrix and inorganic fillers, which have mismatching coefficients of thermal expansion. This mismatched thermal movement generates micro-shear stresses at the matrix-filler interface, promoting microcracking, filler debonding, and hydrolytic degradation. Furthermore, water sorption during thermal cycling leads to plasticization and swelling of the resin matrix. These microstructural alterations create nanoscale surface irregularities that impair specular light reflection, leading to a substantial drop in surface gloss across all groups.^{9,14}

To contextualize these findings, it is useful to consider previously reported visual thresholds for surface gloss. da Costa et al.¹⁸ reported visually acceptable gloss thresholds for resin composites in the range of approximately 40-50 GU. Both Twist Dia and Sof-Lex Disc achieved immediate post-polishing gloss values above this range (66.32 ± 14.43 GU to 81.04 ± 15.93 GU), whereas post-aging values across the experimental groups decreased to 16.21 ± 4.41 GU to 27.03 ± 7.37 GU. Although these laboratory values fall below the reported visual acceptability range, they should not be interpreted as demonstrating clinical unacceptability directly. Thermocycling is an accelerated artificial-aging procedure and does not reproduce the full complexity, duration, or combined mechanical, chemical, and biological challenges of clinical service. Therefore, the post-aging findings indicate a substantial reduction in gloss under the present experimental conditions rather than a direct prediction of clinical aesthetic failure.

Interestingly, while the choice of polishing system did not significantly influence gloss immediately after polishing, a significant difference emerged between polishing systems after thermal aging [$F(2,87) = 8.01$, $p < .001$ overall; Sof-Lex vs. Twist Dia, $p = .002$, Bonferroni-corrected]. Specifically, specimens polished with the Sof-Lex Disc system retained higher gloss values than those polished with Twist Dia after 15,000 thermal cycles. Multi-step aluminum oxide discs, such as Sof-Lex, use sequentially finer abrasives ($55 \mu\text{m}$ to $8 \mu\text{m}$), which may contribute to differences in the surface produced by the polishing procedure. One possible explanation for the different post-aging behavior is that the two polishing protocols generated surfaces with different topographical characteristics that subsequently responded differently to thermal stress. However, surface roughness and morphology were not directly assessed in the present study; therefore, mechanisms involving microscopic grooves, subsurface stresses, filler exposure, or interfacial degradation remain hypothetical and cannot be confirmed from the current data. The present findings support only the conclusion that Sof-Lex showed greater gloss retention than Twist Dia under the applied thermocycling conditions. Ozaslan et al.¹⁵ likewise reported polishing-system-dependent differences after artificial aging, although direct mechanistic comparisons should be made cautiously because of differences in materials and outcome measures.

It is important to note that while artificial aging protocols provide valuable insight into material durability, 15,000 thermal cycles represent an accelerated environmental challenge rather than a direct mathematical equivalent of clinical exposure. Although 10,000 cycles are frequently cited as approximating one year of clinical service, laboratory thermal cycling lacks complex intraoral dynamics such as mechanical wear, tooth brushing, saliva buffering, bio-abrasion, and dietary chemical exposure.^{9,14} Therefore, the findings of this study should be interpreted as a comparative evaluation of composite formulation and polishing system resistance under thermal stress, rather than an exact prediction of clinical longevity.

Limitations

Although this study provides valuable insights into the immediate efficacy and thermal stability of different composite polishing systems, several inherent limitations associated with the in vitro design should be acknowledged:

- **Absence of complex intraoral dynamics:** The thermal cycling protocol (15,000 cycles) simulated temperature fluctuations but did not incorporate other critical intraoral aging factors, such as mechanical wear from tooth brushing, bio-abrasion, salivary buffering and enzymatic action, cyclic fatigue loading, or exposure to dietary chemical challenges.
- **In vitro polishing standardization:** All polishing procedures were performed by a single experienced operator using standardized rotational speeds, sequences, and application times; however, polishing pressure was applied manually and was not instrumentally quantified or standardized. Consequently, small variations in applied force may have influenced the resulting gloss values. This limitation should be considered when interpreting differences between polishing systems and when extrapolating the findings to clinical practice.



- **Limited range of materials and systems:** Only two composite resin formulations (a microhybrid and a nanohybrid) and two polishing protocols (a two-step spiral and a four-step disc system) were investigated. Therefore, these results may not be directly extrapolated to other composite categories (such as bulk-fill, flowable, or single-shade resin composites) or alternative polishing technologies (such as one-step systems or diamond polishing pastes).
- **Single-parameter evaluation:** Surface gloss was evaluated as the primary outcome parameter. Surface roughness and morphology were not directly assessed; therefore, proposed mechanisms involving microscopic grooves, subsurface stresses, filler exposure, or other topographical changes cannot be confirmed by the present data. Incorporating surface roughness profiling, scanning electron microscopy (SEM), or atomic force microscopy (AFM) in future studies would provide a more comprehensive understanding of the surface changes occurring before and after thermal aging.

CONCLUSION

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

- **Efficacy of polishing systems:** Immediately after polishing, the two-step diamond-impregnated spiral system (Twist Dia) achieved surface gloss values comparable to those obtained with the traditional four-step aluminum oxide disc system (Sof-Lex Disc). This indicates that two-step elastomeric spiral systems offer a clinically efficient and effective alternative for initial gloss generation without requiring multi-step disc protocols.
- **Influence of composite formulation:** Composite type did not significantly affect overall surface gloss [$F(1.84)=3.02$, $p=.086$]; however, a non-significant trend toward higher initial gloss was observed in Filtek Z250 compared with GrandioSO ($p=.050$), and the significant composite type $\times$ thermal cycling interaction ($p<.001$) indicates that the two composites lost gloss differently over the course of thermal aging.
- **Impact of thermal aging:** Thermal aging (15,000 thermal cycles) caused a marked and statistically significant reduction in surface gloss across all evaluated composite resins and polishing systems, demonstrating the susceptibility of polished composite surfaces to thermal-induced degradation and microstructural stress.
- **Long-term gloss retention:** Although initial gloss levels were equivalent between the polishing systems, the Sof-Lex Disc system demonstrated superior resistance to thermal aging compared to Twist Dia, retaining significantly higher gloss values after 15,000 thermal cycles. Sequential aluminum oxide disc polishing appears to provide better long-term gloss stability under thermal stress.

ETHICAL DECLARATIONS

Ethics Committee Approval

Ethics committee approval was not required because this was an in vitro laboratory study conducted exclusively using commercially available resin composite materials, without

involving human participants, human-derived biological specimens, or animals.

Informed Consent

Informed consent was not required because this in vitro laboratory study did not involve human participants or human-derived biological materials.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The author declares no conflicts of interest related to this study.

Financial Disclosure

The author received no financial support for the conduct or publication of this research.

Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

Acknowledgements

The author would like to thank Assist. Prof. Gökçe Keçeci/Kahramanmaraş Sütçüimam University for her valuable technical assistance and support during the experimental procedures.

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