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Surface treatment, liquid, and aging effects on color and surface properties of monolithic ceramics

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PURPOSE. The purpose of this study was to investigate the effects of surface treatments, liquids, and aging on color, translucency, and surface properties of monolithic ceramics. **MATERIALS AND METHODS.** Lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS) ceramics (n = 135 each) were cut and divided into three groups [crystallization+glaze (single stage), crystallization-glaze (two stages), and crystallization-polish (two stages)]. One sample from each group was examined using scanning electron microscopy (SEM). Remaining samples were divided into four subgroups (distilled water, coffee, grape juice, and smoothie) (n = 11 each), stored for 12 d in the respective liquids, and thermally aged. One sample from each subgroup was analyzed using SEM. The color, gloss, and roughness values of the samples were analyzed after surface treatment (initial) and storage under different liquids+aging conditions. The initial data and both the aged data and data change values were analyzed using robust two- and three-way analyses of variance. **RESULTS.** The glazed groups exhibited smoother surfaces. Ceramic type and ceramic-surface treatment interactions affected the initial translucency parameter (TP) ($P < .001$) and the initial and aged roughness values ($P \leq .001$). Surface treatment type affected the color change ($P < .001$), and ceramic type affected the aged TP values ($P < .001$). Type of ceramic, surface treatment, and their interactions affected both the initial and aged gloss ($P \leq .001$) and TP change values ($P \leq .015$). Surface treatment type and ceramic-surface treatment interactions affected the gloss change values ($P \leq .001$). **CONCLUSION.** Although both ceramics and all surface treatments are clinically applicable, crystallization-glaze is recommended. When gloss and smoothness are important or when translucency is important, ZLS or LDS may be preferred, respectively. [J Adv Prosthodont 2024;16:174-88]

KEYWORDS
Ceramics; Scanning electron microscopy; Color; Aging

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INTRODUCTION

With the development of computer-aided design-computer-aided manufacturing (CAD-CAM) systems, monolithic ceramics are frequently preferred in the construction of dental restorations owing to their excellent mechanical and esthetic properties, absence of veneering porcelain, and reduction of both clinical and laboratory time.[1-4] Among the monolithic ceramic materials, lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS) ceramics are frequently preferred, particularly in laminate, inlay, and single crown restorations.[5-7]

Optical and surface properties play an important role in the long-term clinical success of dental restorations.[3,8-13] The color of monolithic restorations can be affected by various factors, such as the color of the material and the underlying tooth, material composition and thickness, glazing/polishing technique, cement type, stomach acid reflux, drinking, smoking, and oral hygiene.[3,13-16] Additionally, the oral environment, including chewing, temperature, and humidity changes can affect the color and surface properties of dental ceramics.[14,15,17]

Numerous studies investigated the effects of materials;[18] materials and aging;[19] materials, surface treatments, liquids, and aging;[20] and surface treatments, liquids, and aging[21] on the optical properties of monolithic ceramics. On the other hand, the effects of materials and surface treatments;[22] surface treatments;[23,24] surface treatments and liquids;[25,26] types of liquids;[27] and storing in liquid[28] on the surface properties (gloss and roughness) of monolithic ceramics were investigated.

For the surface treatment of LDS ceramics, some studies[21,24] recommended glazing, whereas Brescansin *et al*.[23] recommended polishing. For ZLS ceramics, Aldosari *et al*.[21] recommended glazing.

Regarding optical properties, some studies[21,23] found that the color differences of LDS and ZLS materials were clinically acceptable. Brescansin *et al*.[23] reported that polishing increased the translucency in LDS ceramics, whereas glazing reduced the translucency. Tango *et al*.[20] observed that LDS and ZLS ceramics exhibited lower translucency than other monolithic ceramics (resin nanoceramics, polymer infiltrated ceramics).

People consume different types of beverages.[20,21,25-28] Studies reported[20,25-27] that acidic beverages could affect the surface of CAD-CAM monolithic ceramics and change the structure of these materials over time.

Before monolithic ceramic restorations are delivered to the patient, the manufacturer recommends using glazing or polishing as surface finishing methods to obtain smoother and brighter surface structures.[29,30] Although glazing or polishing can be recommended for monolithic restorations, no study has evaluated the effects of surface treatments and liquids at different pH values on the optical and surface properties of LDS and ZLS ceramics.

The purpose of this *in vitro* study was to examine the effects of surface treatments, liquids, and aging on the color, translucency, and surface properties (gloss and roughness) of two types of monolithic ceramics, namely LDS and ZLS ceramics. The research hypotheses are as follows:

1. The initial (after surface treatment) translucency, gloss, and roughness values would not be affected by the type of ceramic and surface treatment.
2. The post-aging translucency, color change, gloss, and roughness values would not be affected by the type of ceramic, surface treatment, and liquid.
3. The translucency, gloss, and roughness change values would not be affected by the type of ceramic, surface treatment, and liquid.

MATERIALS AND METHODS

A power analysis was performed prior to this study to determine the number of samples in each subgroup. The effect size, Type 1 error (α), and working power for the numerical variables (color, translucency, gloss, and roughness data) were calculated to be 0.4, 0.05, and 0.80, respectively. The minimum number of samples in each subgroup (24 subgroups, including two ceramics, three surface treatments, and four liquids) was determined using the G*Power statistical program (version 3.1.9.7) to be 7. Therefore, 240 samples (10 from each subgroup) were included in this study.

Two monolithic ceramics (n = 135 each) (A2 HT),

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namely LDS (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) and ZLS (Vita Suprinity PC; Vita Zahnfabrik, Bad Säckingen, Germany), were cut (1.5 mm thick) using a low-speed sectioning machine (Isomet 1000; Buehler Ltd., Lake Bluff, IL, USA) with water cooling. The samples were then cleaned with distilled water in an ultrasonic cleaner (GB-928; Shantou Chuangxin Technology Co. Ltd., Shantou, China) for 5 min. The 135 samples from each ceramic group were further divided into three groups (n = 45 each) according to the surface treatment method used. The surface treatment methods in each group were implemented by the same practitioner in accordance with the recommendations of the manufacturer (Table 1) and are described below.

Crystallization+Glaze (C+G): C+G firing was performed for each ceramic in a porcelain furnace (Programat P310; Ivoclar Vivadent, Schaan, Liechtenstein) in a single stage. A glazing material (IPS e.max CAD Crystall/Glaze Paste; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to a single surface of the LDS ceramic samples using a porcelain brush, followed by firing in a porcelain furnace. Powder- (Vita Akzent Plus Glaze LT; Vita Zahnfabrik, Bad Säckingen, Germany) and liquid- (Vita Akzent Plus; Vita Zahnfabrik, Bad Säckingen, Germany) form glaze materials were mixed in a container and applied to a single surface of the ZLS ceramic samples using a porcelain brush, followed by firing in a porcelain furnace.

Crystallization-Glaze (C-G): Each ceramic sample was first C- and then G-fired in a porcelain furnace (Programat P310; Ivoclar Vivadent AG, Schaan, Liechtenstein). For the LDS ceramic, after C-firing, the powder- (IPS Ivocolor Glaze Powder; Ivoclar Vivadent, Schaan, Liechtenstein) and liquid- (IPS Ivocolor Mixing Liquid allround; Ivoclar Vivadent, Schaan, Liechtenstein) form glaze materials were mixed in a container and applied to a single surface of the samples using a porcelain brush, followed by firing the samples in a porcelain furnace. For the ZLS ceramic, after C-firing, the powder- (Vita Akzent Plus Glaze LT; Vita Zahnfabrik, Bad Säckingen, Germany) and liquid- (Vita Akzent Plus; Vita Zahnfabrik, Bad Säckingen, Germany) form glaze materials were mixed in a container and applied to a single surface of the samples using a porcelain brush, followed by firing the samples in a porcelain furnace.

Crystallization-Polish (C-P): Each ceramic sample was first C-fired in a porcelain furnace (Programat P310; Ivoclar Vivadent, Schaan, Liechtenstein) and

Table 1. Firing parameters of the LDS and ZLS ceramics

	LDS		ZLS	
	Crystallization+Glaze/ Crystallization	Glaze	Crystallization+Glaze/ Crystallization	Glaze
Standby temperature (°C)	403	403	400	400
Closing time (min)	6:00	6:00	4:00	4:00
Heating rate (°C/min)	t_1 90 t_2 30	60	55	80
Firing temperature (°C)	T1 830 T2 850	710	830	800
Holding time (min)	H1 0:10 H2 7:00	1:00	8:00	1:00
Vacuum (°C)	V1 (°C) 1_1 550 1_2 830 V2 (°C) 2_1 830 2_2 850	V1 (°C) 450 V2 (°C) 709	V1 (°C) 410 V2 (°C) 829	-
Long term cooling (°C)	710		680	
Cooling rate (°C/min)	0		0	

then polished. Single surfaces of the LDS ceramic samples after C-firing were polished using disc-shaped pink and yellow rubbers (DPR HP Set; EVE Ernst Vetter GmbH, Keltern, Germany). Polishing was done using a handpiece at 10000 rpm for 30 s for each rubber without water cooling through movements parallel and horizontal to the sample surface. Single surfaces of the ZLS ceramic samples after C-firing were polished using disc-shaped pink (10000 rpm) and gray rubbers (6000 rpm) (VITA SUPRINITY Polishing Set Technical; Vita Zahnfabrik, Bad Säckingen, Germany). Polishing was done using a handpiece for 30 s for each rubber without water cooling and through movements parallel and horizontal to the sample surface.

One sample from each surface treatment group of each ceramic was examined using scanning electron microscopy (SEM) (Nova NanoSEM 650; FEI Company, Hillsboro, SA, USA) at ×1000 magnification to examine the effect of the surface treatment methods on the surface topography of the monolithic ceramics. The remaining ceramic samples in each surface treatment group of each ceramic (n = 44) were divided into four subgroups [distilled water (DW (control); Aqua; Aqua Medikal Tıbbi Araç ve Gereçler İnş. San. Dış Tic. Ltd. Şti, İstanbul, Turkey; pH 7), coffee (C; Nescafe Gold; Nestle Gıda Sanayi A.Ş., İstanbul, Turkey; pH 5.31), grape juice (GJ; Pınar Frii; Pınar Su ve İçecek San. ve Tic. A.Ş., İzmir, Turkey; pH 2.99), and smoothie (S; Dimes, Dimes Gıda San. ve Tic. A.Ş., İzmir, Turkey; pH 3.69)] according to the type of liquid in which they were stored (n = 11). Each sample was stored in separate containers filled with the relevant liquid in an incubator (M 420BP; Elektro-mag Laboratuvar Aletleri San. ve Tic. A.Ş., İstanbul, Turkey) at 37°C for 12 d. The average time for consumption of one cup of drink has been reported to be 15 min and the average consumption of each drink is 3.2 cups per day.[28,31-34] Therefore, the 12 d period corresponds to approximately 1 year of consumption.[28,31-34] The samples were then thermally aged (5 - 55°C, 10000 cycles, duration of 30 s, and transfer time of 15 s) in a thermal cycling device (Gökçeler Makine; Plastik İml. İhr.Tic. ve San. Ltd. Şti., Sivas, Turkey). Subsequently, one sample from each ceramic group (total of 24 samples) that was subjected to surface treatment, storage in the liquids, and aging was examined using SEM at ×1000 magnification.

The color, gloss, and roughness of the samples in each subgroup (n = 10) were assessed in two stages: after surface treatment (initial) and after storage in liquid+aging. The color analyses (L, a, and b) were performed twice at the center of each sample on three different backgrounds (gray, black, white) using a spectrophotometer (CM-2300d; Konica Minolta, Tokyo, Japan). Measuring characteristics of the spectrophotometer were standard illuminant D65, specular component included (SCI) mode, illumination geometry d/8 degree, 10 degree colorimetric standard observer, measurement area of 8 mm in diameter, illumination area of 11 mm in diameter, wavelength range 360 - 740 nm, and wavelength pitch 10 nm. Zero and white calibrations of the device were performed before the measurements on each background. The color change (ΔE) values of the samples were calculated using the obtained color measurement values (L, a, b) on a gray background (L = 57.61, a = 1.22, b = 1.39) using CIELab color difference formula [Equation (1)].[3,19,21,35,36]

$$\Delta E = [(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2]^{½} \quad (1)$$

where L_2 is the L value after storage in liquid+aging; L_1 is the initial L value; a_2 is the a value after storage in liquid+aging; a_1 is the initial a value; b_2 is the b value after storage in liquid+aging; and b_1 is the initial b value.

The ΔE values were evaluated in terms of perceptibility and acceptability thresholds as reported by Paravina *et al*.[37] They reported that for CIELab (ΔE_{ab}), the perceptibility and acceptability thresholds were 1.22 and 2.66, respectively.[37]

The translucency parameter (TP) values of the initial and aged samples were calculated from the color values recorded on standardized black (L = 27.70, a = 0.18, b = -1.45) and white (L = 94.45, a = 1.48, b = -6.94) backgrounds based on CIELab formula using Equation (2).[18,19,36]

$$TP = [(L_b - L_w)^2 + (a_b - a_w)^2 + (b_b - b_w)^2]^{1/2} \quad (2)$$

where L_b is the L value on a black background, L_w is the L value on a white background, a_b is the a value on a black background, a_w is the a value on a white

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background, b_b is the b value on a black background, and b_w is the b value on a white background.

An opaque white mold fitting both a gloss meter (Micro-TRI-Gloss; BYK-Gardner GmbH, Geretsried, Germany) and the samples was used to prevent light transmission during the gloss measurements. The device was calibrated before each measurement, and gloss measurements were performed in two different regions of each sample at 60°. The average gloss (GU) value of each sample was determined (i) after surface treatment and (ii) after storage in liquid+aging.

The surface roughness of each sample was measured in three different regions using a profilometer (TR200; TIME Group Inc., Beijing, China) with a cut-off value of 0.8 mm and measuring length of 4 mm. Prior to the measurement, the device was calibrated against a reference block (Ra = 1.49 µm). The device was calibrated after the measurements on each group. The average surface roughness value (Ra; µm) of each sample was determined (i) after surface treatment and (ii) after storage in liquid+aging.

The data were analyzed using IBM SPSS V23 and Rstudio v2022.12.0. Robust two-way analysis of variance (ANOVA) was used to compare the initial data (translucency, gloss, and roughness), and robust three-way ANOVA was used to compare both the aged data (translucency, ΔE, gloss, and roughness) and the data change values (aged-initial; translucency, gloss, and roughness). Multiple comparisons were performed using the Bonferroni correction. The pairwise relationships for the initial and aged parameters were analyzed using Pearson (normally distributed data) or Spearman correlation (non-normally distributed data) analyses ($P < .05$).

RESULTS

The SEM analyses revealed that the C+G and C-G groups had smoother surface structures than the C-P group (Fig. 1). The C+G treated LDS ceramic samples stored in DW, C, and GJ exhibited similar and smooth surface morphologies (Fig. 2A-C); however, irregularities and pits were observed on the surface of the sample stored in S (Fig. 2D). The C+G treated ZLS (Fig. 3A-D), and C-G treated LDS (Fig. 2E-H) and ZLS samples (Fig. 3E-H) stored in all liquids exhibited similar surface morphologies. The surfaces of the C-P treated LDS samples stored in C and S (Fig. 2J, L) had more

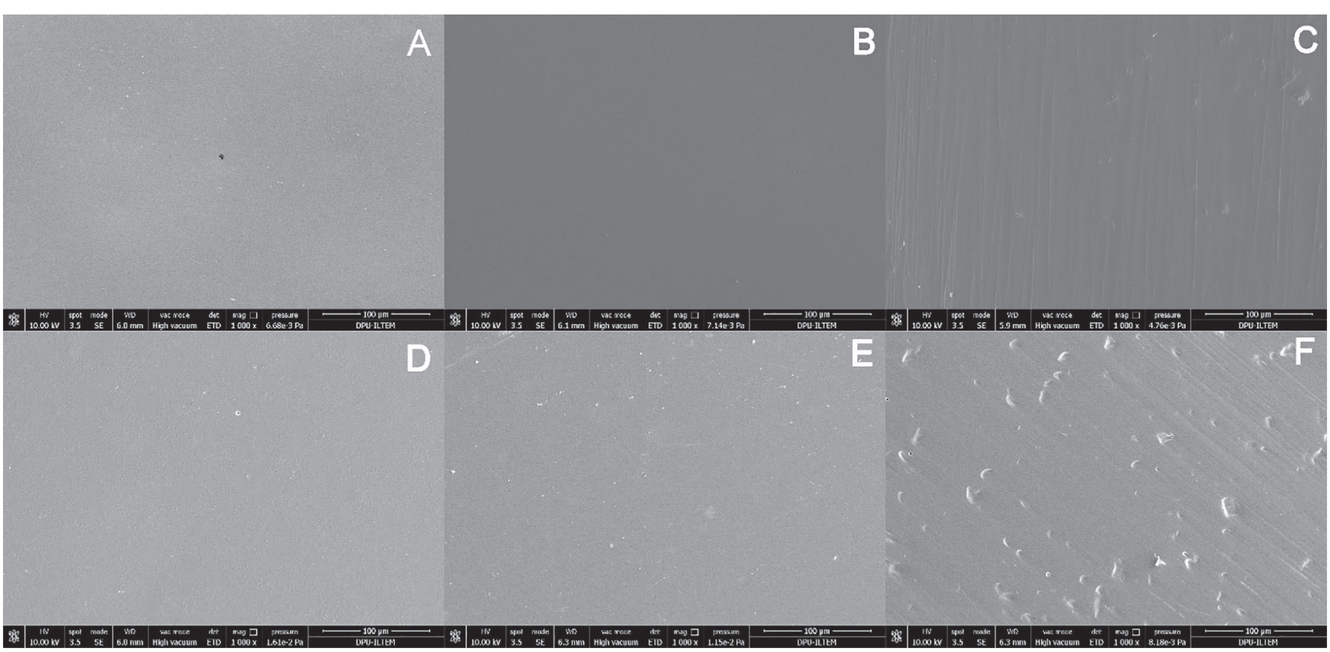

Fig. 1. SEM images (×1000 magnification) of the surface-treated ceramics. (A-C) LDS; (D-F) ZLS; (A, D) Crystallization+Glaze; (B, E) Crystallization-Glaze; (C, F) Crystallization-Polish.

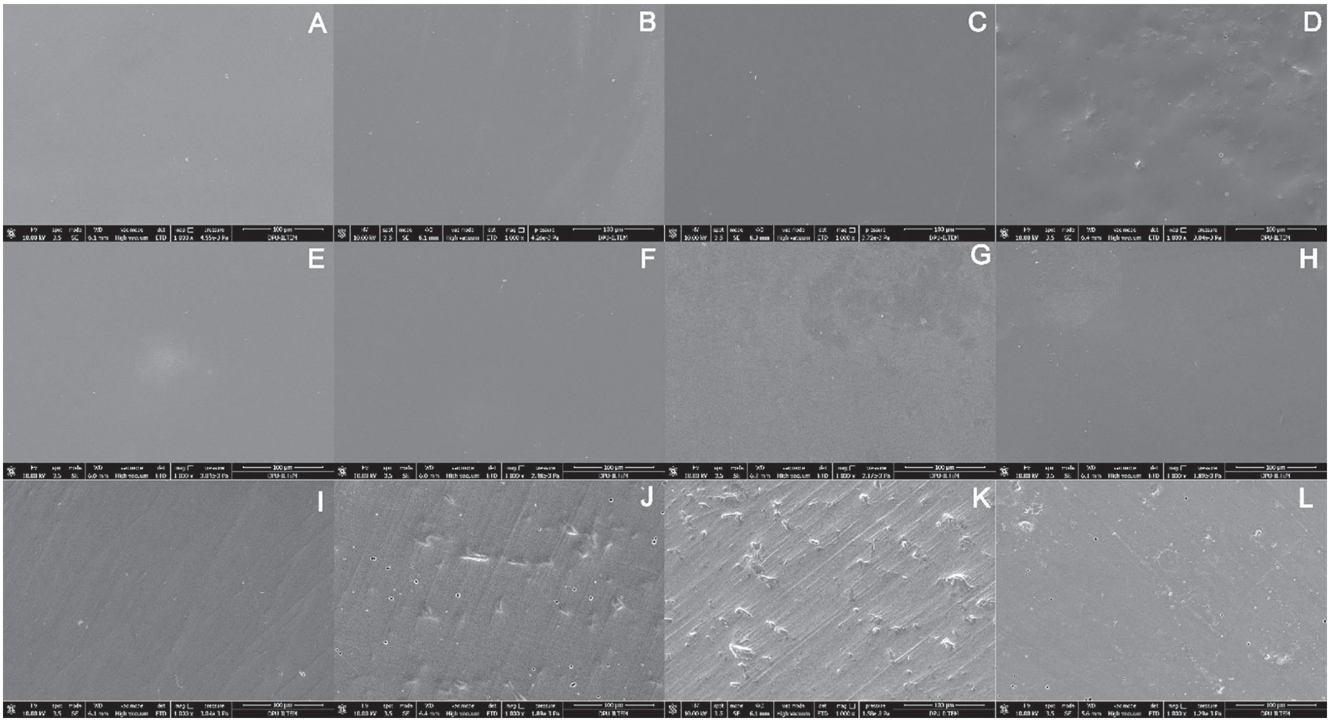

Fig. 2. SEM images (×1000 magnification) of the surface-treated, liquid-stored, and aged LDS ceramics. (A-D) Crystallization+Glaze; (E-H) Crystallization-Glaze; (I-L) Crystallization-Polish; (A, E, I) Distilled water; (B, F, J) Coffee; (C, G, K) Grape juice; (D, H, L) Smoothie.

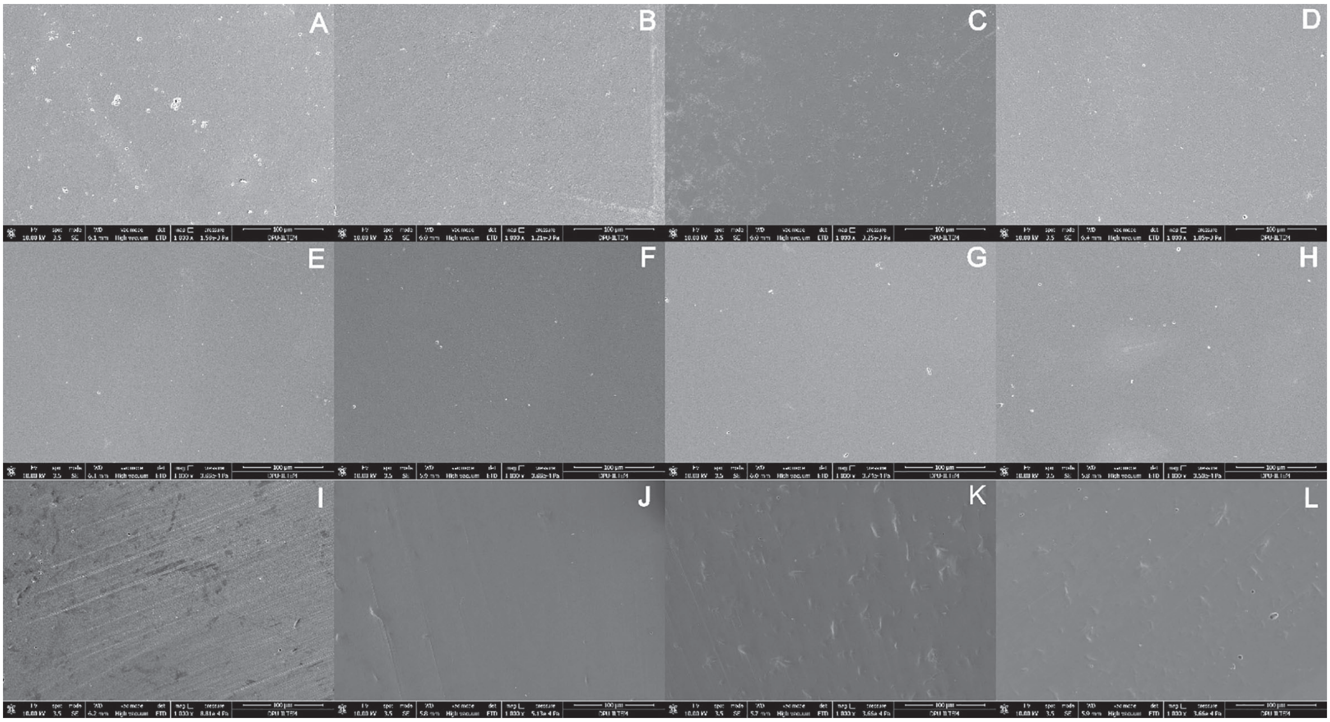

Fig. 3. SEM images (×1000 magnification) of the surface-treated, liquid-stored, and aged ZLS ceramics. (A-D) Crystallization+Glaze; (E-H) Crystallization-Glaze; (I-L) Crystallization-Polish; (A, E, I) Distilled water; (B, F, J) Coffee; (C, G, K) Grape juice; (D, H, L) Smoothie.

pits than those stored in DW (Fig. 2I). The C-P treated ZLS ceramic sample stored in C (Fig. 3J) exhibited fewer surface irregularities than those stored in DW, GJ, and S (Fig. 3I, K, L).

The robust ANOVA results indicated that ceramic type ($P < .001$) and ceramic-surface treatment interactions ($P < .001$) affected the initial TP values; however, only ceramic type ($P < .001$) affected the TP values after aging. Both the initial and aged LDS samples exhibited higher TP values than those of the ZLS samples ($P < .001$) (Table 2 and Table 3). In terms of ceramic-surface treatment interactions, initially, all surface treatment groups of LDS exhibited higher TP values than those of ZLS ($P < .001$) (Table 2).

The robust three-way ANOVA indicated that surface treatment type ($P < .001$) affected the ΔE values. In terms of surface treatment type, both the C+G and C-P groups exhibited higher ΔE values than the C-G group ($P \leq .037$) (Table 3).

The robust ANOVA results indicated that ceramic type ($P < .001$), surface treatment type ($P < .001$), and their interactions ($P \leq .001$) affected both the initial and aged gloss values. In terms of ceramic type, both the initial and aged ZLS samples exhibited higher gloss values than the LDS samples ($P < .001$) (Table 2 and Table 4). In terms of surface treatment type, initially, both the C+G and C-G groups exhibited higher gloss values than the C-P group ($P \leq .038$) (Table 2); however, the aged C-G group exhibited higher gloss values than the C+G and C-P groups ($P \leq .017$) (Table

Table 2. Descriptive statistics and multiple comparison results of the initial translucency parameter (TP), gloss (GU), and roughness values (Ra) (μm)

	Surface Treatment	Ceramic		Total
		LDS	ZLS	
TP (Initial)	C+G	14.02 ± 1.58 14.39 (8.38 - 16.07)^{A}	11.15 ± 1.69 11.05 (6.11 - 16.21)^{B}	12.59 ± 2.17 12.80 (6.11 - 16.21)
	C-G	14.60 ± 1.31 14.93 (9.13 - 16.17)^{A}	11.68 ± 1.39 11.65 (8.44 - 14.01)^{B}	13.14 ± 1.99 13.58 (8.44 - 16.17)
	C-P	14.60 ± 1.18 14.55 (11.11 - 17.37)^{A}	11.74 ± 1.35 11.76 (7.67 - 15.33)^{B}	13.17 ± 1.91 13.09 (7.67 - 17.37)
	Total	14.41 ± 1.38 14.55 (8.38 - 17.37)^{1}	11.52 ± 1.49 11.58 (6.11 - 16.21)^{2}	12.97 ± 2.04 13.17 (6.11 - 17.37)
GU (Initial)	C+G	34.59 ± 9.88 36.38 (15.40 - 52.60)^{AB}	51.31 ± 6.99 52.68 (30.90 - 63.95)^{D}	42.95 ± 11.96 44.55 (15.40 - 63.95)^{b}
	C-G	40.57 ± 6.38 41.73 (22.05 - 50)^{AC}	47.58 ± 6.23 47.60 (35.85 - 63.10)^{E}	44.07 ± 7.19 44.53 (22.05 - 63.10)^{b}
	C-P	35.87 ± 6.19 33.95 (24.55 - 51.20)^{B}	44.18 ± 7.72 44.85 (26.55 - 58.20)^{CE}	40.02 ± 8.11 38.55 (24.55 - 58.20)^{a}
	Total	37.01 ± 8.03 37.28 (15.40 - 52.60)^{1}	47.69 ± 7.54 47.75 (26.55 - 63.95)^{2}	42.35 ± 9.44 43.53 (15.40 - 63.95)
Ra (Initial)	C+G	0.82 ± 0.23 0.82 (0.42 - 1.47)^{A}	0.37 ± 0.17 0.34 (0.08 - 0.77)^{D}	0.59 ± 0.30 0.57 (0.08 - 1.47)
	C-G	0.67 ± 0.18 0.64 (0.48 - 1.35)^{B}	0.42 ± 0.25 0.37 (0.15 - 1.36)^{D}	0.55 ± 0.25 0.53 (0.15 - 1.36)
	C-P	0.56 ± 0.22 0.58 (0.18 - 0.97)^{BC}	0.51 ± 0.31 0.41 (0.19 - 1.37)^{CD}	0.54 ± 0.27 0.47 (0.18 - 1.37)
	Total	0.68 ± 0.23 0.66 (0.18 - 1.47)^{1}	0.44 ± 0.26 0.38 (0.08 - 1.37)^{2}	0.56 ± 0.28 0.53 (0.08 - 1.47)

Mean ± Standard Deviation, Median (Minimum-Maximum).
* For each parameter (TP, GU, and Ra), the same superscript numbers indicate no difference between the ceramic types, the same superscript lowercase letters indicate no difference among the surface treatment types, and the same superscript capital letters indicate no difference among the ceramic - surface treatment interactions.

Table 3. Descriptive statistics and multiple comparison results of the color change (ΔE) and translucency parameter (TP) values after aging

	Surface Treatment	Liquid	Ceramic		Total
			LDS	ZLS	
ΔE	C+G	DW	0.17 ± 0.04	0.49 ± 0.13	0.29 ± 0.07
		C	0.16 ± 0.03	0.21 ± 0.04	0.19 ± 0.03
		GJ	0.25 ± 0.05	0.77 ± 0.39	0.37 ± 0.06
		S	0.26 ± 0.05	0.22 ± 0.04	0.23 ± 0.03
		Total	0.21 ± 0.03	0.32 ± 0.05	0.26 ± 0.03[b]
	C-G	DW	0.18 ± 0.03	0.18 ± 0.04	0.19 ± 0.02
		C	0.20 ± 0.05	0.13 ± 0.02	0.16 ± 0.03
		GJ	0.27 ± 0.01	0.16 ± 0.03	0.23 ± 0.02
		S	0.20 ± 0.02	0.13 ± 0.02	0.16 ± 0.02
		Total	0.22 ± 0.02	0.15 ± 0.01	0.18 ± 0.01[a]
	C-P	DW	0.25 ± 0.04	0.25 ± 0.03	0.25 ± 0.02
		C	0.34 ± 0.04	0.23 ± 0.02	0.28 ± 0.03
		GJ	0.35 ± 0.06	0.24 ± 0.03	0.29 ± 0.04
		S	0.19 ± 0.02	0.27 ± 0.02	0.23 ± 0.03
		Total	0.27 ± 0.02	0.25 ± 0.01	0.26 ± 0.01[b]
	Total		0.23 ± 0.01	0.23 ± 0.01	0.23 ± 0.01
TP (Aged)	C+G	DW	13.68 ± 0.90	11.83 ± 0.52	12.69 ± 0.61
		C	13.89 ± 0.34	11.20 ± 0.39	12.49 ± 0.49
		GJ	14.32 ± 0.23	11.57 ± 0.53	13.12 ± 0.48
		S	14.31 ± 0.32	10.89 ± 0.48	12.74 ± 0.57
		Total	14.14 ± 0.24	11.36 ± 0.27	12.75 ± 0.29
	C-G	DW	14.36 ± 0.24	12.24 ± 0.28	13.22 ± 0.39
		C	14.78 ± 0.22	11.67 ± 0.27	13.07 ± 0.54
		GJ	14.99 ± 0.23	11.89 ± 0.42	13.69 ± 0.52
		S	15.45 ± 0.16	11.41 ± 0.40	13.24 ± 0.75
		Total	14.88 ± 0.15	11.78 ± 0.21	13.30 ± 0.28
	C-P	DW	14.52 ± 0.12	12.26 ± 0.30	13.65 ± 0.44
		C	14.84 ± 0.12	11.67 ± 0.22	13.40 ± 0.54
		GJ	15.28 ± 0.31	12.13 ± 0.34	13.62 ± 0.53
		S	14.77 ± 0.34	11.74 ± 0.32	12.94 ± 0.58
		Total	14.83 ± 0.13	11.93 ± 0.17	13.40 ± 0.26
	Total		14.67 ± 0.10[1]	11.72 ± 0.13[2]	13.16 ± 0.16

Trimmed Mean ± Standard Error.
* For each parameter (ΔE and TP), the same superscript numbers indicate no difference between the ceramic types, and the same superscript lowercase letters indicate no difference among the surface treatments.

4). In terms of ceramic-surface treatment interactions, initially, significant differences were observed among each of the C+G and C-P groups of LDS and all surface treatment groups of ZLS, between the C-G and C-P groups of LDS, among the C-G group of LDS and the C+G and C-G groups of ZLS, and between the C+G group of ZLS and each of the C-G and C-P groups of ZLS ($P \leq .045$) (Table 2). After aging, both the C+G and C-G groups of ZLS exhibited higher gloss values than all the surface treatment groups of LDS, and significant differences were observed among all the surface treatment groups of ZLS ($P \leq .030$) (Table 4).

Table 4. Descriptive statistics and multiple comparison results of the gloss (GU) and roughness values (Ra) (μm) after aging

	Surface Treatment	Liquid	Ceramic		Total
			LDS	ZLS	
GU (Aged)	C+G	DW	35.48 ± 3.19	50.99 ± 4.13	42.66 ± 3.19
		C	31 ± 5.61	52.66 ± 1.38	44.52 ± 3.28
		GJ	31.65 ± 3.21	44.70 ± 4.32	37.66 ± 3.61
		S	34.76 ± 4.52	48.29 ± 3.18	43.31 ± 2.66
		Total	33.38 ± 2.19[A]	49.69 ± 1.59[B]	41.98 ± 1.75[a]
	C-G	DW	38.20 ± 2.40	57.39 ± 2.60	46.68 ± 3.83
		C	37.66 ± 3.82	58.33 ± 4.03	47.75 ± 4.03
		GJ	43.12 ± 4.11	51.72 ± 2.39	48.54 ± 1.72
		S	44.62 ± 2.56	65.12 ± 1.84	54.45 ± 3.93
		Total	40.64 ± 1.87[A]	58.04 ± 1.95[C]	49.01 ± 1.74[b]
	C-P	DW	35.53 ± 4.22	38.34 ± 3.35	36.83 ± 2.61
		C	41.84 ± 2.76	43.18 ± 2.18	42.76 ± 1.52
		GJ	34.51 ± 1.40	33.84 ± 1.95	34.08 ± 1.14
		S	30.68 ± 1.51	42.29 ± 2.13	35.77 ± 1.99
		Total	34.57 ± 1.15[A]	40.03 ± 1.54[A]	37.28 ± 1.08[a]
	Total		36.28 ± 1.07[1]	48.80 ± 1.15[2]	42.15 ± 0.86
Ra (Aged)	C+G	DW	0.84 ± 0.06	0.41 ± 0.05	0.61 ± 0.07
		C	0.86 ± 0.07	0.28 ± 0.05	0.57 ± 0.10
		GJ	0.71 ± 0.05	0.47 ± 0.07	0.62 ± 0.04
		S	0.86 ± 0.10	0.37 ± 0.04	0.58 ± 0.09
		Total	0.81 ± 0.04[A]	0.38 ± 0.03[C]	0.59 ± 0.04
	C-G	DW	0.62 ± 0.04	0.38 ± 0.03	0.50 ± 0.04
		C	0.70 ± 0.07	0.34 ± 0.05	0.52 ± 0.07
		GJ	0.66 ± 0.07	0.55 ± 0.10	0.63 ± 0.06
		S	0.67 ± 0.06	0.40 ± 0.03	0.56 ± 0.06
		Total	0.66 ± 0.03[AB]	0.40 ± 0.03[C]	0.55 ± 0.03
	C-P	DW	0.57 ± 0.11	0.47 ± 0.08	0.51 ± 0.07
		C	0.46 ± 0.02	0.55 ± 0.12	0.47 ± 0.04
		GJ	0.64 ± 0.08	0.62 ± 0.11	0.62 ± 0.06
		S	0.64 ± 0.05	0.45 ± 0.11	0.57 ± 0.06
		Total	0.56 ± 0.03[B]	0.51 ± 0.05[BC]	0.54 ± 0.03
	Total		0.68 ± 0.02[1]	0.42 ± 0.02[2]	0.56 ± 0.02

Trimmed Mean ± Standard Error.
* For each parameter (GU and Ra), the same superscript numbers indicate no difference between the ceramic types, the same superscript lowercase letters indicate no difference among the surface treatment types, and the same superscript capital letters indicate no difference among the ceramic-surface treatment interactions.

The robust ANOVA results indicated that ceramic type ($P < .001$) and ceramic-surface treatment interactions ($P \leq .001$) affected both the initial and aged roughness values. In terms of ceramic type, both the initial and aged LDS samples exhibited higher roughness values than those of the ZLS samples ($P < .001$) (Table 2 and Table 4). In terms of ceramic-surface treatment interactions, initially, significant differences were observed between the C+G group of LDS and each of the C-G and C-P groups of LDS, among the C+G and C-G groups of LDS and all surface treatment groups of ZLS, and between the C-P group of

LDS and each of the C+G and C-G groups of ZLS ($P \leq .013$) (Table 2). In terms of ceramic-surface treatment interactions, after aging, significant differences were observed between the C+G and C-P groups of LDS, between the C+G group of LDS and each of the surface treatment groups of ZLS, and between each of the C-G and C-P groups of LDS and each of the C+G and C-G groups of ZLS ($P \leq .009$) (Table 4).

The robust three-way ANOVA results indicated that ceramic type ($P < .001$), surface treatment type ($P = .012$), and their interactions ($P = .015$) affected the translucency change values, and surface treatment type ($P < .001$) and ceramic-surface treatment interactions ($P = .001$) affected the gloss change values. However, none of these factors affected the roughness change values.

Analyzing the translucency change values in terms of ceramic type indicated that ZLS had a higher TP change value than LDS ($P < .001$). In terms of the surface treatment, a significant difference was observed between the C-G and C-P groups ($P = .007$). In terms of ceramic-surface treatment interactions, significant differences were observed between the LDS C+G group and each of the ZLS C+G and ZLS C-P groups, between the LDS C-G group and each of the ZLS C+G and ZLS C-P groups, between the LDS C-P and ZLS C+G groups, and between the ZLS C+G and ZLS C-G groups ($P \leq .031$) (Table 5).

Analyzing the gloss change values in terms of surface treatment type showed that there was a significant difference between the C+G and C-G groups and between the C-G and C-P groups ($P = .001$). For ceramic-surface treatment interactions, significant differences were observed between LDS C+G and ZLS C-G, among LDS C-G, ZLS C-G, and ZLS C-P, among LDS C-P, ZLS C-G, and ZLS C-P, between ZLS C+G and ZLS C-G, and between ZLS C-G and ZLS C-P groups ($P \leq .023$) (Table 5).

Positive and negative correlations were observed between the initial translucency and gloss values of LDS ($P < .001$) and between the initial gloss and roughness values for both LDS and ZLS ($P < .001$), respectively. Negative correlations were observed between the color and gloss of the aged samples of LDS and ZLS ($P \leq .026$) and between the gloss and roughness values of the aged samples of LDS and ZLS ($P < .001$). A positive correlation was observed between the translucency and gloss values of the aged LDS samples ($P < .001$) (Table 6).

DISCUSSION

The first and second hypotheses were rejected because of the following: 1) the ΔE values were affected by the surface treatment type ($P < .001$), 2) the initial TP ($P < .001$) and both the initial and aged roughness values ($P \leq .001$) were affected by ceramic type and ceramic-surface treatment interactions, 3) the TP values after aging were affected by the ceramic type ($P < .001$), and 4) both the initial and aged gloss values were affected by the type of ceramic and surface treatment ($P \leq .001$). The third hypothesis was partially rejected because of the following: 1) except for the roughness change values, the translucency change values were affected by ceramic type, surface treatment type, and their interactions ($P \leq .015$), and 2) the gloss change values were affected by surface treatment type and ceramic-surface treatment interactions ($P \leq .001$).

The effects of materials;[18] materials and aging;[19] and materials, surface treatments, liquids, and aging[20] on the TP were examined. In contrast to these studies,[18-20] both the initial and aged LDS samples in this study had higher TP values than the ZLS samples. This may be attributed to the larger crystal size and higher firing temperature of LDS than those of ZLS and the use of different glaze materials for both ceramics.[38,39]

The effects of surface treatments, liquids, and aging,[21] and materials and aging[19] on the ΔE of the monolithic ceramics were examined. In this study, the ΔE values of all subgroups of both ceramics were below the clinically perceptible threshold value ($\Delta E < 1.22$)[37] and acceptable threshold value ($\Delta E < 2.66$).[21,37] The C-G group exhibited the lowest ΔE, which might be because the C-firing and G-firing in this group were performed separately.

The effects of storage in liquid,[28] materials, and surface treatments[22] on the gloss were examined. Al-Angari *et al*.[28] reported that the liquid type (coffee) did not significantly affect the LDS gloss; however, Vichi *et al*.[22] reported that both the material (LDS and

Table 5. Descriptive statistics and multiple comparison results of the translucency and gloss change values (aged-initial)

	Surface Treatment	Liquid	Ceramic		Total
			LDS	ZLS	
Translucency Change (Aged-Initial)	C+G	DW	0.02 ± 0.05	0.37 ± 0.08	0.15 ± 0.06
		C	-0.03 ± 0.08	0.42 ± 0.08	0.19 ± 0.08
		GJ	0.07 ± 0.05	0.18 ± 0.21	0.11 ± 0.11
		S	-0.01 ± 0.07	0.30 ± 0.05	0.14 ± 0.07
		Total	0.02 ± 0.03[A]	0.36 ± 0.05[C]	0.15 ± 0.04[ab]
	C-G	DW	0.07 ± 0.07	0.002 ± 0.11	0.04 ± 0.05
		C	0.04 ± 0.02	-0.06 ± 0.07	0.01 ± 0.03
		GJ	0.02 ± 0.06	0.22 ± 0.08	0.10 ± 0.06
		S	0.03 ± 0.04	0.27 ± 0.05	0.14 ± 0.05
		Total	0.04 ± 0.02[A]	0.11 ± 0.05[AB]	0.07 ± 0.03[a]
	C-P	DW	0.09 ± 0.04	0.23 ± 0.06	0.15 ± 0.04
		C	0.16 ± 0.10	0.10 ± 0.08	0.13 ± 0.06
		GJ	0.18 ± 0.07	0.25 ± 0.09	0.20 ± 0.05
		S	0.19 ± 0.09	0.25 ± 0.046	0.23 ± 0.05
		Total	0.15 ± 0.04[AB]	0.21 ± 0.031[BC]	0.18 ± 0.02[b]
	Total		0.06 ± 0.02[1]	0.22 ± 0.03[2]	0.13 ± 0.02
Gloss Change (Aged-Initial)	C+G	DW	-0.88 ± 0.90	-1.48 ± 0.80	-1.18 ± 0.61
		C	-0.96 ± 1.15	-1.66 ± 0.72	-1.31 ± 0.80
		GJ	-3.23 ± 0.89	-7.54 ± 3.03	-4.81 ± 1.54
		S	-0.50 ± 2.12	-0.57 ± 2.49	-0.62 ± 1.50
		Total	1.53 ± 0.69[ABD]	-2.44 ± 1.09[ABD]	-1.80 ± 0.055[a]
	C-G	DW	-1.29 ± 0.32	10.96 ± 2.66	2.98 ± 2.35
		C	-0.32 ± 1.37	8.38 ± 1.83	3.50 ± 1.71
		GJ	1.67 ± 1.60	6.14 ± 2.33	3.70 ± 1.55
		S	0.84 ± 3.09	17.00 ± 2.55	8.73 ± 3.18
		Total	-0.29 ± 0.90[A]	10.17 ± 1.33[C]	4.29 ± 0.98[b]
	C-P	DW	0.54 ± 0.39	-5.21 ± 1.47	-1.65 ± 1.06
		C	1.70 ± 0.73	-2.64 ± 1.19	-0.42 ± 0.79
		GJ	-1.07 ± 1.00	-5.93 ± 1.20	-3.10 ± 1.28
		S	-1.00 ± 0.50	-5.15 ± 1.93	-2.48 ± 1.03
		Total	-0.10 ± 0.44[A]	-4.46 ± 0.83[D]	-1.86 ± 0.52[a]
	Total		-0.63 ± 0.40[1]	0.11 ± 0.96[2]	-0.44 ± 0.42

Trimmed Mean ± Standard Error.
* For each parameter (translucency change and gloss change), the same superscript numbers indicate no difference between the ceramic types, the same superscript lowercase letters indicate no difference among the surface treatment types, and the same superscript capital letters indicate no difference among the ceramic-surface treatment interactions.

ZLS) and the surface treatment [polished (30 and 60 s) and glaze (paste and spray)] significantly affected the gloss. Similar to the study by Al-Angari *et al.*,[28] the aged gloss values in this study were not affected by the liquid type, and similar to the study by Vichi *et al.*,[22] both the initial and aged gloss values in this study were affected by the type of ceramic and surface treatment ($P \leq .001$). The higher initial and aged gloss values of ZLS relative to those of LDS in this study may be due to (i) the initial and aged LDS exhibiting higher roughness values than the initial and aged ZLS, (ii) the differences between the content and

Table 6. Correlations between the initial and aged LDS and ZLS

Parameters	Ceramic	Initial		Aged	
		r	*P*	r	*P*
Translucency-Gloss	LDS	.436 ‡	< .001	.420 ‡	< .001
	ZLS	.024 †	.794	.021 †	.816
Translucency-Roughness	LDS	-.172 ‡	.061	-.162 ‡	.077
	ZLS	.027 ‡	.769	.049 ‡	.596
Gloss-Roughness	LDS	-.530 †	< .001	-.324 ‡	< .001
	ZLS	-.523 ‡	< .001	-.442 ‡	< .001
Color-Translucency	LDS			-.039 ‡	.675
	ZLS			.136 ‡	.138
Color-Gloss	LDS			-.203 ‡	.026
	ZLS			-.251 ‡	.006
Color-Roughness	LDS			-.085 ‡	.357
	ZLS			.023 ‡	.805

* r: Correlation coefficient († Pearson, ‡ Spearman) and *P*: *P* value.

hardness values of the ceramic materials, and (iii) the differences between the composition and density of the glaze materials used for both ceramics.

It was reported that gloss values of 40-60 GU are suitable for dental restorations.[40] In this study, the gloss values of the glaze groups (C+G and C-G), the initial C-G group of LDS, and both the initial and aged groups of ZLS complied with this reference range.

The effects of materials and surface treatments;[22] surface treatments;[23,24] surface treatments and liquids;[25,26] and types of liquids[27] on the surface roughness of the monolithic ceramics were examined. Vichi *et al*.[22] reported that the type of ceramic (ZLS and LDS) and surface treatment [polish (30 and 60 s) and glaze (paste and spray)] significantly affected the surface roughness. ZLS had a lower roughness than LDS. The polished group (30 s) of ZLS had a higher roughness value than the glaze (paste) group of ZLS, whereas no significant difference was observed between the polish (30 s) and glaze (paste) groups of LDS. Although Brescansin *et al*.[23] did not find a significant difference between the roughness of polished and glazed LDS samples, Brodine *et al*.[24] reported that glazed samples of LDS exhibited lower roughness values than polished samples of LDS. Kiliç Avşar *et al*.[26] reported that the roughness values of ZLS were not affected by the surface treatment type (glaze and polish) and liquid type (coffee and wine), whereas Alencar-Silva *et al*.[25] reported that the LDS roughness values were not affected by the liquid type (distilled water, coffee, tea, wine, and cola), but were significantly affected by the surface treatment type (polish and glaze). Alsilani *et al*.[27] reported that storage in different liquids (coffee, cola) did not change the roughness of LDS. The initial roughness values in this study were similar to those of Vichi *et al*.,[22] and the LDS roughness values after storage in different liquids+aging were similar to those reported by Alsilani *et al*.[27] The lower initial and aged surface roughness values of ZLS relative to those of LDS may be attributed to the small crystal size of ZLS (0.5 µm).[39]

This study investigated two types of monolithic ceramics with crystallization properties that exhibit high esthetic properties. The surface-treated ceramic samples were stored in different types of liquids that are frequently consumed in daily life at different pH values. Ten thousand cycles were used in the thermal aging process to mimic the *in vivo* environment, corresponding to approximately 1 year of clinical use.[41] The gloss measurements in this study, similar to those in previous studies,[22,28,42,43] were performed at 60°. The basic parameters for evaluating the clinical success of restorations, such as the optical and surface properties, were evaluated in two stages in this

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study, namely at initial (after surface treatments) and after storage in different liquids+aging.

This study had some limitations. Two types of monolithic ceramics with a single thickness (1.5 mm) were used. The samples were prepared in a rectangular prism shape for standardization, and all analyses were performed under *in vitro* conditions. Another limitation is that only four different liquids were used and specimens were subjected to only thermal aging. The effects of different surface treatments and aging on the optical (color, translucency, and opacity) and surface properties (topography, microhardness, gloss, and roughness), and fracture strength of different types of monolithic ceramics should be examined in future studies. Long-term clinical studies are required to obtain more reliable results.

CONCLUSION

The following conclusions were drawn based on the findings of this *in vitro* study:

Considering the correlation analyses results, clinical importance should be given to the gloss of monolithic restorations, as gloss is related to the translucency, ΔE, and roughness.

An aggregated analysis of the SEM, translucency, ΔE, gloss, roughness, data change, and correlation analyses results indicated that although both monolithic ceramics and all surface treatments can be used in clinical practice, C-G is the preferable surface treatment to be applied. ZLS or LDS may be preferred if gloss and smoothness or translucency are important, respectively.

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