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RESEARCH

Comparative evaluation of color stability in polished and glazed CAD/CAM ceramics subjected to coffee thermal cycling: an in vitro study

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Abstract

Background and aims Optimal color stability is crucial for patient satisfaction in prosthetic dentistry. This study assessed the impact of coffee immersion on the color stability and translucency of polished and glazed lithium disilicate, zirconia, and zirconia-reinforced lithium disilicate ceramics.

Materials and methods This in-vitro study evaluated the color stability and translucency of three CAD-CAM ceramics: lithium disilicate (IPS e.max CAD), monolithic zirconia (Incoris ZI), and zirconia-reinforced lithium disilicate (Vita Suprinity). Ninety specimens (30 per ceramic type) were divided into glazing, polishing, and control groups. After thermal cycling in a coffee solution, color changes (ΔE) and translucency parameters (TP) were measured with a spectrophotometer. ANOVA was used to analyze differences between groups. Post-hoc comparisons were conducted using the Tukey test, with a significance threshold of $p < 0.05$.

Results The results showed no significant differences in color changes (ΔE) between the polished, glazed, and control groups after coffee immersion ($P = 0.096$). Although coffee immersion caused detectable color changes, these were not clinically perceptible ($\Delta E > 1.01$). Translucency (TP) measurements revealed significant differences between the groups ($P < 0.001$), with monolithic zirconia showing lower translucency compared to the other ceramics.

Conclusion This in-vitro study showed that coffee immersion negatively impacted the color of all tested CAD-CAM ceramics, although the changes remained within clinically acceptable limits. Surface treatments, including polishing and glazing, had no significant effect on the color stability or translucency of the ceramics. Coffee immersion also did not affect translucency.

Keywords Coffee, Color, Dental materials, Dental porcelain, Esthetics, Materials testing, Surface treatments

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Introduction

Restorations with optimal color and optical properties are a key demand among dental clinic patients [1, 2]. However, one of the significant challenges in prosthetic treatments is the gradual discoloration of restorations [3]. Surface texture and roughness impact restoration color stability and success, with rough surfaces promoting discoloration due to plaque retention and cleaning difficulties [4]. Dentists often need solutions to minimize surface roughness and its potential adverse effects after adjusting to achieve proper contour and occlusion. Glazing and polishing are two effective methods for reducing surface roughness [5–9]. Polishing involves smoothing and creating a glossy surface by abrasion, typically done in-office without laboratory equipment [10]. Glazing is a porcelain firing process that fills surface pores to create a smooth, glossy finish and improves the mechanical strength of ceramic restorations [11]. However, the ideal clinical approach, whether reglazing or polishing after adjusting the glazed surface, remains unclear in the existing literature [8].

Studies have demonstrated that common beverages such as coffee, tea, cola, and fruit juices can cause noticeable color changes in restorative materials [12, 13]. Coffee is a popular beverage worldwide and a primary caffeine source. It is a staple in daily routines. However, few studies have investigated the effect of coffee thermal cycling on lithium disilicate glass ceramics [14].

Lithium disilicate is regarded as the most aesthetically pleasing biomaterial among ceramics due to its exceptional optical properties [15]. However, its main limitations are low fracture resistance and brittleness [16–18]. On the other hand, zirconia offers superior fracture resistance but lacks desirable optical properties [15]. To address the need for biomaterials that combine aesthetics and high fracture resistance, zirconia-reinforced lithium silicate was developed [19]. VITA Suprinity (VITA Zahnfabrik) is an example of this material [20], which the manufacturer claims exhibits optical properties comparable to natural teeth [19]. Newer ceramics, including high-translucency zirconia (4Y-TZP, 5Y-TZP), polymer-infiltrated ceramics (Vita Enamic), and advanced lithium silicates (Celtra Duo), have been developed to enhance both esthetic and mechanical properties. High-translucency zirconia improves optical qualities while maintaining strength, polymer-infiltrated ceramics offer better elasticity and fracture resistance, and advanced lithium silicates provide superior translucency and durability compared to conventional lithium disilicate [21].

Lithium disilicate, monolithic zirconia, and zirconia-reinforced lithium disilicate are among the most popular restorative materials. While newer ceramics with enhanced optical and mechanical properties have been introduced, these three materials remain widely used in clinical practice. To the best of our knowledge, no study has yet evaluated the combined effects of surface treatments (polishing and glazing) and coffee thermal cycling on the color stability of different zirconia-based materials. Therefore, this study aimed to evaluate the color stability of polished and glazed specimens of three CAD-CAM ceramics types. It is hypothesized that there is no significant difference in the color stability between polishing and glazing lithium disilicate (LD), monolithic zirconia (Z), and zirconia-reinforced lithium disilicate (ZLS) after coffee thermal cycling.

Materials and methods

This experimental, in-vitro study was conducted from January to December 2023. Based on a similar previous study [22], using Advanced Repeated Measure ANOVA and PASS11 software, with $\alpha = 0.05$, $\beta = 0.2$, effect size = 0.76, and a standard deviation of 0.66, the minimum specimen size for each subgroup was calculated to be ten specimens, considering ceramic type (3 types) and surface treatment method (glazing, polishing, and control). In total, 90 specimens will be divided into nine groups, with ten specimens in each group. The university's ethical committee approved the study under the ethical code IR.IAU.DENTAL.REC.1399.174.

Preparation of ceramic specimens

The shape and dimensions of the specimens were as follows:

Lithium disilicate zirconia-reinforced blocks (ZLS) (Suprinity, Vita Zahnfabrik, Germany with 10 mm x 10 mm x 1 mm (rectangular) dimensions.

Lithium disilicate blocks (LD) (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein) with dimensions of 10 mm x 10 mm x 1 mm (rectangular).

Monolithic zirconia blanks (Z) (Incoris ZI, Dentsply Sirona, Germany) with dimensions of 13 mm x 13 mm x 1.7 mm (square). All materials were in color A2. The compositions and structures of these materials are detailed in Table 1.

The blocks and blanks were cut using a diamond blade at a speed of 3000 rpm with a Low-Speed Precision Cutting Machine (MECATOM, T 201 A Presi Co, USA) with abundant water spray. After drying with air spray, ZLS and LD blocks underwent crystallization in a furnace (Auto Therm-100, Koushafan Pars, Iran). The Z specimens were sintered in a furnace (InFire HTC Speed, Dentsply Sirona) following the manufacturer's instructions (Table 2).

After heat treatment, the dimensions of the specimens remained as follows:

ZLS: 10 mm x 10 mm x 1 mm (rectangular).

LD: 10 mm x 10 mm x 1 mm (rectangular).

Z: 10 mm x 10 mm x 1 mm (rectangular).

Table 1 Ceramic composition

Trade Name	Classification	Composition (% by Weight)	Manufacturer
Suprinity LS	Lithium Silicate Zirconia-Reinforced Ceramic	SiO_2 (56–64) Li_2O (15–21) ZrO_2 (8–12) P_2O_5 (3–8) K_2O (1–4) Al_2O_3 (1–4)	Vita Zahnfabrik, Germany
IPS e.max CAD	Lithium Disilicate Glass Ceramic	SiO_2 (57–80) Li_2O (11–19) K_2O (0–13) P_2O_5 (0–11) ZrO_2 (0–8) ZnO (0–8)	Ivoclar Vivadent, Liechtenstein
Incoris ZI	Monolithic Zirconia Ceramic	$ZrO_2 + HfO_2 + Y_2O_3 \geq 99.0$ Y_2O_3 (4.5-6.0) HfO_2 (0–5) Al_2O_3 (0-0.5) Fe_2O_3 (0-0.3)	Dentsply Sirona, Germany

Table 2 Firing specifications of ceramics

Material	Stand-by Temperature (°C)	Closing Time (Minutes)	Heating Rate (°C/min)	Firing Temperature (°C)	Cooling Time (Minutes)	Vacuum Temperature (°C)
Suprinity	400	4	55	840	8	First at 410 Second at 840
IPS e.max CAD	403	6	90	820	7:10	First at 550 Second at 820
Incoris ZI	300	3	8	1300	60	

The specimens were then randomly divided into three treatment groups:

1. **Group 1 (G)**: Glazed according to the manufacturer's instructions (Fig. 1).
2. **Group 2 (P)**: Polished using the polishing kit. (Diapol and Diapol Twist kits, EVE Ernst Vetter, Germany) for 15 s with a rotational motion (Fig. 2).
3. **Group 3 (C)**: Remained untreated.

For **Group 1 (G)**:

- For LD, a 1:1 layer of Empress Universal Glaze and Glaze Paste (IPS Empress, Ivoclar Vivadent, Liechtenstein) was used.
- For ZLS, a layer of Glaze Paste (Akzent Plus, Vita, Germany) was applied.
- For Z, a layer of glaze paste (glaze paste, Zirkonzahn GmbH, Italy) was used.

Glazing parameters

- For ZLS, a temperature of 800 °C for 5 min with a heating rate of 80 °C per minute and an initial temperature of 400 °C was used.
- For IZ, a temperature of 960 °C for 2 min with a heating rate of 60 °C per minute and an initial temperature of 500 °C was applied.
- For LD, a temperature of 820 °C for 4 min with a heating rate of 65 °C per minute and an initial temperature of 390 °C was applied.

For **Group 2 (P)**:

- The specimens were polished in six stages using the polishing kits (Diapol and Diapol Twist, EVE, Germany) as follows:
  - **Stage 1**: Smoothing with W16Dg (light blue),
  - **Stage 2**: Pre-polishing with W16Dmf (pink),
  - **Stage 3**: High-shine polishing with W16D (white).
- Then, with the **Diapol Twist kit**:
  - **Stage 1**: Smoothing (light blue),
  - **Stage 2**: Pre-polishing (pink),
  - **Stage 3**: High-shine polishing (white).
- The recommended rotational speed was 15,000 rpm for 15 s, with the operator applying controlled hand pressure for each bur.

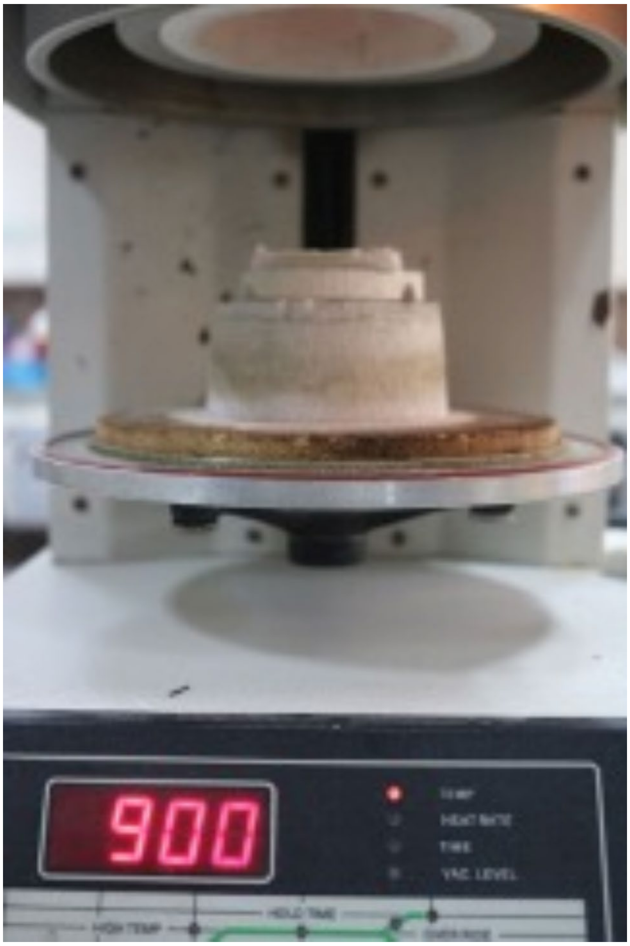

Fig. 1 Glazing of the specimens

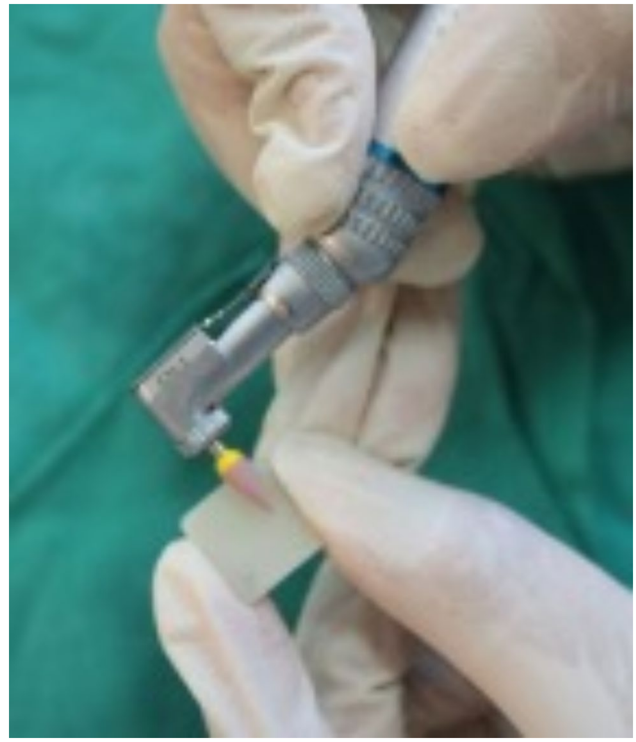

Fig. 2 Pre-polishing of the specimens with W16Dmf

Initial evaluation of color parameters

Next, the specimens were assessed using a spectrophotometer (X-Rite SP60, X-Rite Inc., USA). The spectrophotometer was positioned 80 cm from the specimen, focusing on a 2.8 mm diameter area at its center for measurement. Two light sources, angled at 45 degrees, were used to illuminate the specimen's surface. A standard white calibration tile (16176001, Calibration Plate, Japan) was utilized for calibration.

Immersion in coffee thermal cycling

All specimens were subjected to 5000 thermal cycles in a coffee solution. Two chambers were prepared at 5 °C and the other at 55 °C. Each specimen was immersed for 30 s in each chamber, with a 10-second transition between chambers. This thermal cycling protocol simulates 6 months of restoration exposure in the oral environment, as per the literature [23]. The coffee solution was prepared by adding one tablespoon of coffee (Nescafe Classic Refill, Nestlé, Switzerland) to 177 ml of water using a filtered coffee machine, according to the manufacturer's instructions. The coffee solution in each chamber was replaced every 12 h (Fig. 3). After thermal cycling in coffee, the specimens were cleaned by brushing 10 times in a circular motion with toothpaste (Procter and Gamble, Crest, USA) under water pressure.

Secondary evaluation of color parameters

For the secondary color evaluation after thermal cycling, the specimens were placed in the spectrophotometer, and the data were recorded for each specimen using the same method.

The color changes (ΔE) were calculated using the CIE Lab system. The values were documented at each stage of color parameter measurement. To calculate ΔE*, the following formula was applied: [24]

$$\Delta E* = \sqrt{[(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]}$$

L (lightness, from 0 for black to 100 for white), a* (green-red spectrum, with negative values for green and positive values for red), and b* (blue-yellow spectrum, with negative values for blue and positive values for yellow) [25].

Color measurements were conducted under consistent environmental conditions.

To assess the translucency of each specimen, the following formula was used: [24]

$$TP = \sqrt{[(LB - LW)^2 + (aB - aW)^2 + (bB - bW)^2]}$$

Fig. 3 Coffee thermal cycling of the specimens with 5000 cycles

In this formula, W represents the white background, and B represents the black background.

Two standard backgrounds were used to measure translucency:

A standard black background with parameters: L* = 7.60, a* = 0.45, b* = 2.44.

A standard white background with parameters: L* = 88.83, a* = -4.95, b* = -6.07.

For translucency determination, each specimen was placed on both the black and white backgrounds. Then, it was illuminated with light from a spectrophotometer with a wavelength range of 400–700 nm.

Statistical analysis

The statistical analysis involved comparing pre- and post-immersion ΔE* values and TP values among the three surface treatment groups using one-way ANOVA to assess the effect of glazing and polishing on color stability. Additionally, repeated measures ANOVA was used to evaluate translucency changes before and after immersion in coffee. Post-hoc comparisons were conducted using the Tukey test, with a significance threshold of $p < 0.05$.

Table 3 Descriptive statistics and group comparisons for ΔE (Color change) for different ceramic types

Ceramic Material	ΔE (Black Background) Mean ± SD	ΔE (White Background) Mean ± SD	*P*-value Black Background	*P*-value White Back-ground
Suprinity	3.33 ± 4.56^{a}	2.70 ± 4.48^{a}	0.059	0.096
IPS Emax	3.18 ± 5.08^{a}	2.65 ± 4.69^{a}		
Sirona	0.91 ± 0.59^{a}	0.65 ± 0.55^{s}		

Table 4 Descriptive statistics and group comparisons for ΔE (Color change) for different surface treatments

Treatment type	ΔE (Black Background) Mean ± SD	ΔE (White Background) Mean ± SD	*P*-value Black Background	*P*-value White Back-ground
Glazed	1.56 ± 1.23^{a}	2.11 ± 1.32^{a}	0.311	0.566
Polished	1.70 ± 0.98^{a}	2.42 ± 1.18^{a}		
Control	2.12 ± 1.55^{a}	2.70 ± 1.14^{a}		

Table 5 Descriptive statistics and group comparisons for TP0 and TP1 across different ceramic types

Ceramic Material	TP0 Mean ± SD	TP1 Mean ± SD	*P*-value TP0	*P*-value TP1
Suprinity	20.22 ± 2.57^{a}	20.93 ± 2.33^{a}	0.000	0.000
IPS Emax	19.94 ± 1.40^{a}	19.85 ± 1.39^{a}		
Sirona	5.92 ± 0.72^{b}	5.89 ± 0.71^{b}		

Table 6 Descriptive statistics and group comparisons for TP0 and TP1 for different surface treatments

Treatment type	TP0 Mean ± SD	TP1 Mean ± SD	*P*-value TP0	*P*-value TP1
Glazed	19.90 ± 2.80^{a}	21.10 ± 2.43^{a}	0.152	0.660
Polished	20.00 ± 3.50^{a}	20.85 ± 3.45^{a}		
Control	20.10 ± 4.60^{a}	20.95 ± 5.63^{a}		

Results

The average ΔE* values of black and white backgrounds for before and after immersion in coffee for each ceramic type are summarized in Table 3.

The ΔE* values across all groups—glazed, polished, and control—were not statistically significant before and after coffee immersion ($P > 0.05$) (Table 4). However, coffee immersion caused minimal color changes (ΔE > 1.01), which remained below the clinically perceptible threshold.

Significant differences were found in the translucency parameters (TP0 and TP1), where the groups differed notably, with Monolithic zirconia showing lower translucency compared to other ceramics ($P < 0.001$) (Table 5). However, Translucency changes were not significant among different surface treatment groups. ($P > 0.05$) (Table 6).

Discussion

The optical properties of CAD-CAM materials are crucial in restorative dentistry for replicating natural dental structures. These properties can be altered by glazing or polishing after adjustment [26]. This study aimed to compare the color stability of polished and glazed specimens of three CAD-CAM ceramics types using color parameters of L*, a*, b*, and ΔE. The study found no significant differences in ΔE values between the polished, glazed, and control groups, with coffee immersion causing detectable color changes, but these changes were not clinically perceptible; however, translucency remained unaffected, with Sirona zirconia showing lower translucency compared to other ceramics. Therefore, the initial hypothesis of the study was confirmed.

The thresholds for clinical acceptability and perceptibility of ΔE for intraoral detection by the naked eye are 3.7 and 1, respectively [27]. This study used the CIE-Lab system to evaluate color stability. This system evaluates color based on individual perception using three parameters. This system is widely used in dental research due to its accuracy, and the parameters are measured using a spectrophotometer [22, 28–32]. The spectrophotometric results on both white and black backgrounds revealed that, on the white background, ZLS and Z exhibited the lowest *P*-value (0.085), indicating the greatest translucency difference. In contrast, LD and ZLS showed the highest *P*-value (0.99), indicating the smallest difference. These findings were consistent on the black background as well.

Coffee was selected as the staining agent due to its strong pigmentation and acidic nature, which impact the color stability of dental materials. Its widespread consumption makes it a relevant factor in assessing the long-term aesthetic performance of restorations [33, 34].

In Gulce Alp et al. [35] 's study, zirconia-reinforced lithium silicate (Vita Suprinity PC) and lithium disilicate (IPS e.max CAD) blocks were evaluated using a methodology similar to the present study. The results showed that color changes were clinically acceptable after coffee thermal cycling, except for the polished LDS group, where the color change was perceptible but still within clinically acceptable limits. The difference in the findings for the polished LDS group may be attributed to the use of a different polishing kit and variations in specimen thickness. Similarly, Aldosari et al. [36] investigated the effect of immersion in hot Arabic Qahwa and cold coffee, followed by thermal cycling, on the color stability (ΔE*) of polished and glazed CAD-CAM restorative materials. They reported clinically acceptable ΔE* values for glazed or polished materials, with significant changes observed only in Vita Suprinity specimens.

Demirel et al. [37] evaluated the color stability (ΔE00) of advanced lithium disilicate (ALDS), LD, and ZLS after coffee thermal cycling, reporting similar ΔE00 values across all tested materials, with no statistically significant differences. However, they observed substantial effects of material type and thermal cycling on relative translucency parameter values, with LD demonstrating the highest and ZLS the lowest translucency before and after thermal cycling. The differences in translucency values between the current study and Demirel et al. [37]'s study can be attributed to variations in material composition (lithium disilicate, zirconia-reinforced lithium silicate, and monolithic zirconia vs. advanced lithium disilicate), specimen dimensions (10 mm x 10 mm x 1 mm vs. 12 mm x 1.2 mm disks), surface treatment protocols (glazing, polishing, and control vs. glazing and spray glaze), and spectrophotometer settings (CIEDE2000 formula vs. a different calibration method).

Khomprang et al. [14] investigated the effects of coffee thermal cycling on IPS E.max CAD and IPS E.max ZirCAD Prime, reporting ΔE values exceeding clinical acceptability thresholds, unlike the current study, where color changes remained within acceptable limits (ΔE < 3.03). In contrast to the present study, Khomprang et al. observed a significant increase in translucency for lithium disilicate, whereas translucency changes were not significant here. These discrepancies may be due to differences in materials, specimen dimensions, and experimental protocols, including the application of 30,000 thermal cycles, a more intensive protocol than in this study.

Cakmak et al. [38] investigated the impact of material thickness, resin cement shade, and coffee thermal cycling on the optical properties of zirconia-reinforced lithium silicate (ZLS) specimens. They found that coffee thermal cycling reduced the translucency of all specimens. Their different results in translucency values compared to the current study could be attributed to several factors, including variations in the material compositions used, the surface treatments applied, and the specific methods used to measure translucency.

Demirkol and Ozen [39] assessed the color stability of LAVA Ultimate (LU), and IPS e.max CAD (EC) under thermal cycling with coffee and cola. Similar to our study, ΔE was evaluated, and ANOVA was used for analysis. Both studies found that pigmented beverages negatively impacted ΔE, though color changes remained within an acceptable range (ΔE > 3.03). Differences included Demirkol's finding that polished EC showed the most color change after coffee thermal cycling and recommended glazing for better stability. The differences between the two studies may be due to variations in polishing kits and specimen thickness, which was smaller in Demirkol's study (0.5 ± 0.05 mm).

In a study by Eldwakhly et al. [40], five ceramic materials were immersed in coffee, ginger, cola, and distilled water for 28 days, with daily solution changes and twice-daily agitation to simulate 2.5 years of oral conditions. While their methodology differed from the current study, both studies measured ΔE and ΔTP on white and black backgrounds. The results showed that IPS e.max exhibited the least ΔE, with resin-based ceramics in aqueous solutions demonstrating greater color change due to water absorption, even in distilled water. IPS e.max, the only ceramic material common to both studies, showed minimal color change, remaining within an acceptable range, consistent with the current study's findings.

In a study by Abu-Obaid et al. [41], three types of CAD-CAM ceramics were tested for color stability after immersion in a pigmented solution (coffee). The ceramics were divided into three groups: (1) glaze (control), (2) finishing and polishing, and (3) re-glazing after polishing. Color changes were measured before and after immersion. The results showed that polishing caused the most significant color change, but all changes remained clinically acceptable. Ceramics with more homogeneous microstructures, like Vita Suprinity, showed better stain resistance.

This experimental, in-vitro study provides insight into the effects of surface treatment methods (glazing, polishing, and control) on the color stability of three types of ceramics (lithium disilicate zirconia-reinforced, lithium disilicate, and monolithic zirconia) under thermal cycling in a coffee solution. Although the study utilized precise specimen preparation, thermal cycling, and color evaluation methods, it was limited by using a single staining solution and the 6-month simulated exposure. Future studies should investigate a wider variety of staining agents and longer exposure times to better simulate real-life clinical conditions and enhance the generalizability of the results.

Conclusion

This in-vitro study demonstrated that coffee immersion negatively impacted the color of all tested CAD-CAM ceramics, but the changes remained within clinically acceptable limits. Surface treatments, including polishing and glazing, did not significantly affect the ceramics' color stability and translucency. Coffee immersion did not affect translucency. Monolithic zirconia showed the lowest translucency among the ceramics tested.

Abbreviations

ΔE*	Color difference (CIE Lab system)
ΔTP	Change in translucency parameter
ALDS	Advanced lithium disilicate
CAD-CAM	Computer-aided design and computer-aided manufacturing
CBCT	Cone-beam computed tomography
EC	IPS e.max CAD
LD	Lithium disilicate
LU	LAVA Ultimate
TP	Translucency parameter
Z	Monolithic zirconia
ZLS	Zirconia-reinforced lithium silicate

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Author contributions
R.N. conducted data acquisition, project administration, data analysis, and original draft preparation. Arash Zarbakhsh supervised the project and contributed to project administration. A.M. acquired funding, conceptualized and designed the study, drafted the article, and approved the final manuscript. S.G. provided resources and data curation, contributed to software development, and approved the final manuscript. N.Y. performed critical revisions, contributed to methodology, and helped draft the article. S.K. contributed to resources and data curation, software development, and critical revisions. All authors reviewed and approved the manuscript.

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Data availability
The data supporting this study's findings are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The School of Dentistry, Islamic Azad University, Tehran's ethics committee approved the study. (Ethical code: IR.IAU.DENTAL.REC.1399.174.)

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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