Effect of Surface Finishing on the Color Stability and Translucency of High-translucent Multilayer Zirconia Following 10,000 Cycles of Coffee Thermocycling

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Abstract

Many patients have asked whether daily coffee consumption affects restorations' long-term optical properties. Thermocycling with coffee solutions on high-translucent zirconia materials has not been extensively investigated. This study aimed to investigate how 10,000 cycles of coffee thermocycling affected the color stability and translucency values of gradient multilayered yttria-stabilized zirconia (GZ) following surface finishing methods. Methodology: Twenty-seven rectangular GZ plates were categorized similarly into three surface finishing methods: glazed, glazed+pumice, and polished. At the baseline and after 10,000 cycles of coffee thermocycling, a spectrophotometer was used to determine the color difference (ΔE) and translucency differences (ΔTP) in each zone of multilayer zirconia. A contact-type profilometer was employed to evaluate surface roughness, and scanning electron microscopy (SEM) was utilized for surface analysis. Statistical analysis was conducted using two-way ANOVA followed by Tukey's post hoc test. Result: No significant differences were found in ΔE ($p = 0.676$) and ΔTP ($p = 0.669$) among the surface finishing methods of the specimens. This study found that ΔE was significantly higher in the upper zone of the polished group ($p < 0.001$) and the glazed group ($p < 0.001$) compared to other zones, except for the glazed + pumice group ($p = 0.069$). Conclusions: Following 10,000 cycles of coffee thermocycling, surface finishing methods did not impact the color stability or translucency of high-translucent zirconia. However, color stability was influenced by the distinct regions within the polished or glazed multilayer zirconia.

Keywords: *color stability, high-translucent zirconia, optical properties, thermocycling, translucency, surface treatment*

1. Introduction

The rapidly increasing popularity of computer-aided design and computer-aided manufacturing (CAD-CAM) technology can be due to the well-designed and easily accessible CAD-CAM equipment. The rapid production process makes single-visit restoration possible. Additionally, ceramic materials have been manufactured to improve the mechanical and visual appearance. Therefore, CAD-CAM materials are often used as monolithic ceramics with a polished or glazed finish. Rapid technological development is an advantage of the digital age (Marchesi et al., 2021).

In dentistry, partially stabilized zirconia (PSZ) stabilized with approximately 5 mol% yttria (5Y) has been used. 5Y-PSZ can be utilized to produce monolithic restoration in esthetic regions due to its translucency, similar to the optical properties of lithium disilicate. It has been shown to be significantly more translucent than 3Y-PSZ. However, 5Y-PSZ exhibits considerably lower flexural strength compared to 3Y-PSZ, as high-translucent zirconia contains a higher proportion of the cubic phase and a lower proportion of the tetragonal phase (Zhang, & Lawn., 2018). Layered restorations, which are composed of opaque zirconia cores together with ceramic veneering, may need additional manufacturing processes compared to high-translucent monolithic zirconia. Monolithic restorations offer several benefits, including minimizing abutment tooth reduction, reducing antagonist tooth attrition, improving biological properties, and decreasing production time and the likelihood of errors (Ban, 2020).

Many companies currently manufacture novel polychromatic materials. These materials are smooth and have a natural shading (Michailova et al., 2020). The color is distributed uniformly across the block due to its unique manufacturing technique. According to the manufacturer's data, these materials can be used to restore the anterior regions because of their good mechanical strength and esthetic outcomes. However, to substantiate the company's claims of enhanced esthetics for these new dental ceramics, it is essential to examine the material's translucency and color stability after the aging process.

Nowadays, a single zirconia generation or a combination of many zirconia generations into a single block can be used to create monolithic zirconia. To mimic the natural shades of tooth structures, a polychromatic high-translucent multilayer zirconia was recently introduced. The layers produce unique combinations based on the stabilizer quantity and chemical composition, which may result in variations in the material characteristics of the various layers (Kolakarnprasert et al., 2019; Toma et al., 2022).

According to the manufacturing processes, CAD-CAM materials exhibit greater variation in visual appearance and roughness during thermocycling than heat-pressed materials (Vasiliu et al., 2020). Furthermore, the aging process has a significant impact on the translucency of CAD-CAM materials (Vasiliu et al., 2020; Al-Zordk, & Saker, 2020). After 50,000 cycles of thermocycling, high-translucent zirconia has been reported to show an increase in translucency parameter values. However, the color stability remained below the limits of clinically acceptable thresholds with statistical significance (Aljanobi, & Al-Sowygh, 2020). The optical characteristics of restorations can be affected by surface roughness (O'Brien et al., 1984; Wang et al., 2011). More specular reflection may be seen on a smooth surface, whereas diffuse light reflection may be linked to a rough surface (Obregon et al., 1981). After the ceramic is fabricated, any pores or minor flaws are sealed with a glazing process, which makes the surface smooth and glossy. In a clinical setting, occlusal adjustment might be required during a try-in visit to remove interferences. The polishing technique is an effective method for decreasing roughness with a shiny surface after occlusal adjustments (Kulvarangkun et al., 2022). Thus, the surface finishing of a restoration, before and after clinical adjustment, may influence the material's optical properties.

Because coffee beverages are widely consumed (Yerliyurt, & Sarıkaya, 2022), they are frequently employed to mimic staining during in vitro investigations (Acar et al., 2016). This study also investigated color staining on multilayer zirconia after one year of use. During recall check-ups, patients typically undergo teeth cleaning with pumice polishing to remove external staining. Therefore, one of the surface finishing methods applied in this study was pumice polishing following 10,000 cycles of coffee thermocycling (Gale, & Darvell., 1999).

2. Objectives

This study's objective was to investigate how surface finishing methods affect color stability and translucency values of high-translucent multilayer zirconia after 10,000 cycles of coffee thermocycling.

3. Materials and Methods

3.1 Specimen Preparation

The sample size was determined using the program (N4studies Version 1.4.1, Thailand) using the delta E (ΔE) averages and the standard deviations from previous research (Aljanobi, & Al-Sowygh, 2020). Hence, in this investigation, nine specimens were used in each group.

Ceramic plates (n = 27) with a layer thickness of 1.0 ± 0.1 mm and dimension of 14 x 16 mm were prepared using a ceramic disc with the A2 shade of gradient multilayered yttria-stabilized zirconia (GZ) (Ivoclar Vivadent, Schann, Liechtenstein). These plates were divided into three surface finishing methods: glazed surface, glazed surface with pumice polishing (glazed+pumiced), and polished surface. Following the manufacturer's recommendations. A ceramic furnace (Infire Rapid Speed; Dentsply Sirona, Charlotte, NC, USA) was used to sinter the high-translucent zirconia plate fully.

Group 1 (glazed group): The specimens were sandblasted for 10 seconds at a distance of 10 mm, under a 2.5 bar pressure employing a sandblasting machine (Basic eco; Renfert, Hilzingen, Germany) with aluminum oxide particles (50 µm). Following that, the samples were ultrasonically cleaned in distilled water for 15 minutes. Each specimen was then coated, on one side, with a thin layer of Ivocolor Glaze paste (Ivoclar Vivadent, Schann, Liechtenstein) and fired following the manufacturer's instruction. Group 2 (glazed+pumiced group): the specimens were prepared similarly to the glazed group process. Using a rubber cup, pumice powder (Whip Mix Corporation, Louisville, Kentucky, USA), and a prophy handpiece (Kavo INTRAmatic Prophy Handpiece 31ES, Biberach, Germany). The specimens were polished after the coffee thermocycling was finished. Polishing with pumice was performed for 15–30 seconds at a low speed of 2500–3000 rpm (Madan et al., 2009). Group 3 (polished group): the specimens were wetly ground using silicon carbide abrasive paper, grit ranging from 400 to 4,000, to finish each polishing surface. Every surface treatment was applied to one side of the specimen while leaving the other side untreated. The same operator performed all the glazing and polish finishing techniques.

3.2 Color Measurement

Figure 1 shows the zones according to the manufacturer's design in the GZ material, which was separated into three zones: the incisal zone (5Y), the transition zone (5Y-3Y), and the dentin zone (3Y).

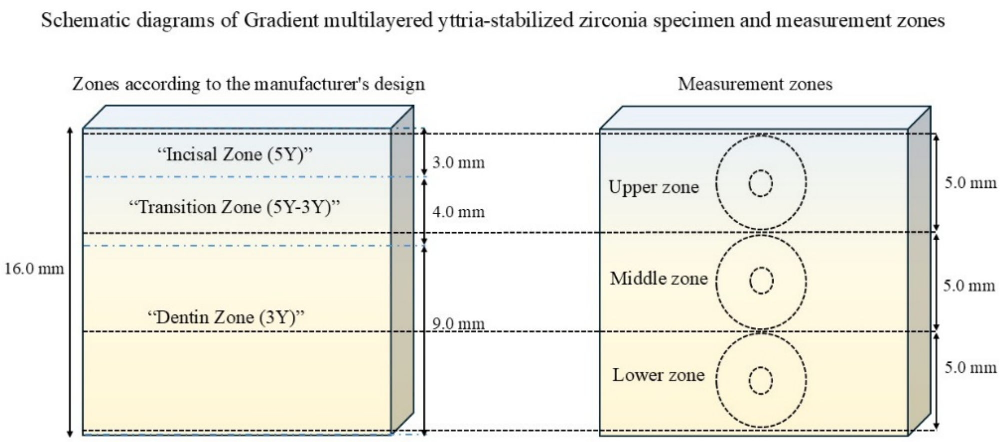

Figure 1 Schematic diagrams of gradient multilayered yttria-stabilized zirconia specimen and measurement zones

A spectrophotometer with a 5.0 mm diameter tip (VITA Easyshade Compact; Vident, A VITA Company, California, USA) was used to measure the CIE L*a*b* values in each specimen measurement zone. The measurement zone was divided into three equal parts: upper, middle, and lower (Figure 1). Using CIE L*a*b* values following ISO/CIE 11664-4:2019 on black and white backgrounds, the beginning and the final color values of each specimen were obtained.

The L* value represents lightness; a value of 0 represents black, while a value of 100 represents perfect white. Negative a* values are used to represent green, and those that are positive are used to represent red. In a similar way, negative values of b* indicate blue, whereas the opposite positive values indicate yellow (Aljanobi, & Al-Sowygh, 2020).

Utilizing L*a*b* values on a black background, color stability (ΔE) was determined using the following formula: $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (Aljanobi, & Al-Sowygh, 2020). The color stability (ΔE) prior to (E0) and after 10,000 cycles of coffee thermocycling (E1) was determined using the acceptance threshold (AT) of 2.7 and the perceptibility threshold (PT) of 1.2. (Paravina et al., 2019).

The translucency parameter (TP) was determined using the L*a*b* values of the samples on the black and white backgrounds. The following formula was used to calculate TP: TP= $[(L^*W- L^*B)^2 + (a^*W-$

a*B)^2 + (b*W- b*B)^2]$^{1/2}$ (Della Bona et al., 2014). The translucency difference (ΔTP) between baseline (T0) and after 10,000 cycles of coffee thermocycling (T1) was calculated using the formula ΔTP = TP1 – TP0. Comparing data with the acceptance threshold (AT) of 4.4 and the perceptibility threshold (PT) of 1.3 had significance to determine ΔTP values (Paravina et al., 2019).

3.3 Aging Process in Coffee Solution

A thermocycling machine (TC301; King Mongkut's Institute of Technology Ladkrabang, Thailand) was used to age all specimens following ISO 11405 guidelines thermally. One teaspoon of coffee was mixed with 180 milliliters of water, according to the manufacturer's instructions. The coffee solution (Nescafe Red Cup; Chachoengsao, Thailand) temperature range was 5 to 55 degrees Celsius, and the specimens were soaked for 30 seconds and transferred over 10 seconds. The coffee solution was changed in both baths every 24 hours. This study used 10,000 cycles of coffee thermocycling.

3.4 Surface roughness measurement

Every sample was evaluated for mean surface roughness (Ra) at the baseline and following 10,000 cycles of coffee thermocycling. The specimens were measured on each side using a contact-type surface roughness device (Talyscan 150 with a stylus for contact 3D scanning; Taylor Hobson Limited, Leicester, England).

3.5 Scanning Electron Microscope (SEM) micrographs

The surface of the samples was analyzed using scanning electron microscopy (Thermionic SEM JEOL JSM 5410LV). The samples were scanned before and after 10,000 cycles of coffee thermocycling at a magnification of x30,000.

3.6 Statistical Analysis

A statistical program (IBM SPSS Statistics, v.21 for Windows; IBM Corp.) was used to perform the statistical analyses. The Kolmogorov–Smirnov test demonstrated that the data had a normal distribution ($p <$ 0.05). Surface roughness (Ra) was compared using the paired sample T-Test. The translucency difference (ΔTP) and color difference (ΔE) of the specimens were determined using a two-way ANOVA. For multiple comparisons, the Tukey honestly significant difference (HSD) test was used in all analyses, with p values of 0.05.

4. Results and Discussion

4.1 Results

A statistically significant difference in ΔE values was observed only in the GZ areas following 10,000 cycles of coffee thermocycling, according to two-way ANOVA; see Table 1. The Tukey post hoc test revealed no significant differences across regions (p = 0.069) in the glazed+pumice group, while the glazed group's upper region (p <.001) and the polished group's upper region (p <.001) had a statistically significant increase in ΔE compared to other regions; see Table 2. Table 2 shows that the ΔE for each surface finishing method was not significantly different in any specimen region. The study found that ΔE was higher than PT values (ΔE > 1.2) in every surface finishing group region. Moreover, after 10,000 cycles of coffee thermocycling, the upper region of the polished and glazed groups had ΔE values higher than AT values (ΔE > 2.7) (Figure 2).

Table 1 Two-way ANOVA results of the color difference (ΔE) and translucency difference (ΔTP) of high-translucent zirconia following 10,000 cycles of coffee thermocycling

Source		df	Sum of Squares	Mean Square	F	P value
Color difference (ΔE)	Regions (A)	2	24.841	12.420	19.579	<.001*
	Surface finishing (B)	2	0.499	0.249	0.393	0.676
	Regions * Surface finishing (A x B)	4	1.631	0.408	0.643	0.634
Translucency difference (ΔTP)	Regions (A)	2	47.227	23.613	0.542	0.584
	Surface finishing (B)	2	35.228	17.614	0.404	0.669
	Regions * Surface finishing (A x B)	4	378.235	94.559	2.171	0.081

* Tukey post hoc test: statistically significant at a significance level of $p < 0.05$

Table 2 Results of mean color difference (ΔE) of high-translucent zirconia following 10,000 cycles of coffee thermo-cycling, divided by material regions and surface finishing methods

Surface finishing methods	Mean ± SD Upper region	Mean ± SD Middle region	Mean ± SD Lower region	P value
Glazed	2.83 ± 1.40^{A}	1.60 ± 0.24^{B}	1.41 ± 0.87^{B}	<.001 *
Glazed+pumice	2.26 ± 0.99	1.49 ± 0.53	1.50 ± 0.54	0.069
Polished	2.79 ± 0.70^{A}	1.49 ± 0.68^{B}	1.26 ± 0.67^{B}	<.001 *
P value	0.248	0.951	0.813	

* Tukey post hoc test: statistically significant at a significance level of $p < 0.05$. The different superscript letter indicates significant differences within the same row (same surface finishing methods)

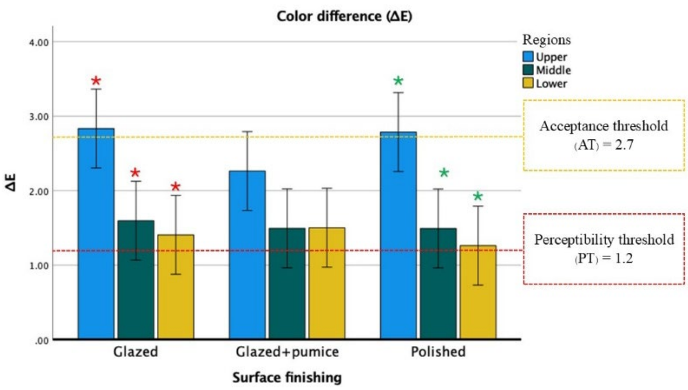

Figure 2 The bar chart of color difference (ΔE) of high-translucent zirconia following 10,000 cycles of coffee thermo-cycling, divided by different material regions and surface finishing methods. * Green indicates the significant difference between the upper and other regions in the polished group. * Red indicates the significant difference between the upper and other regions in the glazed group. The yellow horizontal line displays the acceptance threshold (AT), while the red horizontal line represents the perceptibility threshold (PT).

In terms of translucency differences (ΔTP), A two-way ANOVA revealed that following 10,000 cycles of coffee thermocycling, there was no significant difference in ΔTP between surface finishing methods and regions; see Tables 1 and 3. According to the results, TP values were slightly higher in every region of every surface finishing group. Additionally, the results showed that ΔTP values were higher than AT values in the lower and middle regions of the polished group and the upper region of the glazed group (ΔTP > 4.4) (Figure 3).

Table 3 Results of mean translucency differences (ΔTP) of high-translucent zirconia following 10,000 cycles of coffee thermocycling, divided by material regions and surface finishing methods

Surface finishing methods	Mean ± SD Upper region	Mean ± SD Middle region	Mean ± SD Lower region	P value
Glazed	7.44 ± 8.46	1.01 ± 5.71	0.63 ± 6.00	0.062
Glazed+pumice	3.55 ± 3.20	2.50 ± 8.53	0.54 ± 6.65	0.633
Polished	0.85 ± 8.41	5.52 ± 6.22	5.06 ± 5.81	0.277
P value	0.122	0.358	0.273	

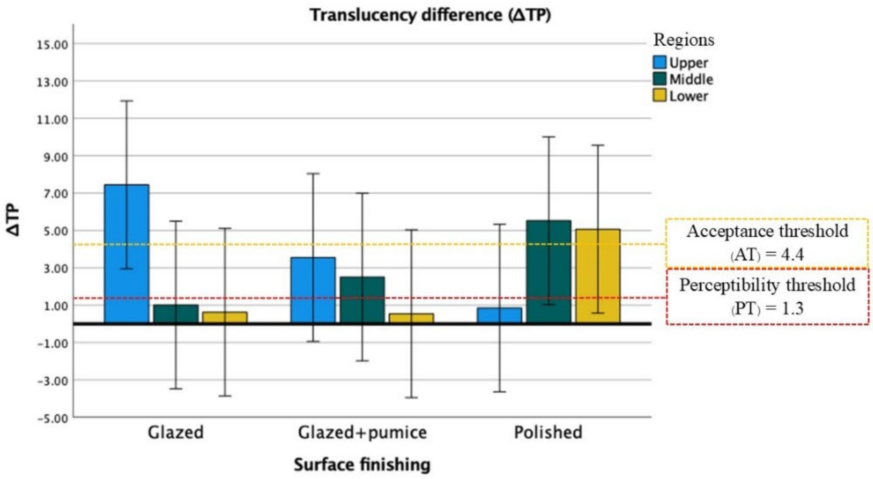

Figure 3 The bar chart translucency differences (ΔTP) following 10,000 cycles of coffee thermocycling, divided by different material regions and surface finishing methods. The yellow horizontal line displays the acceptance threshold (AT), while the red horizontal line represents the perceptibility threshold (PT).

In terms of surface roughness (Ra), the surface roughness before and after 10,000 cycles of coffee thermocycling was not significantly different, according to the paired sample t-test. Ra increased by 0.001 µm only in the glazed+pumice group after 10,000 coffee thermocycling cycles. The average surface roughness of every specimen was approximately 0.04 µm before and after 10,000 cycles of coffee thermocycling; see Figure 4.

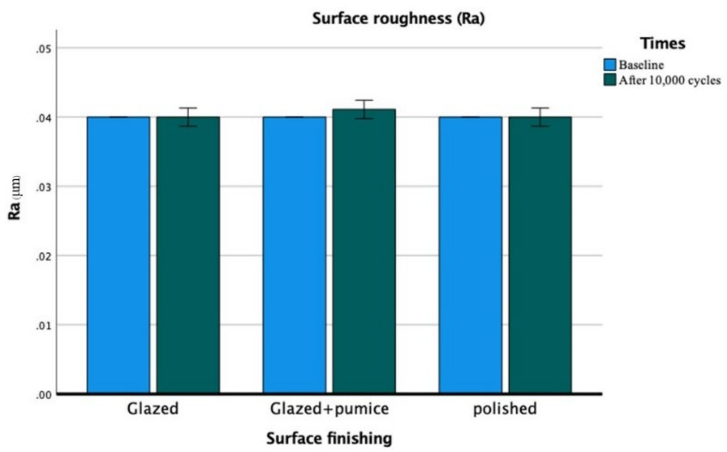

Figure 4 The bar chart surface roughness (Ra) at baseline and following 10,000 cycles of coffee thermocycling, divided by different surface finishing methods.

SEM micrographs (magnification x30,000) of each specimen group at baseline demonstrated regular surface morphology (Figure 5A, 5B, 5C). After 10,000 cycles of coffee thermocycling, the surface of the glazed+pumice group (Figure 5E) showed slight roughness compared to the baseline (Figure 5B).

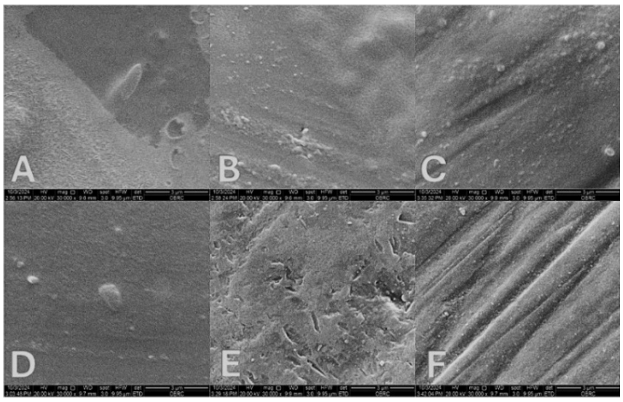

Figure 5 Scanning electron micrographs (magnification×30,000) of high-translucent zirconia at the baseline and following 10,000 cycles of coffee thermocycling of Glazed: A, D; Glazed + Pumice: B, E; Polished: C, F, respectively

4.2 Discussion

In this vitro experiment, coffee solutions were used instead of distilled water in the thermocycling machines, and it was assumed that the material surfaces were exposed to coffee 24 hours a day. However, people usually just occasionally drink coffee. Therefore, color stability may have been overestimated in this study. Meanwhile, the thermocycling procedure involves submerging the specimen in 5°C and 55°C solutions, simulating exposure to both hot and cold real-world situation temperatures.

According to ISO/CIE 11664-4:2019, color difference and translucency parameters can be calculated using CIELAB and CIEDE2000. The previous investigation found that the CIEDE2000 formula represented color differences perceived by the human eye in a manner similar to the CIELAB formula (Gómez-Polo et al., 2020). Additionally, the CIELAB (CIE L*a*b*) formula was utilized to calculate color change and translucency parameters in a previous study (Aljanobi, & Al-Sowygh, 2020), similar to this study. For this reason, we have chosen to calculate the color change and translucency parameters in this study using CIE L*a*b*.

The quality of color stability of dental material correlates largely with the magnitude and direction of color stability. The smallest color difference that can be perceived by an observer is referred to as a just-noticeable difference (JND) or the perceptibility threshold (PT). When 50% of the observers detect a color difference stability between two objects, while the other 50% do not detect, this is known as a 50:50% perceptibility threshold. Similarly, a 50:50% acceptance threshold (AT) is equivalent to the color difference deemed acceptable by 50% of observers. For color detection, visual thresholds are an essential quality-control tool. In dentistry, it is essential to maintain quality control. Ideally, color matching should be at or below PT. However, the AT value can predict product acceptability by enhancing its function and matching patient expectations for the esthetic outcome (Paravina et al., 2019).

This research demonstrated that surface finishing methods had no effect on the optical properties of the materials following 10,000 cycles of coffee thermocycling. However, the study indicated that color stability was influenced by the specimen's region; see Table 1. The upper region exhibited higher ΔE values than the other regions across all surface finishing groups, with the glazed and polished groups showed statistically significant differences in ΔE compared to the other regions; see Table 2. The aforementioned result may be related to the upper region of the GZ, which consisted of the transition zone (5Y-3Y) and showed an increase in roughness after the aging process (Koo et al., 2025). As a result, the transition zone may retain more coffee stains. However, this study did not initially incorporate zone-based surface roughness measurement techniques. Therefore, future studies should consider dividing the surface into zones based on the material for a more accurate measurement of surface roughness.

Additionally, ΔE values were higher than AT values in the upper region of the polished and glazed groups, while it was lower than AT values in the upper region of the glazed + pumice groups. These results may be attributed to the potential of pumice polishing to reduce staining, while the SEM images revealed slight surface roughness in the glazed+pumice group after 10,000 cycles of coffee thermocycling (figure 5E). However, this surface roughness did not result in a statistically significant increase in the Ra value (Figure 4). Therefore, polishing with pumice during dental recall visits may aid in removing staining from ceramic materials without causing any significant disruption to surface smoothness.

The ΔE and ΔTP results from this study demonstrated that the middle and lower regions were nearly similar; see Tables 2 and 3. This might have been caused by the measurement zone design, as the middle and lower zones were situated in the dentine zone (3Y); see Figure 1. The spectrophotometer's 5.0 mm diameter tip restricted it from being designed for locating the center of the aperture at each material zone.

A recent study on the color stainability of high-translucency monolithic zirconia with a thickness of 0.5 ± 0.02 mm reported that after 10,000 cycles of coffee thermocycling, the glazed surface exhibited the lowest ΔE compared to the polished surface (Tabatabaian et al., 2022). In contrast, the zirconia used in this study had a thickness of 1.0 ± 0.1 mm and showed no significant differences in ΔE between the different surface finishing methods. Based on these findings, the author suggests that the thickness of the zirconia specimen may influence its color stability after thermocycling in a coffee solution.

The translucency difference results of this study indicated that high-translucent zirconia exhibited a slight increase in ΔTP after 10,000 cycles of coffee thermocycling. This finding is consistent with the results of a previous study, which also reported a slight increase in ΔTP for high-translucent zirconia after 10,000 cycles of coffee thermocycling (Aljanobi, & Al-Sowygh, 2020). The slight increase in ΔTP in zirconia after the aging process may be attributed to an increase in grain size and a transformation to monoclinic form, which may occur only in the outermost layer of the material (Wang et al., 2013; Putra et al., 2017).

According to this study, no significant differences in color stability or translucency were observed among the three surface finishing methods for GZ materials. Since 10,000 cycles of coffee thermocycling, which correspond to one year of oral function (Gale, & Darvell, 1999), were used in this investigation, the author suggests that this number of coffee thermocycling cycles may not be sufficient to differentiate between the surface finishing techniques. Therefore, future studies may need to increase the number of thermocycling cycles to better assess long-term optical stability.

5. Conclusion

Within the limitations of this study, surface finishing methods did not affect the color stability or translucency of high-translucent multilayer zirconia. However, color stability was influenced by the distinct regions within the polished or glazed multilayer zirconia after 10,000 cycles of coffee thermocycling.

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