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EFFECT OF SIMULATED TOOTH BRUSHING AND ARABIC COFFEE THERMOCYCLING ON THE COLOUR OF LITHIUM DISILICATE AND TRANSLUCENT ZIRCONIA CERAMICS

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*This study evaluated and compared the effects of simulated tooth brushing and Arabic coffee thermocycling on the colour stability of lithium disilicate and translucent zirconia dental restorative materials. Sixty disc-shaped specimens (10 × 1.2 mm^2) were fabricated from zirconia and lithium disilicate (N = 30). The specimens from each material were allocated to three groups (n = 10) based on the surface interventions – simulated tooth brushing (TB), Arabic coffee thermocycling (TC), and TC followed by TB (TC+TB) – to be received. The colour of the specimens was recorded at baseline and after the interventions using a spectrophotometer in 3D CIEL*a*b* colour space. The colour difference (ΔE) between the groups was statistically analysed using an analysis of variance (ANOVA) and the least significant difference post-hoc test ($p < 0.05$). The mean ΔE for both lithium disilicate and translucent zirconia was high after all the interventions ($p < 0.05$). The mean ΔE was high after TC+TB, followed by TB, and TC for both the tested materials. The overall mean ΔE was highest (1.98 ± 0.92) in lithium disilicate after TC+TB and the least in translucent zirconia after TC (0.96 ± 0.87). In comparison with translucent zirconia, the ΔE was highest in lithium disilicate after TC+TB followed by TB and the least in TC. For the lithium disilicate group, the mean ΔE was highest after TC+TB and the least after TC ($p < 0.05$). Similarly, the mean ΔE for the zirconia group was highest after TC+TB and the least after TC ($p > 0.05$). In comparison with the translucent zirconia, the ΔE was higher in lithium disilicate demonstrating lower colour stability. In conclusion, the combined effect of simulated tooth brushing and Arabic coffee thermocycling demonstrated the highest ΔE among the interventions, irrespective of the materials tested. Although the colour differences presented in the study were clinically perceptible following the interventions, the overall differences were clinically insignificant.*

INTRODUCTION

In the past, mechanical qualities took precedence over aesthetics in dentistry. However, in recent years, dental aesthetics have become vital to a person's self-esteem [1, 2]. The unquestionable impact of social media and all digital technologies has substantially increased patient demands for obtaining a particular aesthetic image, which has increased the need for aesthetic procedures and expanded the aesthetic dental profession [3]. Aesthetic dental practices have brought various novel clinical techniques and innovations in dental materials [4]. These modern procedures with newer innovative materials are considered to fulfil both the mechanical and aesthetic requirements equally. Ceramic materials have shown the most potential for the long-term success among aesthetic materials.

Regarding physical, biological, and aesthetic qualities, lithium disilicate glass-ceramic and zirconia stand out as the commonly utilised ceramic materials [5, 6]. Due to their highly acceptable aesthetics and advantageous optical characteristics, they have been used for a range of prosthetic restorations. Ceramic restorations can be produced with various technologies, including thermal pressing, infiltrated systems, and computer-aided design and computer-aided manufacturing (CAD-CAM) systems [5]. Lithium disilicate (LD) is a glass-ceramic introduced in the late 1990s; however, in 2005, a novel formulation with smaller and more uniformly dispersed crystals was introduced as "IPS e.max Press"

(Ivoclar Vivadent) [7]. Due to their superior physical and mechanical properties, these materials were extended to monolithic restorations without veneering ceramics. They were anatomically formed, coloured by surface stains, and characterised by a higher fatigue resistance than bi-layered ones [8]. Zirconia (ZrO_2) is a classic restorative material commonly used in dentistry. In ceramic dentistry, zirconia is considered a heterogeneous, highly resistant, polycrystalline ceramic having good mechanical and favourable optical characteristics [9, 10]. Its many properties, including biocompatibility, minimal plaque retention compared to the other materials, and radiopacity, make it a better choice as a restorative material. In addition, it is not soluble in water, and its susceptibility to corrosion in the oral environment is negligible [7].

Colour stability is a crucial parameter to determine the aesthetic success of a dental restoration. Any change in colour over time may limit the longevity and quality of restorations [7, 11-13]. In general, intrinsic or extrinsic factors could affect the colour of ceramics. Extrinsic factors like beverages, mouthwashes, acidic solutions, tooth brushing, and higher temperatures are expected to cause changes in the surface degradation of ceramics. This is mainly due to the extrinsic pigment absorption or adsorption from the oral cavity, which is affected by the ceramic materials' composition and surface morphology [14]. As different materials perform differently in terms of water sorption, the possibility of pigment accumulation increases, especially when exposed to daily beverage consumption. This will vary depending on the ceramic material type [15, 16]. These material properties need to be clearly understood to unlock the reasons for the discoloration of these materials over a long period [17].

Tooth brushing is a routine activity that helps remove stains and weakly accumulated substances that have adhered to the material surface [18]. However, the mechanical effect of this alone or with other daily routines could remove the characterisation layer and negatively impact the restorations [16]. Combined with beverage consumption and other causes of ageing, it may lead to a rougher surface. Consequently, it may attract pigments and change colour [14]. Coffee is one of the popular worldwide beverages and is consumed differently in different regions of the world [18]. That said, the Saudi population consumes a particular type of coffee called Arabic coffee. It contains some additives, including saffron, ginger, and cardamom, and it has been suggested that it might be a staining factor in aesthetic restorations [1]. Previous studies have reported the effect of Arabic coffee on ceramic materials. However, the literature regarding the effect of tooth brushing and exposure to Arabic coffee and the combination of these interventions on lithium disilicate and translucent zirconia is scarce.

Therefore, this study aimed to evaluate and compare the effects of simulated tooth brushing and Arabic coffee thermocycling on the colour of lithium disilicate and translucent zirconia restorative materials. The null hypothesis is that there is no significant difference in the colour stability of zirconia and lithium disilicate materials following simulated tooth brushing, Arabic coffee thermocycling, and combined treatment involving thermocycling and tooth brushing.

EXPERIMENTAL

The details of the restorative materials used in the study are presented in Table 1.

Sixty disc-shaped specimens (10×1.2 mm^2) were fabricated from zirconia and lithium disilicate materials. For the fabrication of zirconia specimens, a stereolithography (STL) file was designed using CAD software (CARES® Visual, Straumann Holding AG, Basel, Switzerland) to standardise the design of the specimens. Thirty specimens were milled from a pre-sintered zirconia block using dry milling (Expert 5, Opera, Monaco, France). The milling process used carbide burs per the manufacturer's recommendations, followed by sintering (Programat S1/S1 1600, Ivoclar

Table 1. Details of the materials used in the study.

Material and Brand	Composition	Manufacturer
Zirconia IPS E.max ZirCad A1/Medium translucency	Zirconium dioxide (ZrO_2) 86 – 93.5 % Yttrium oxide (Y_2O_3) 6.5 – 8 % Hafnium oxide (HfO_2) ≤ 5 % Aluminium oxide (Al_2O_3) ≤ 1 % ≤ 1.0 % other oxides	Ivoclar Vivadent AG, Schaan Liechtenstein
Lithium disilicate IPS E.max Press A1/Medium translucency	Silicon dioxide (SiO_2) 57 – 80 % Lithium superoxide (Li_2O) 11 – 19 % Potassium oxide (K_2O) 0 – 13 % Phosphorus pentoxide (P_2O_5) 11 – 19 % Zirconium dioxide (ZrO_2) 0 – 8 % Zinc oxide 0 – 8 % other oxides and ceramic pigments 0 – 10 %	Ivoclar Vivadent AG, Schaan Lichtenstein

Vivadent, Schaan, Liechtenstein) [19]. The specimens were thoroughly cleaned by jet blasting using alumina particles (50 – 110 µm) at a maximum of 1.5 psi. This was followed by drying using a stream jet to remove any ZrO_2 dust to facilitate glazing (IPS Ivocolor glaze paste, Ivoclar Vivadent, Schaan, Liechtenstein).

The same STL file was used to fabricate zirconia specimens and print wax patterns to standardise the specimen dimensions for the fabrication of the lithium disilicate specimens. The STL file was transferred to a 3D printer (MAX UV, Asiga, NSW, Australia), and the wax pattern was printed using 3D print resin (Optiprint cast, Dentona AG, Dortmund, Germany) as per the desired dimensions (Figure 1).

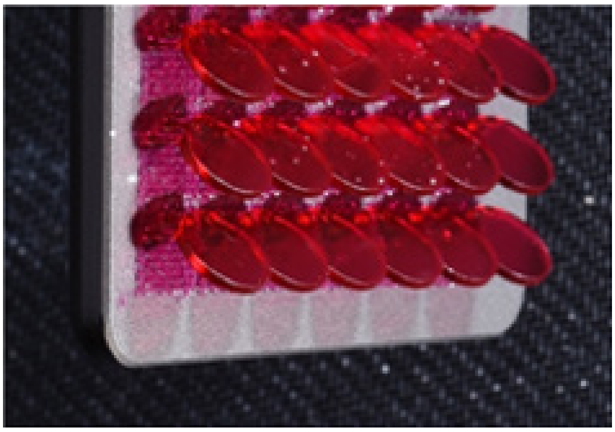
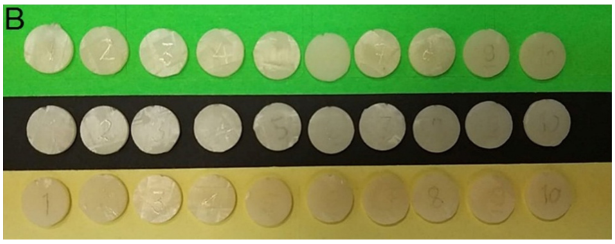


Figure 1. 3D printed wax patterns.

The disc-shaped wax patterns were then sprued and invested using a universal phosphate-bonded investment material (IPS PressVest, Ivoclar Vivadent, Schaan, Liechtenstein). The investment was placed in a preheating furnace (Ultramat 500, Teknik Dental, Topkapı, Istanbul) to eliminate the wax, and the IPS E.max ingot was pressed in the pressing machine (Programat-EP 3010, Ivoclar Vivadent, Schaan, Liechtenstein) [19]. The specimens were sandblasted with 110 microns of alumina particles at 1.5 psi. Then, the specimens were cleaned in an ultrasonic bath (IPS E.max Press Invex Liquid, Ivoclar Vivadent, Schaan, Liechtenstein) for 15 minutes at 40 °C followed by sandblasting with 60 microns of alumina at 1.5 psi before glazing. The final dimensions of the glazed specimens were verified using Holex digital callipers (Sorotec GmbH, Rheinmünster, Germany).

All the specimens were stored in deionised water in a digital incubator (JSGI-150T, JSR, General Incubator, Gongju-City, South Korea) at 37 ± 1 °C for 24 hours before the baseline colour measurements and surface interventions [2]. The prepared specimens from zirconia (Figure 2a) and lithium disilicate (Figure 2b) were allocated to three groups (n = 10) based on the surface interventions to be received.

a) Zirconia



b) Lithium disilicate

Figure 2. Prepared specimens.

a) Group 1 (TB): The specimens were brushed in a tooth brushing simulating machine (SD Mechatronik GMBH, Feldkirchen-Westerham, Germany) equipped with a soft nylon bristle brush (Tara Toothbrush Company, Dammam, Saudi Arabia). The toothbrushing containers were filled with a slurry of toothpaste (Colgate® Optic White®, Colgate-Palmolive Co., Jeddah, Saudi Arabia) and distilled water mixed at a ratio of 1:1. A total of 1,60,000 brushing cycles were applied to simulate ten years of ageing. The brushing parameters included a load of 2 N with a 10 mm travel length and speed of 5 mm·s^{-1} [12, 18, 20].

b) Group 2 (TC): The specimens were thermocycled in a simulation device (Thermocycler 1100, SD Mechatronik GMBH, Feldkirchen-Westerham, Germany) containing an Arabic coffee beverage. The thermocycler bath was set at 5 °C and 55 °C with a transfer time of 10 s and a dwell time of 30 s [2]. The specimens were aged for 4582 cycles to simulate ten years of ageing in the oral cavity [2]. The Arabic coffee beverage was prepared as per the manufacturer's instructions by dissolving 5 g of coffee powder (Baja Moderate, Baja, Riyadh, Saudi Arabia) into 150 ml of boiling water and continuously stirring to dissolve the coffee powder properly [1].

c) Group 3 (TC+TB): As detailed above, the specimens were exposed to a combined intervention involving TC and TB.

The specimen distribution and interventions applied are presented as a flowchart in Figure 3.

A benchtop spectrophotometer (LabScan XE, Hunter Associates Laboratory, Inc, Reston, VA, USA) was used to measure the specimens in CIELab colour space [16]. The specimens were placed in a custom-made holder and scanned at three different positions (0°, 90° and 180°) against a white background under D65 illumination as stipulated by the International Organization for Standardization (ISO) number ISO/

TR 7491:2000 standard [21]. The average of the three readings determined the colour of that specific specimen. The colour difference was calculated using the following formula [18].

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

L_1*, a_1* and b_1* are the colour readings at baseline and L_2*, a_2* and b_2* are the colour readings after surface intervention. L denotes the distinction between light and dark shade, a denotes the distinction between the red and green chromatic scale, and b denotes the distinction between the amount of yellow and blue [18]. According to Paravina et al. [22], the stated values for the CIELab 50 % perceptibility threshold (PT) is ΔE = 1.2, and the CIELab 50 % acceptability threshold (AT) is ΔE = 2.7. Any ΔE reading over the AT limit is clinically unfavourable.

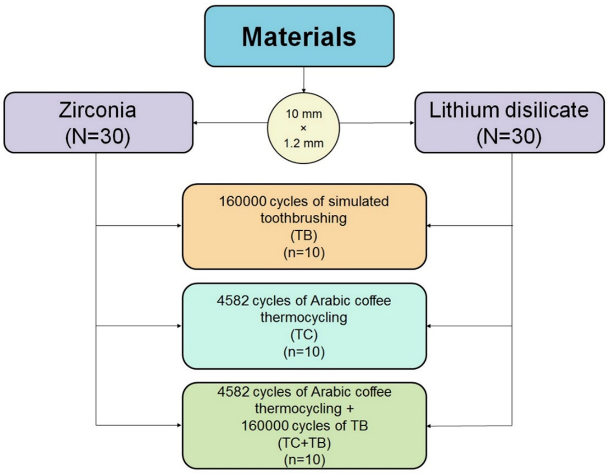


Figure 3. Flowchart illustrating specimen allocation and interventions applied.

The ΔE data collected was analysed using statistical software (IBM SPSS v.22, IBM Corp, Armonk, NY, USA). The Shapiro-Wilk test showed normal distribution of the ΔE data; hence, parametric tests were applied for the statistical analysis. The mean and standard deviation were used to present the descriptive findings. A one-way analysis of variance (ANOVA) was used to compare the mean ΔE between the interventional groups. The least significant difference post hoc test was used for multiple comparisons between the interventional groups ($p \leq 0.05$).

RESULTS AND DISCUSSION

The two-way ANOVA demonstrated that the independent factors, namely the material type, and interventions, revealed that each factor significantly affected the ΔE ($p \leq 0.05$). However, the interaction between the factors did not significantly affect the ΔE ($p = 0.088$) (Table 2).

A descriptive analysis of ΔE for the tested materials following the interventions is presented in Table 3. The mean ΔE was the highest in lithium disilicate after TC+TB (1.98 ± 0.92) and the least in translucent zirconia after TC (0.96 ± 0.87). Considering the interventions, ΔE was the highest after TC+TB, followed by TB, and the lowest in TC for lithium disilicate and translucent zirconia. Compared with translucent zirconia, ΔE was higher in lithium disilicate for all the surface interventions.

Table 4 presents the mean comparison of ΔE between the materials for the different interventions.

The mean ΔE significantly differed between the two materials for all the surface interventions ($p < 0.05$).

Multiple comparisons of the ΔE between the interventions for the study materials are presented in Table 5. The mean ΔE showed no statistically significant difference between the interventions for the translucent zirconia material ($p > 0.001$). On the contrary, a significant difference was observed between TB and TC ($p = 0.009$) and between TC+TB and TC ($p = 0.001$) for the lithium disilicate material. However, no statistically significant difference was seen between TB and TC+TB ($p = 0.503$).

Figure 4 presents the ΔE values of the materials concerning the AT and PT limits. The ΔE values of zirconia material following TB and TC were below the PT limit (ΔE < 1.2), but the combined effect of TB+TC demonstrated ΔE values above the PT limit.

Table 2. Two-way analysis of variance of the ΔE.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	28.065[a]	5	5.613	10.145	0.000
Intercept	337.678	1	337.678	610.331	0.000
Material	17.873	1	17.873	32.305	0.000*
Interventions	7.460	2	3.730	6.741	0.002*
Material * Interventions	2.732	2	1.366	2.469	0.088
Error	96.269	174	0.553	-	-
Total	462.011	180	-	-	-
Corrected Total	124.334	179	-	-	-

*Statistically significant at $p < 0.05$

Table 3. Descriptive analysis of the ΔE for the tested materials.

Material	Group	Mean	SD	Std. Error	95 % CI	
					Lower Bound	Upper Bound
Zirconia	TB	1.01	0.48	0.14	0.74	1.28
	TC	0.96	0.87	0.14	0.69	1.23
	TC+TB	1.20	0.32	0.14	0.93	1.46
Lithium disilicate	TB	1.83	1.05	0.14	1.56	2.10
	TC	1.24	0.54	0.14	0.97	1.51
	TC+TB	1.98	0.92	0.14	1.71	2.25

Table 4. Two-way analysis of variance of the ΔE.

Interventions	Materials		Sig.
	Zirconia	Lithium disilicate	
TB	1.01 ± 0.48	1.83 ± 1.05	0.000*
TC	0.96 ± 0.87	1.24 ± 0.54	0.004*
TC+TB	1.20 ± 0.32	1.98 ± 0.92	0.000*

*Mean difference between the materials is statistically significant at $p < 0.05$

Table 5. Multiple comparison of the ΔE between the interventions for the study materials.

Group (I)	Group (J)	Mean Difference (I-J)	Std. Error	Sig.	95 % CI	
					Lower Bound	Upper Bound
Zirconia						
TB	TC	0.05	0.16	0.73	-0.26	0.36
TB	TC+TB	0.19	0.16	0.24	-0.12	0.49
TC+TB	TC	0.24	0.16	0.128	-0.07	0.55
Lithium disilicate						
TB	TC	0.59	0.22	0.009*	0.15	1.04
TB	TC+TB	0.15	0.22	0.503	-0.29	0.59
TC+TB	TC	0.74	0.22	0.001*	0.30	1.19

*Mean difference between the interventions is statistically significant at $p < 0.01$

On the contrary, lithium disilicate material demonstrated ΔE values above the PT limit for all the interventions. However, the values were well below the AT limit (ΔE = 2.7).

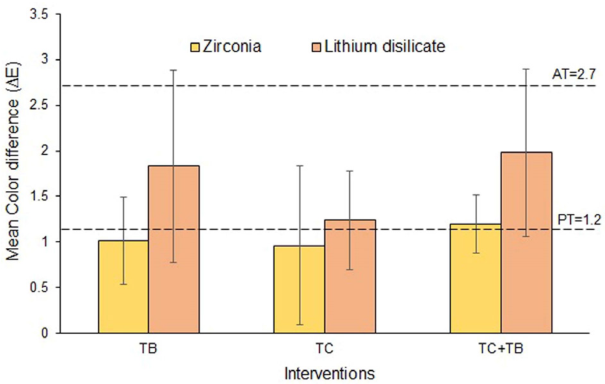


Figure 4. Mean ΔE of the materials following different interventions. Bars indicate the SD. The dotted line indicates the perceptibility threshold (PT) and acceptability threshold (AT).

The success of a restorative treatment outcome is based on the aesthetics and the function it provides. The position, contour, texture, and colour are the four fundamental aspects that determine the aesthetics of a restoration [23]. The present study investigated and compared the effect of simulated tooth brushing and Arabic coffee thermocycling on the colour stability of the most commonly used ceramic materials, translucent zirconia, and lithium disilicate. The null hypothesis is that there is no significant difference in the colour stability of zirconia and lithium disilicate materials following surface interventions, which was rejected as there was a significant difference in the colour stability between the tested materials.

The exposure of dental materials to the ageing process and its effect on the surface and optical properties, specifically on the colour, is an essential aspect from an aesthetic point of view [24]. The results obtained have more significant clinical implications so that patients can understand the impact of their daily activities on the aesthetic quality and longevity of their restorations. The current study found that the ΔE mean was the highest in lithium disilicate after TB (1.98 ± 0.92) and the least in translucent zirconia after TC (0.96 ± 0.87). Similar to the present outcome, a previous study showed that tooth brushing brought about colour differences in lithium disilicate (e.max Press) after a simulation of a period of 12 years. Nevertheless, these changes were not clinically relevant. They also reported a possible protective effect provided by the glaze, which led to the lower effect of brushing on the ceramic [14]. Another study also observed that exposure to Arabic coffee resulted in a significant difference in the mean ΔE before and after immersing in Arabic coffee for all the materials and thicknesses used. They also noted significant differences in colour changes between glazed and polished specimens. It was further concluded that the colour change caused by the Arabic coffee was not significantly related to the specimens' thickness [1].

Previous studies [25, 26] showed that zirconia material surfaces had a homogeneous, fine, rod-like crystalline structure with an average crystal size of approximately 0.5 mm. At the same time, lithium disilicate material surfaces showed needle-shaped crystals with an average crystal size of approximately 1.5 mm. This difference in the surface changes with larger crystal particles and the more heterogeneous structure of lithium disilicate compared to zirconia. This explains the minor colour change observed in the translucent zirconia compared to the lithium disilicate in the present study. The results of the present study also agree with the findings of Alp et al. [27], where they concluded that the material type significantly affected the colour stability. However, the ΔE values of all the materials in the previous study were below the clinical acceptability threshold (< 1.8 units).

Perceptibility refers to detecting the colour difference between a tooth and an adjacent coloured restoration, while acceptability refers to the colour difference that would be acceptable for that restoration [22]. Although the colour difference was seen in the present study, it was well below the acceptability threshold of the colour [16, 22]. If the colour differences are evaluated as to the perceptibility and acceptability thresholds, which can serve as a quality control to guide the selection of dental materials in vivo and dictate to us regarding its clinical performance [13, 28], both materials closely fall within the range of acceptability.

In the present study, the mean values of the colour changes after exposure to tooth brushing and Arabic coffee thermocycling were within the AT. The ΔE was higher after TC+TB, followed by TB or TC alone. Similar results were observed by Yuan et al., where the authors concluded that the effect was related to the synergistic effect of three interventions on the specimens in the wet environment [16]. Wetness has been shown to increase the rate of low-temperature degradation, and this degradation process has been associated with modifications in the mechanical behaviour, such as increased wear rate and surface roughening, which, in turn, affects the mechanical and aesthetic outcomes, especially the colour changes [29].

Tooth brushing is a routine activity that removes stains and accumulated debris that have weakly adhered to the surface of the dental material. However, it was shown in previous studies that, irrespective of surface treatment, brushing did not significantly change the staining or degradation caused by the solutions, suggesting that the observed changes occurred at a structural and permanent level [20]. The present study results do not agree with the study of Yuan et al. [16], in which they demonstrated no influence of intervention and simulated years or their interaction on the colour differences of lithium disilicate CAD specimens. Furthermore, in another study [30], lithium silicate-based and lithium disilicate-based ceramic materials were more colour-stable than other resin materials exposed to coffee and red wine. Colour changes were more significant than the acceptability threshold after immersion in coffee. The differences in the observed results were directed to different study designs, protocols, and exposure to ageing process materials.

In the current study, tooth brushing and Arabic coffee thermocycling were chosen to mimic the real-life exposure of the materials. The experimental design used in the present study is time-tested with few drawbacks and close to the natural exposure during an individual's daily routine. Thus, the study design used in the present study is well-justified and acceptable. The present study assessed the colour change using a spectrophotometer. A spectrophotometer measures CIELab values, giving a numerical representation of the 3D colour measurement. The specimens' dimensions used in the present study had a diameter of 10 mm and a thickness of 1.2 mm, which is similar to previous studies [16, 31]. In a study by Yuan et al. [16], using different material thicknesses did not show a significant difference; all the colour changes seen were within the limits of the colour acceptability range. Thus, the thickness of the material used in the present study is justified.

The current study has a few limitations. It is an *in vitro* study, and thus, the outcome may not precisely replicate oral conditions since the ageing process is not a limited exposure study as it occurs in the *in vitro* experiment. The material, once cemented, may undergo changes with exposure to different materials. Thus, long-term clinical studies are necessary to support the outcome. Only one type of zirconia and one type lithium disilicate were used in this study, and they were both from the same manufacturer. However, different generations and types of these materials have different formulations, which could affect the outcome. The material in the present study was exposed from both surfaces.

However, in the oral cavity, the material is bonded with selected luting materials to the tooth structure and exposed to different types of liquids on one side. The changes seen in the present study may have an exaggerated effect compared to the actual clinical scenario. In the present study, only one thickness of the disc-shaped specimens was used. However, in the actual clinical situation, there may be variations in the thickness of the materials being used, ranging from 0.9 to 2 mm.

Future studies should include the exposure of materials to different agents that can closely mimic the actual scenario in the oral cavity. Different genera-tions of materials have different formulations and molecular structures. Comparing these materials or the same generation from different manufacturers could provide a more comprehensive overview of the material behaviour. Since the material's thickness may vary, incorporating these aspects with different thickness factors will help to develop an outcome that is more beneficial to clinical practice. The specimens' design could resemble the crowns/veneers used in the oral cavity for a closer outcome than the disc-shaped specimens used in the present study.

CONCLUSIONS

Compared with translucent zirconia, the ΔE value was higher in lithium disilicate with perceptible colour changes recorded after each intervention. Translucent zirconia showed better colour stability compared to lithium disilicate after each intervention. Although some recorded colour differences in the study were perceptible, the ΔE differences were clinically insignificant. The highest colour change was caused by the combined effects of TC+TB, followed by TB, and a minor effect was after TC for both the materials tested.

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