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EVALUATION OF COLOR CHANGE FOR DENTAL CERAMICS BY CIELAB AND CIEDE2000 FORMULAS; AN IN VITRO STUDY

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ABSTRACT

Aim: This study aimed to evaluate the efficiency of the CIELAB and CIEDE2000 formulas for measurements color change of lithium disilicate (LD) and zirconia reinforced lithium silicate (ZL) ceramics after immersion in different mouthwashes.

Materials and Methods: Fifty disc shaped samples (5X2mm) were prepared, 25 samples for each group, LD (Group A): E-max and ZL (Group B): Suprinity. The samples were subdivided into 5 subgroups (n=5) according to the immersion type; distilled water, chlorhexidine, iodopovidone, green tea and whitening mouthwashes, for subgroups I-V respectively. Samples were stored separately in their corresponding immersion solution. The samples were evaluated by clinical spectrophotometer before and after immersion. Changes in color (ΔE) were calculated using CIELAB and CIEDE2000 1:1:1 and 2:1:1 formulas. Then, comparisons between ΔE values versus corresponding acceptable threshold (AT) and correlation between them were calculated.

Results: The comparisons by one sample t-test for the values of ΔE_{lab}, ΔE_{2000} and ΔE_{20002} versus their corresponding AT displayed significance between ΔE_{lab} values and AT in subgroups III-V in group A and III and V in group B. A significance difference between ΔE_{2000} values and AT displayed in subgroups III and V for both groups. The $\Delta E_{lab,}$ ΔE_{2000} and ΔE_{20002} values showed significantly strong positive correlation between each other.

Conclusion: The ΔE_{20002} was more efficient than ΔE_{lab} and $\Delta E_{2000.}$ Using iodopovidone and pyrophosphate based mouthwashes could cause more dramatic changes in color of LD higher than ZL. Despite the strong correlation between ΔE values, ΔE_{lab} cannot always be used to estimate ΔE_{2000} and ΔE_{20002} findings.

KEYWORDS: CIELAB, CIEDE2000, lithium disilicate, mouthwashes and zirconia reinforced lithium silicate

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INTRODUCTION

Dental ceramic materials are widely used by prosthodontics for their excellent aesthetic, high physical and mechanical properties. Lithium disilicate ceramics (LD) and zirconia reinforced lithium silicate ceramic (ZL) are commonly used as full crowns and veneers in high aesthetic bearing areas. However, attention for long term stability in the oral environment should be considered.[1]

Nowadays, color stability for aesthetic restorative material has gained a particular interest from both dentist and patient. [2] Various factors can affect the color stability of dental ceramics, particularly the types that contain a glassy phase in their microstructure. Foods, beverages and chemical agents in oral hygiene maintaining products are contributing to color changing of dental ceramics. Numerous mouthwashes are available, over the counter (OTC), without medical prescription. Mouthwashes acquired an extent of concern in changing color on account of being used by patients for long periods of time, disrespecting the dentist and manufacturer instructions. [3, 4]

The color of an object is detected in the human eye by the retina. The light reflected from an object's surface stimulates cones and rods in the retina, which transfer the stimulus to the optical nerve, then to the brain, which can distinguish the colors.[5] The retinal rods detect the brightness and they have achromatic vision of the object, while the retinal cones have photosensitive pigments for color detecting. The retinal cones are three types. They can respond selectively according to the wavelength of the primary colors, then, transfer a combined stimuli to create all colors in the visible spectrum. For that reason, normal color vision can be termed as trichromatic vision.[5, 6]

Dentally, color can be measured by various methods: visual methods, in aid of shade guides, and instrumental methods, in aid of colorimeters, spectrophotometers and intraoral scanners.[6, 7] The visual method is subjective and depends on many factors, such as the surrounding environments, light source, the optical properties of the material examined, the observer's visual apparatus and its perception of color involved in these factors.[8] On the other hand, instrumental method is objective, repeatable, reliable and can recognize small color discrepancies superior to the human observer.[9]

Colors are commonly described by Munsell color system in three dimensions: hue (H), chroma (C) and value (L). Hue is referred to as the dominant wavelength detected by the eye, while the chroma is the intensity of the hue and the value is the brightness or darkness of the hue.[10] Another common system to describe the color is the CIE Lab system, which is described by the Commission International de I'Eclairage (CIE) organization. The CIE Lab color space system is based on trichromatic normal vision, where L^* is the value axis, a^* is the red-green axis and $b^*$is the yellow-blue axis. The CIE organization also introduced illumination standardization and color difference (ΔE) concepts, which are used to measure the color changes.[11, 12]

Color difference can be calculated by various formulas. The CIELAB formula (ΔE_{lab}), introduced in 1976, is the most commonly used formula in the dental field. However, the efficacy of this formula is questionable. Aiming to improve the relation between calculated and perceived color change, the CIEDE2000 formula (ΔE_{2000}) is introduced.[13] This formula includes hue, chroma and S_L, S_C, S_H weighting functions. Parametric factors K_L, K_C and K_H are also involved in the calculation. The K_L, K_C, K_H are correction terms for experimental conditions that can be estimated as 1:1:1 or 2:1:1, respectively. Previous studies assumed that ΔE_{2000} might be more accurate for color change judgments than ΔE_{lab}.[14, 15] However, limited studies on K_L value exists.

Moreover, the perceptibility threshold of color difference (PT) and the acceptability threshold of color difference (AT) are two important concepts that occupied great attention in color change studies. Regarding ISO/TR 28642[16], the 50:50% PT referred to the difference in color that can be disclosed by half of the viewers and the other half noticing no difference between the compared matters. While 50:50% AT referred to the difference in color that can be count acceptable by half of the viewers and the other half replacing or correcting the restoration. Both concepts correlate between visual judgments of the viewer and instrumental color change values allowed by color difference formulas.[17]

Considering the gap of information regarding the efficiency of the CIELAB, CIEDE2000 formulas and K_L value, this study proceeded to evaluate the efficiency of CIELAB and CIEDE2000 formulas for measurements of color change of lithium disilicate (LD) and zirconia reinforced lithium silicate (ZL) ceramics after immersion in chlorhexidine (CHX), iodopovidone (IPV), green tea (GT) and tetrapotassium pyrophosphate/pentasodium triphosphate whitening (TPW) mouthwashes.

The first null hypothesis of our study was that immersion of LD and ZL ceramics in mouthwashes did not raise the ΔE values exceeding the AT. The second null hypothesis was that the efficiency of the CIELAB(ΔE_{lab}), CIEDE2000 (1:1:1) (ΔE_{2000}) and CIEDE2000 (2:1:1) (ΔE_{20002}) formulas were similar. The third null hypothesis was that correlations between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} values were nonsignificant.

MATERIALS AND METHODS

Sample size calculation

Based on previous study of Alpkilic *et al*, 2021[18], the calculated effect size was f=1.09. Accordingly, sample size was calculated by G*Power software (G*Power 3.1.9.7) with a power of 80% and a 0.05 significance level. A minimal of 30 total samples (n=3) was found to be sufficient. The authors added 2 samples in each subgroup for confirmation of the results. Consequently, the total number of samples used in this study was 50, 25 samples for each group, n=5 in the subgroup.

Sampling and grouping

Lithium disilicate ceramic (LD) (IPS e.max ceram, Ivoclar- Vivadent AG, Germany) and zirconia reinforced lithium silicate ceramic (ZL) (VITA SUPRINITY pc, VITA Zahn fabric, Bad Säkingen, Germany) were used in this study and distinguished as group A and B, respectively. Fifty disc samples of 5mm diameter and 2mm thickness were milled, 25 samples for each ceramic type. Then, the discs were processed for crystallization, finished and polished regarding their manufacturer's instructions. After that, all samples were ultrasonically cleaned for 10 minutes in water bath. Discs in groups A and B were divided randomly into 5 subgroups I-V (n=5), Distilled water (control), chlorhexidine (CHX), iodopovidone (IPV), green tea (GT) and tetrapotassium pyrophosphate/pentasodium triphosphate whitening (TPW) mouthwashes respectively. The pH of the mouthwashes was measured using pH meter. The composition and pH of the mouthwashes are shown in table (1).

Immersion protocol:

Each sample was stored in a separate container filled with 20ml of distilled water, which was renewed twice daily for 90 days. Subgroups II-V samples were soaked with agitation in 10 ml of fresh equivalent mouthwash for 1 minute every 12 hours to match the patient usage twice daily during the test period. [19]

Color changes

The color of each sample was determined by a clinical spectrophotometer (VITA Easy shade ® V, VITA Zahanfabrik H. Rauter Gmbh & Co.KG, Bad Säckingn, Germany) before (T_0) and after (T_1) the end of immersion period. One operator performed the measurements on a standard black

TABLE (1) Composition, manufacturer and pH of the mouthwashes.

Mouthwash	**Manufacturer**	**Composition**	**pH**
Chlorhexidine mouthwash (Orovex)	Macro capital, Egypt	Thymol, Menthol, Glycerine, Sodium Fluoride, Chlorhexidine and Sodium Saccharine.	6.6
Iodopovidone mouthwash (BETADINE)	El- Nile Co. Cairo	Iodopovidone 1%, Glycerine, Sodium Saccharine, Ethyle alcohol, Sodium hydroxide, Methyl salicylate, Menthol and Purified water	3.5
Green tea mouthwash (Listerine, Green tea)	Johnson & Johnson, Italy	Aqua, Propylene Glycol, Sorbitol, poloxamer 407, Sodium Lauryl Sulphate, Sodium Saccharin, Aroma, Eucalyptol, Benzoid Acid, Sodium Benzoate, Methyl Salicylate, thymol, Sodium Fluoride, Menthol, Sucralose, Camellia Sinensis Leaf Extracts, Caffeine, CI 47005, CI 42053, contains sodium fluoride (220 ppm F).	4.8
Whitening mouthwash (Listerine ,Advanced white)	Johnson & Johnson, Italy	Aqua, Sorbitol, Propylene Glycol, Tetrapotassium Pyrophosphate, Pentasodium Triphosphate, Citric Acid, Poloxamer 407, Aroma, Sodium Methyl Cocoyl Taurate, Caprylyl Glycol, Eucalyptol, Thymol Sodium, Saccharin, Menthol, Sodium Fluoride, Sucralose, Contains Sodium Fluoride (220 ppm F).	6.5

background. The device was adjusted according to instructions of manufacturer on tooth single measurement mode and the tip was held at a 90° angle to the disc. Three readings for each sample were done at each time and the mean values of L*, a* and b* values were recorded as the sample reading. The total color change was calculated regarding to the CIELAB(ΔE_{Lab}) formula (1), CIEDE2000 (ΔE_{2000}) (1:1:1) and CIEDE2000 (ΔE_{20002}) (2:1:1) formulas (2)

$$\Delta E_{Lab}=\sqrt{(\Delta L*)^2+(\Delta a*)^2+(\Delta b*)^2} \quad (1)$$

Where: $\Delta L^*= L(T_1) - L(T_0)$, $\Delta a^*= a(T_1) - a(T_0)$ and $\Delta b^*= b(T_1) - b(T_0)$

The AT considered as ΔE_{Lab}=2.7

$$\Delta E_{2000}=\sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2+\left(\frac{\Delta C'}{K_C S_C}\right)^2+\left(\frac{\Delta H'}{K_H S_H}\right)^2+R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)} \quad (2)$$

Where $\Delta L'= L(T_1) - L(T_0)$, $\Delta C'= C(T_1) - C(T_0)$, $\Delta H'= H(T_1) - H(T_0)$, R_T is the rotation function that accounts for the interaction between C and H differences in the blue region, S_L, S_C, S_H are weighting functions that adjust the total color difference for variation in the location of the color difference pair in L*, a*, b* coordinates and finally the parametric factors K_L, K_C, K_H are correction terms for experimental conditions that can be estimated as 1:1:1 or 2:1:1, respectively, for ΔE_{2000} and ΔE_{20002} . The AT is considered as ΔE_{2000}=1.8 and ΔE_{20002}=1.78.

Statistical analysis

The results were collected, tabulated and statistically analysed using SPSS software version 26. Descriptive statistics were done for parametric quantitative data by mean and standard deviation (SD). The ΔC, ΔH, ΔL, Δa, Δb, ΔE_{lab}, ΔE_{2000} and ΔE_{20002} values were analysed between subgroups within each group with one- way ANOVA, Post-hoc Tukey comparison was done. A $P \leq 0.05$ was accepted as statistically significant. Analysis was done for parametric quantitative data between the two groups using an independent sample t-test and one sample t-test was done to compare the AT value for ΔE of each formula and its corresponding. Moreover, Pearson correlation coefficient was used for the correlation calculation between different parameters.

RESULTS

Among group A results, the ΔC mean values of all subgroups were statistically significant to each other, excluding subgroups II and IV, which were statistically nonsignificant to each other. The ΔH mean values of subgroup II and V were statistically significant to each other and to all other subgroups, excluding subgroup V, which was statistically nonsignificant to IV. Among group B results, the ΔC mean values of subgroups III and V were statistically significant to each other and all other subgroups, excluding subgroup V, which was statistically nonsignificant to IV. The ΔH mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to III.

Comparing ΔC mean values between groups, subgroups I, III and IV were statistically significant between groups A and B. Comparing ΔH mean values between groups, all subgroups except subgroup II were statistically significant to each other between groups A and B. Table (2) Figure (1)

Moreover, among group A results, the ΔL mean values of subgroups III and V were statistically significant to each other and to the other subgroups. The Δa mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to III. The Δb mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to IV. Among group B results, the ΔL mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to IV. The Δa mean values of all subgroups were statistically significant to each other. The Δb mean values of subgroups III and V were statistically significant to each other and to the other subgroups.

Comparing ΔL and Δb mean values of group A to the corresponding values in group B, subgroups I, III and IV were statistically significant. Comparing Δa mean values between groups, subgroups I, III and V were statistically significant between groups A and B. Table (3) Figure (2)

For ΔE measurements, among group A results, the ΔE_{lab} mean values of subgroup III was statistically significant to all other subgroups. Subgroup I was statistically nonsignificant to II and subgroup IV was statistically nonsignificant to V. The ΔE_{2000} mean values of subgroups III and V were statistically significant to each other and all other subgroups, excluding subgroup V, which

TABLE (2) The mean and SD of ΔC and ΔH for groups and subgroups

Subgroups \ Groups	Group A				Group B			
	ΔC		ΔH		ΔC		ΔH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
I	$0.28^{d,A}$	0.12	$0.41^{c,A}$	0.18	$1.35^{c,B}$	0.32	$0.06^{d,B}$	0.05
II	$1.34^{c,A}$	0.23	$1.40^{a,A}$	0.22	$1.30^{c,A}$	0.13	$1.20^{b,A}$	0.07
III	$11.58^{a,A}$	1.01	$0.29^{c,A}$	0.16	$3.91^{a,B}$	0.97	$1.24^{b,B}$	0.09
IV	$1.28^{c,A}$	0.19	$0.61^{b,c,A}$	0.11	$2.12^{c,b,B}$	0.62	$0.45^{c,B}$	0.06
V	$3.33^{b,A}$	0.47	$0.87^{b,A}$	0.31	$2.81^{b,A}$	0.44	$1.65^{a,B}$	0.13

Subgroups with different small letters in the same column are significant.

Subgroups with different capital letters in the same row through the same parameter are significant

TABLE (3) The mean and SD of ΔL, Δa and Δb for groups and subgroups

Subgroups \ Groups	Group A						Group B					
	ΔL		Δa		Δb		ΔL		Δa		Δb	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
I	$-1.56^{b,A}$	0.70	$0.32^{b,A}$	0.13	$0.24^{c,A}$	0.11	$-0.22^{b,B}$	0.09	$0.11^{c,B}$	0.05	$1.35^{b,B}$	0.32
II	$-1.44^{b,A}$	0.76	$1.08^{a,A}$	0.18	$1.26^{b,A}$	0.23	$-2.10^{c,A}$	0.78	$1.22^{b,A}$	0.08	$1.22^{b,A}$	0.13
III	$-13.58^{c,A}$	3.32	$1.16^{a,A}$	0.11	$11.50^{a,A}$	1.01	$-5.20^{d,B}$	0.76	$1.44^{a,B}$	0.13	$3.82^{a,B}$	0.97
IV	$-3.64^{b,A}$	1.01	$-0.34^{c,A}$	0.09	$1.34^{b,A}$	0.18	$-1.70^{c,B}$	0.52	$-0.34^{d,A}$	0.05	$2.14^{b,f,B}$	0.62
V	$4.74^{a,A}$	0.87	$-0.84^{d,A}$	0.21	$-3.24^{d,A}$	0.50	$3.54^{a,A}$	0.87	$-1.78^{e,B}$	0.13	$-2.68^{c,A}$	0.44

Subgroups with different small letters in the same column are significant.

Subgroups with different capital letters in the same row through the same parameter are significant

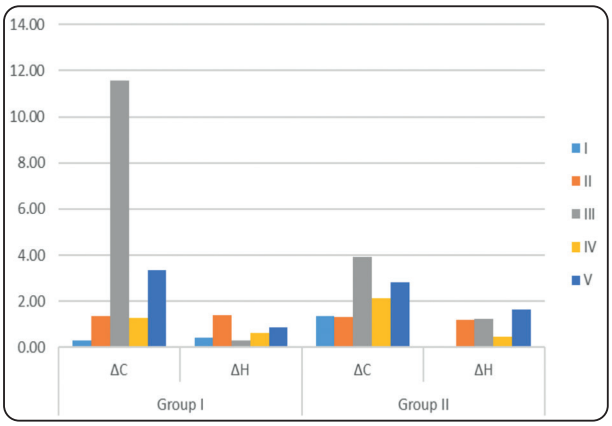

Fig. (1) Bar chart for means of ΔC and ΔH for groups and subgroups

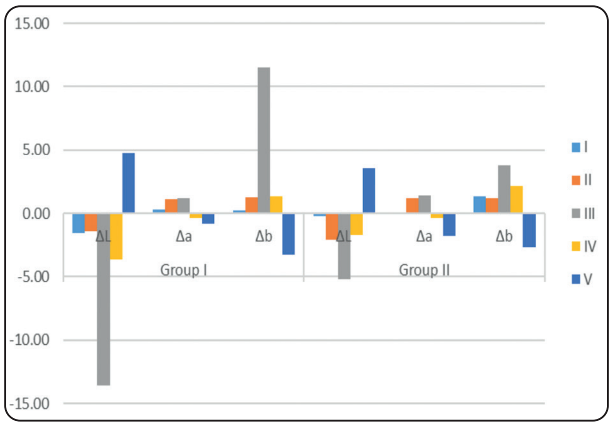

Fig. (2) Bar chart for means of ΔL, Δa and Δb for groups and subgroups

was statistically nonsignificant to IV. The ΔE_{20002} mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to IV. Among group B results, comparing the subgroups to each other, the ΔE_{lab}, ΔE_{2000} and ΔE_{20002} mean values of all subgroups were statistically significant to each other, excluding subgroup II, which was statistically nonsignificant to IV. Table (4)

Comparing ΔE_{lab} and ΔE_{2000} means in group A to the corresponding values in group B, subgroups III-V were statistically significant. For ΔE_{20002} mean values subgroups III and V only were statistically significant between group A and B. Table (4), Figure (3).

Furthermore, comparing the $\Delta E_{lab,}$ ΔE_{2000} and ΔE_{20002} mean values within the same group, for group A, ΔE_{lab}, ΔE_{2000} and ΔE_{20002} were statistically significant to each other in subgroups II-V. In subgroup I, ΔE_{lab} was only significant to ΔE_{20002}. In group B, ΔE_{lab}, ΔE_{2000} and ΔE_{20002} were significant to each other in subgroups III-V. For subgroups I and II, the significance was only between ΔE_{lab} versus both ΔE_{2000} and ΔE_{20002}.

Additionally, ΔE_{lab} mean values of subgroups III-V and subgroups II-V, through group A and B respectively, were higher than the AT (ΔE_{lab}=2.7). The ΔE_{2000} mean values of subgroups III-V and subgroups II, III and V, in groups A and B respectively, were higher than the AT (ΔE_{2000}=1.8).

TABLE (4) The mean and SD of $\Delta E_{lab,}$ ΔE_{2000} and ΔE_{20002} for groups and subgroups

Groups / Subgroups	Group A						Group B					
	ΔE_{lab}		ΔE_{2000}		ΔE_{20002}		ΔE_{lab}		ΔE_{2000}		ΔE_{20002}	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
I	$1.64^{d,A}$	0.65	$1.08^{c,A}$	0.38	$0.66^{d,A}$	0.15	$1.37^{d,A}$	0.33	$0.58^{d,A}$	0.14	$0.56^{d,A}$	0.14
II	$2.28^{c,d,A}$	0.46	$1.74^{c,A}$	0.18	$1.52^{c,A}$	0.10	$2.74^{c,A}$	0.69	$1.82^{c,A}$	0.46	$1.31^{c,A}$	0.19
III	$18.00^{a,A}$	2.14	$10.73^{a,A}$	1.82	$7.28^{a,A}$	0.54	$6.70^{a,B}$	0.24	$4.01^{a,B}$	0.30	$2.58^{a,B}$	0.13
IV	$3.92^{b,c,A}$	0.90	$2.48^{c,d,A}$	0.58	$1.46^{c,A}$	0.23	$2.83^{c,,B}$	0.40	$1.56^{c,B}$	0.22	$1.16^{c,A}$	0.19
V	$5.84^{b,A}$	0.71	$3.69^{b,d,A}$	0.44	$2.59^{b,A}$	0.17	$4.85^{b,B}$	0.48	$2.99^{b,B}$	0.42	$2.12^{b,B}$	0.10

Subgroups with different small letters in the same column are significant.
Subgroups with different capital letters in the same row through the same parameter are significant.

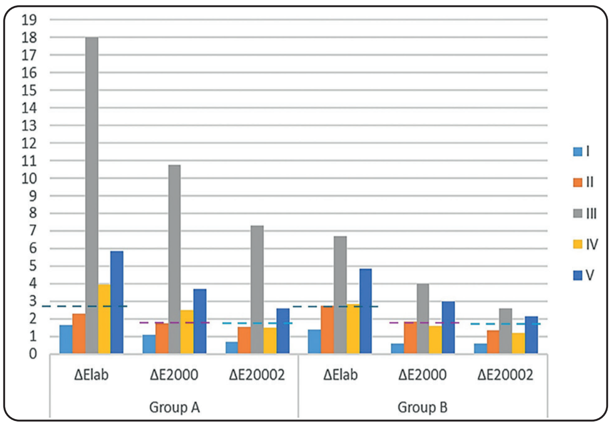

Fig. (3) Bar chart for means of $\Delta E_{lab,}$ ΔE_{2000} and ΔE_{20002} for groups and subgroups represent AT for each formula

The ΔE_{20002} mean values of subgroups III and V in both groups were higher than the AT (ΔE_{20002} =1.78). The results of the comparisons by one sample t-test of the mean values of ΔE_{lab}, ΔE_{2000} and ΔE_{20002} to their corresponding AT value for the values higher than the AT (positive t-value) statistically significance statistically between ΔE_{lab} versus the corresponding AT value in subgroups III-V for group A and subgroups III and V for group B. While significance between ΔE_{2000} and ΔE_{20002} values versus corresponding AT values showed in subgroups III and V for both groups. Table (5)

TABLE (5) The t-values and Sig. ((2-tailed), P value) of $\Delta E_{lab,}$ ΔE_{2000} and ΔE_{20002} for groups and subgroups versus corresponding AT values

Groups	Subgroups	ΔE_{lab} versus AT ΔE_{lab}=2.7		ΔE_{2000} versus AT ΔE_{2000}=1.8		ΔE_{20002} versus AT ΔE_{20002}=1.78	
		t-values	P value	t-values	P value	t-values	P value
Group A	I	-3.679	0.021*	-4.248	0.013*	-17.263	0.000*
	II	-2.067	0.108	-0.693	0.526	-5.946	0.004*
	III	15.958	0.000**	10.996	0.000**	22.902	0.000**
	IV	3.033	0.039**	2.608	0.060	-3.134	0.035*
	V	9.924	0.001**	9.551	0.001**	10.668	0.000**
Group B	I	-9.117	0.001*	-19.333	0.000*	-19.491	0.000*
	II	0.139	0.896	0.101	0.925	-5.550	0.005*
	III	37.724	0.000**	16.623	0.000**	13.751	0.000**
	IV	0.705	0.520	-2.364	0.077	-7.234	0.002*
	V	9.970	0.001**	6.427	0.003**	7.937	0.001**

Values with * are significant and the t-values were negative; values with ** are significant and the t-values were positive

Correlation coefficients and significance between ΔE_{lab}, ΔE_{2000}, ΔE_{20002} and ΔC versus each other showed significantly strong positive correlation. In contrast, the correlation coefficients and significance between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} versus ΔH showed statistically nonsignificant weak negative correlation. Table (6) Figure (4,5 and 6)

TABLE (6) The Pearson correlation coefficients (r) and Sig. (2-tailed) between ΔC, ΔH, ΔE_{lab}, ΔE_{2000} and ΔE_{20002} for groups and subgroups

		ΔC	ΔH	ΔE_{Lab}	ΔE_{2000}	ΔE_{20002}
ΔE_{Lab}	Pearson correlation coefficients (r)	0.957**	-0.14	1.00	0.996**	0.991**
	Sig. (2-tailed)	0.00	0.33		0.00	0.00
ΔE_{2000}	Pearson correlation coefficients (r)	0.932**	-0.10	0.996**	1.00	.988**
	Sig. (2-tailed)	0.00	0.49	0.00		0.00
ΔE_{20002}	Pearson correlation coefficients (r)	0.969**	-0.09	0.991**	0.988**	1.00
	Sig. (2-tailed)	0.00	0.55	0.00	0.00	

Pearson correlation coefficients (r) are significant at the 0.01 level (2-tailed).

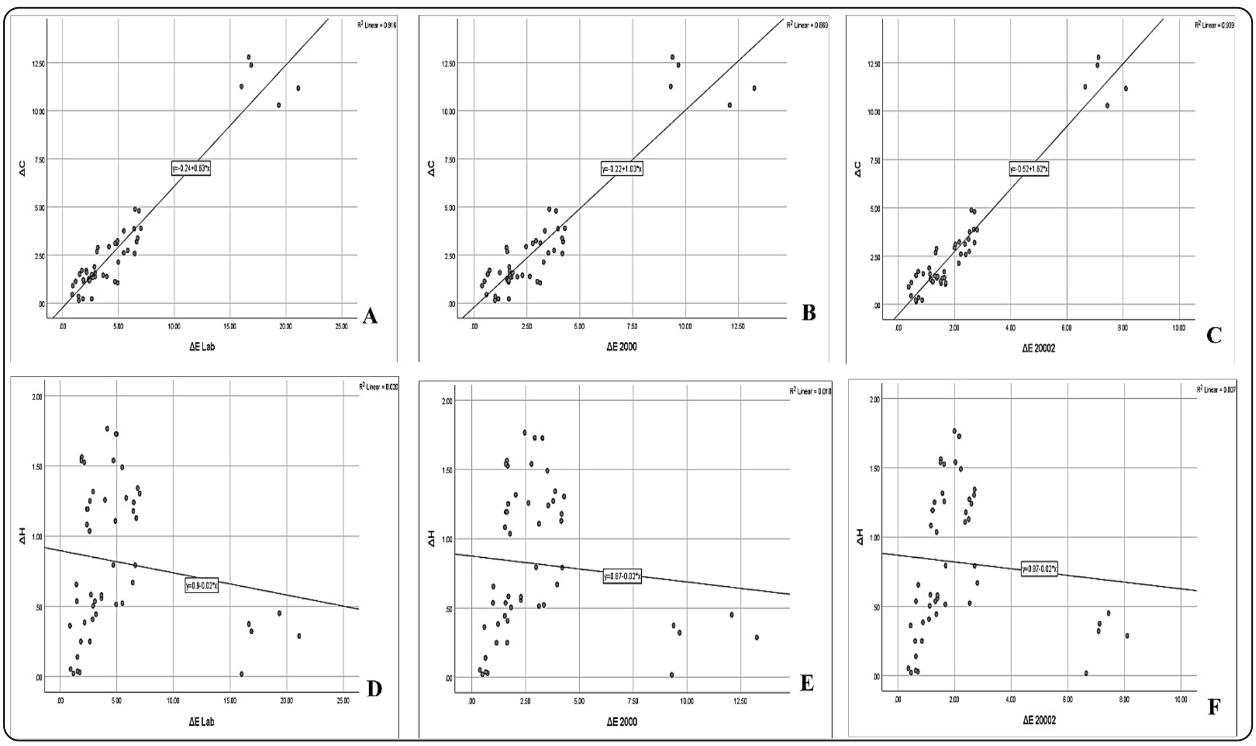

Fig. (4) Scatter plot represent the correlation between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} versus ΔC and ΔH where A represent the correlation between ΔC and ΔE_{lab}, B represent the correlation between ΔC and ΔE_{2000}, C represent the correlation between ΔC and ΔE_{20002}, D represent the correlation between ΔH and ΔE_{lab}, E represent the correlation between ΔH and ΔE_{2000}, F represent the correlation between ΔH and ΔE_{20002}.

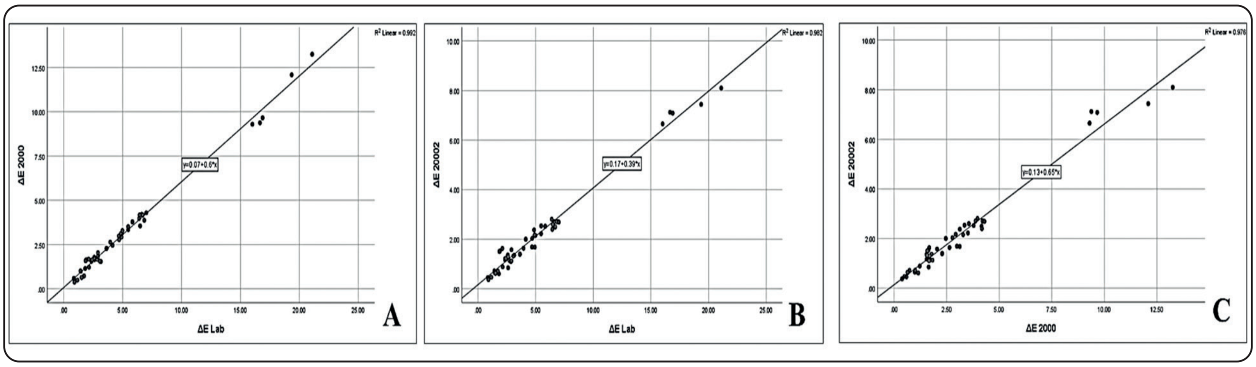

Fig. (5) Scatter plot representing the correlation between ΔElab, ΔE2000 and ΔE20002, where A represents the correlation between ΔElab and ΔE2000, B represents the correlation between ΔElab and ΔE20002 and C represents the correlation between ΔE2000 and ΔE20002.

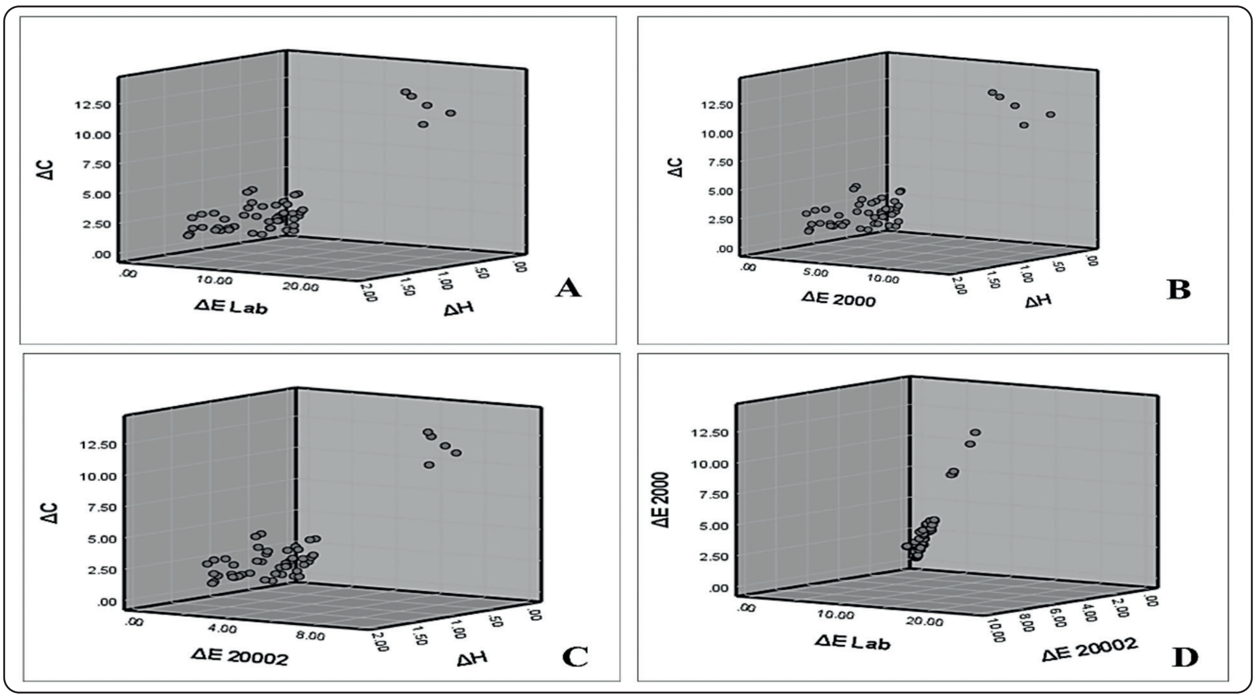

Fig. (6) 3D scatter plot between ΔE_{lab}, ΔE_{2000}, ΔE_{20002}, ΔC and ΔH, where A represents the relation between ΔC, ΔH and ΔE_{lab}; B represents relation between ΔC, ΔH and ΔE_{2000}; C represents the relation between ΔC, ΔH and ΔE_{20002} and D represents the correlation between ΔE_{lab}, ΔE_{2000} and ΔE_{20002}.

DISCUSSION

Aesthetics, along with the composition and mechanical properties of restorative materials, are the major factors in optimal material selection. The color change of dental ceramics is a crucial parameter that can affect the performance of the restoration. [20] Many computers aided design/ computer aided manufacturing (CAD/CAM) ceramics attain the growth of the aesthetic demand by both patients and dentists. Lithium disilicate ceramic, IPS e.max ceram, (LD) and zirconia reinforced lithium silicate, VITA SUPRINITY, (ZL) are among the most highly ranked commercial materials. Both types consist of a crystalline phase and an amorphous glassy matrix.[21, 22] The basic composition of LD is

57.0-80.0 SiO_2, 11.0-19.0 Li_2O, 0.0-8.0 ZrO_2, 0.0-8.0 ZrO_2 and 0.0-5.0 MgO while the composition of ZL is 56-64 SiO_2, 15-21 Li_2O and 8-12 ZrO_2, both have other oxides in lower percentages regarding their manufacture.

Mouthwashes are one of the oral hygiene maintenance products that could have an impact on the ceramic color.[3, 4] Their pH and chemical ingredients could produce degradation of the surface in the form of hydrolysis and exchange of ions, which have deleterious effects on the aesthetics and mechanical properties of the ceramics. [1, 3, 4] The interval of mouthwash usage can be extended for medical reasons, such for patients who cannot maintain their oral hygiene due to disability or patients who suffer from osteoradionecrosis and osteonecrosis[23]. Furthermore, mouthwashes are frequently used by patients for extended time more than that recommended by dentists, aiming to get a beneficial effect of control or reduce pathogenic microbes, bad breath, gingivitis, tooth decay, or even to whiten their teeth.[24] Thence, it is important to investigate the effects of mouthwashes on the color of modern ceramics such as LD and ZL to ensure their aesthetic.

The present study used chlorhexidine (CHX), iodopovidone (IPV), green tea (GT) and tetrapotassium pyrophosphate/pentasodium triphosphate whitening (TPW) mouthwashes. The used mouthwashes in this study were selected with respect to the common purposes the patients used them for. The CHX mouthwash is considered the gold standard for preventing dental plaque and halitosis for its strong antiseptic property.[25] The IPV mouthwash was suggested by ADA emergency guidelines for dental procedures during the COVID-19 pandemic to minimize the risk of COVID-19 and other airborne aerosol viral respiratory tract infection transmission.[26-28] Herbal based GT mouthwash is a newly introduced natural extract based on Camellia Sinensis extract, which has antibacterial and antioxidant behaviour[29]. Whitening mouthwashes, toothpastes and gels are used by patients as they are low cost whitening agents that can be used at home for preventing or removing teeth discoloration.[30] The present study tries to imitate the usage of mouthwashes for 3 months by the immersion cycle.

The evaluation of color change of stained ceramics should include both statistical and color science realization.[31] The color of each sample was determined by a clinical spectrophotometer on a black background trying to simulate the oral perimeter. [31] Color change formulas, which were introduced by the CIE organization, have been used on large scales to calculate overall differences in color and translucency. For a long period of time, the ΔE_{Lab} formula was used. Intending to develop better relations between the calculated and recognized color change by the human eye and to evolve the interpretation for blue and gray colors, the ΔE_{2000} formula was introduced. [15, 32] The ΔE_{2000} formula was assumed to provide superior indication for human perceptibility and acceptability of color differences.[33] The ΔE_{2000} formula is more complicated than the ΔE_{Lab} formula in order that it consider the R_T, S_L, S_C, S_H and the parametric factors K_L, K_C, K_H . Previous studies supposed that considering K_L=1 showed better correlation to observations from a subset of average observers. (9, 13, 34) Other studies supposed that considering K_L=2 has the superior correlation regarding to dental ceramics [15, 31, 35, 36] due to the impact of the surface texture on sample lightness.[36, 37]

The statistically significant mean values of ΔC, ΔH, ΔL, Δa and Δb between subgroups indicate the different considerable effects of each immersion solution compared to the control group. After immersion, positive values of ΔC denote the increase of the color saturation. Also, positive values of ΔL indicate lighter perception, while negative values indicate darker perception. Moreover, the positive values of Δa and Δb demonstrate shifting to the red and yellow directions, respectively, while negative values of Δa and Δb demonstrate shifting to the green and blue directions, respectively. (12)

In addition, ΔE values of subgroups II-V revealed higher mean values than the subgroup I (control group). They can be ordered ascendingly as subgroup II, followed by IV, V and III, respectively. The findings of our study were on harmony with previous study of Haralur et al 2019(38), PiSal et al 2022(39) and *Benli et al 2024*(23). This may be explained by the acidic nature of the mouthwashes. Acidity has a deteriorating effect on the glassy phase of ceramics, as acidic compounds have a high affinity for alkaline ions, leading to their diffusion from the glassy matrix to the surrounding solutions. (40) The diffusion could produce pores and/or channels on the surface causing impairment of the aesthetic and mechanical properties of the ceramics(40). Among the mouthwashes used in this study, the CHX and the TPW mouthwashes have a weak acidic nature, pH=6.6 and 6.5, respectively. Despite their weak acidity, prolonged exposure could aggravate their effect.

Moreover, mouthwashes in subgroups II, IV and V contain sodium fluoride (NaF). Fluoride released from NaF can interact with the bond between oxygen and silicon in SiO_2 which is a basic component in both types of ceramic. This interaction led to attenuation of the bond, increasing the chance of bond breakage and formation of silicon tetrafluoride, which affected the roughness of the surface and led to discoloration. (41-44) Although NaF is present in CHX mouthwash, subgroup II did not display inadmissible color change. This might be explained by combination between NaF and CHX forming chlorohexidine difluoride which affects the properties of fluoride. (45-47) For this reason, the ΔE values of subgroup II showed the lowest values in the experimental subgroups.

Furthermore, subgroup III showed the highest significant ΔE values. This could be clarified by the strong oxidative power of iodine ions (48) that could oxidize the surface of the ceramic in acidic media (pH= 3.5), causing dramatic surface degradation. For subgroup IV, the higher ΔE values compared to subgroup II pointed to the effect of SF in combination with the acidic nature of GI mouthwashes (pH=4.8).

It was recognized by previous studies (49, 50) that chemical agents in the form of pyrophosphates and triphosphates, in whitening oral maintenance products, might be able to reduce stains either by inhibiting their formation or removing them. Tetrapotassium Pyrophosphate ($K_4P_2O_7$) and pentasodium triphosphate ($Na_5P_3O_{10}$) are used as chelating agents and antitartar compounds in whitening mouthwashes. (51, 52) They can bind to ions as Ca^{+2}, Mg^{+2} and other metallic ions. (51) Lithium oxide is a basic component in both types of ceramics. Lithium ions are one of the alkaline metal ions that can react with pyrophosphate, forming insoluble lithium phosphate compounds that have a white color. Additionally, pyrophosphate could react with Mg ions in LD composition causing the higher significant mean values of ΔE in subgroup V for group A. Pyrophosphates and triphosphates action varied regarding their concentration and/or presence of fluoride sources, such as sodium fluoride or sodium monofluorophosphate, from one product to another in oral hygiene maintenance products.(52) Thus, clarify the inconsistency of the finding of group V and previous studies of Soares et al 2015 (49) and Ntovas et al 2021(53). These studies used different products and applied them to enamel rather than ceramic.

The color stability of the ceramic restorations relies on their composition, microstructure, size, shape and allocation of crystals within the matrix (19). In the presented study ΔE mean values of group A in subgroups II-IV were statistically significantly higher than those of group B. This finding was in harmony with Alpkilic et al 2021 (18) study and might be explained by the difference in microstructure and crystallinity content between the LD and ZL. In spite of the LD having 70% lithium disilicate crystals with a size of 1-1.5µm approximately embedded into a glassy matrix[54], while ZL has 40-50% of two types of crystal: lithium silicate, with a size of approximately 0.5µm, and zirconia crystal embedded into a glassy matrix[21,55]. The SiO_2 content in LD was higher than that in ZL which is more susceptible to degradation than other oxides present in the composition.[56]

Regarding the ISO/TR 28642[16], the 50:50% acceptability threshold of color difference (AT) meant the value of color change that can be counted nonacceptable by the half of the viewers. These viewers may prefer replacing or correcting the restoration. Our study did not evaluate the AT but rather relied on previously published studies. The AT values were set as ΔE_{Lab}=2.7 [15, 17, 31, 57-59], ΔE_{2000} =1.8 [15,17,31,36,57,58,60,61] and ΔE_{20002}=1.78 [15, 31, 36].

The relation between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} and their corresponding AT values is highly remarkable in order that it discloses the clinical acceptability and patient satisfaction about the appearance of the ceramic restoration. The results of the comparisons by one sample t-test of the mean values of ΔE_{lab}, ΔE_{2000} and ΔE_{20002} versus their corresponding AT value for the positive t-value showed significance between ΔE_{lab} versus the corresponding AT value in subgroups III-V in group A and III and V for group B. Although ΔE_{lab}, in group B, for subgroups II and IV was higher than AT, there were statistically nonsignificant.While significance between ΔE_{2000} and ΔE_{20002} values versus corresponding AT values showed in subgroups III and V for both groups. Although ΔE_{2000} for subgroups IV in group A and subgroups II in group B were higher than the AT, they were statistically nonsignificant. These findings confirm that the ΔE_{20002} formula has superior efficiency for correlating human acceptability and color changes regarding dental ceramics. This was consistent with the previous studies of del Mar Perez, M et al 2011,[36] Pecho, O. E. et al 2016,[15] Pecho, O. E. et al 2016,[35] Koçak et al 2021,[31] and apart from Choudhury AK et al 2014 [21] who stated that the best performance of the k_L=2 formula is for textiles.

Correlation ΔE_{lab}, ΔE_{2000} and ΔE_{20002} versus each other and versus ΔC indicates significantly strong positive correlation. This finding was in line with Lee et al 2005,[14] Lee et al 2005,[32] Del Mar Perez et al 2008,[2] Kim et al 2009 [62], Bétrisey et al 2018[63] and Koçak et al 2021[31] findings. Our results represent that, although there is a direct correlation between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} findings, the ΔE_{lab} cannot always be used as a linear estimate for ΔE_{2000} and ΔE_{20002}. Regarding the comparison with AT, the finding was in line with Koçak et al 2021[31] and Kim et al 2009[62] studies and it pointed out the uniqueness of each formula. However, the 3 formulas might usually point out the same deduction for comparing between color of restorative material when large differences in the ΔE values are displayed. But, when a minute change in color presents a distinct conclusion for comparing between restorative materials could be displayed. [31]

Concerning the 3 null hypothesis of this study, the 3 null hypothesis were rejected as immersion in IPV and TPW mouthwashes increase the ΔE values to the level exceeding the AT significantly. Furthermore, the CIEDE2000 (2:1:1) formula revealed more efficient correlation to human observation. In addition, ΔE_{lab}, ΔE_{2000} and ΔE_{20002} values were strongly significantly correlated to each other.

The potential limitation of the present in vitro study was the inability to simulate the real oral environment. In spite of the study trying to simulate the patient usage of the mouthwashes and using black backgrounds, other factors such as pH, thermal and stress fluctuation did not apply. Moreover, food and beverage effects on color were not considered. For this reason, further studies including multifactored should be considered.

CONCLUSION

The ΔE_{20002} was more efficient than ΔE_{lab} and ΔE_{2000}. Using iodopovidone and pyrophosphate based mouthwashes for 90 days could cause more dramatic changes in color of LD more than ZL ceramics. Additionally, despite the strong correlation between ΔE_{lab}, ΔE_{2000} and ΔE_{20002} values, ΔE_{lab} cannot always be used to estimate ΔE_{2000} and ΔE_{20002} findings.

CLINICAL RECOMMENDATION

Patients with LD and ZL ceramic restorations should be instructed to use IPV and TPW mouthwashes carefully and do not exceed the recommended instruction period of usage.

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