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INFLUENCE OF REPEATED FIRINGS ON THE OPTICAL PROPERTIES OF ZIRCONIA CERAMIC CORE WITH DIFFERENT THICKNESSES OF VENEERING CERAMIC: AN IN VITRO STUDY

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ABSTRACT

Statement of the problem: The optical properties of the zirconia based ceramic restoration may be affected by its fabrication protocol and the veneer thickness.

Objectives: This study was aimed to investigate the effect of repeated firings and veneer thickness on the final color and translucency of zirconia based ceramic restorations.

Materials and methods: 80 disc-shaped zirconia cores (diameter: 10×1 mm) were constructed then divided based on the veneer thickness into 2 main groups (A) and (B) (n=40) with 0.5 mm and 1.00 mm veneer thicknesses, respectively. According to the number of firing cycles (1, 3, 5, and 7), each main group was further subdivided into four subgroups (n=10). A spectrophotometer was utilized to measure the color and translucency after consecutive firings then used to measure them after artificial thermomechanical aging. Data analysis was performed by One-way ANOVA analysis, Paired t-test and Tukey post hoc test.

Results: All measured L*, a* and b* and ΔE values showed statistical significant differences after repeated firing cycles. Increasing the veneer thickness for all tested subgroups resulted in statistically significant increasing in mean values of L*, a* and b*. Increasing the number of firing cycles significantly increased the TP, while increasing the zirconia veneer thickness significantly decreased them. Following fatigue aging, statistically significant differences were noticed for all color coordinates with all tested subgroups with increased TP.

Conclusions: Both firing cycles and veneer thickness had an impact on optical properties of zirconia-based ceramic restorations. Color parameters and translucency were influenced by artificial fatigue aging.

KEYWORDS: Translucency , Color , Artificial Thermomechanical Aging

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INTRODUCTION

Recently, demands of patients for cosmetic dentistry have been increased. It is crucial for restoration to achieve natural appearance of the teeth in order to achieve patients' request.[1] By using a ceramic core instead of a metal one, the crown provided better light transmission, resulting in restorations that possess superior color and translucency.[2] Ceramic system included combinations of core and veneer with different translucencies and thicknesses to achieve a natural appearance. Different ceramic materials could be used as a core material, for example alumina, zirconia, lithium disilicate and other ceramic materials.[3] Ceramic core (e.g. yttria stabilized tetragonal zirconia) can be veneered with highly esthetic veneering porcelain, improving excellent esthetics outcome in the final restorstion.[2]

Color matching of restorations is affected by several factors; fluorescence, opalescence, translucency, texture of surface, brand of material, condensation technique, number of firings cycles and porcelain thickness.[2] Ceramic restorations become more translucent when the majority of the light is transmitted diffusely, with only a portion of it being scattered.[3] The translucency of ceramic materials was considered as the key which greatly controlled the esthetics of restorations in addition to their final appearance and consequently the restorations success.[4]

It had been revealed that zirconia had low translucency among ceramic materials. So that, zirconia restorations are used usually with a veneering feldspathic ceramic to manage the opacity and provide a more translucent natural appearance for the final restorations. Different types of veneering ceramics could be used for zirconia core-veneered restorations including feldspathic ceramics, lithium disilicate and fluorapatite glass ceramics.[5]

Both core and veneer thicknesses have an impact on optical properties of veneered ceramic restorations.[2] In addition, the firing conditions was another factor which could affect the final esthetic of zirconia based restorations.[6] Repeated firings could be effective in eliminating porosity as well as enhancing hardness and densification.[7] Besides, restoration may be fired Multiple times for color and shape correction to achieve satisfactory esthetic outcome for both clinician and patient. Moreover, multiple firings are indicated after final occlusal adjustments.[1] Studies showed that the repeated firings had a significant influence on optical properties of ceramic restorations and this factor should be taken into account during production of the restoration.[7]

Translucency Parameter (TP) is estimated from color difference (ΔE^*) of objects against white and black backgrounds. The Commission Internationale de l'Eclairage (CIE) suggested measuring color difference according to CIE $L^*a^*b^*$ color coordinates.[2,8] Visual shade matching or instrumental color analysis can be used for color matching. The instrumental analysis (e.g., spectrophotometer), has been suggested for color matching as it offers rapid method, quantifiable and objective results.[2] It was found that, spectrophotometer provide better accuracy by 33% and a more acceptable matching within 93.3% of cases comparing to traditional techniques.[9]

Success of prosthetic dentistry can be obtained by achieving high esthetics. Moreover, the esthetic success of restorations depends mainly on its color stability.[10] In invitro studies, restorations had been subjected to ''artificial thermomechanical aging'' to simulate the oral conditions for understanding how these restorations behave in oral environment. It had been evidenced to be an effective method for determining the color stability of dental restorations.[11,12]

The findings of previous studies performed on influence of veneer thickness and multiple firing cycles on color properties of zirconia-based restorations had been controversial. In addition, limited number of researches have focused on the optical properties of veneered zirconia restorations after accelerated artificial aging step, which is necessary for the long-term success of restorations. Therefore, this study was carried out to evaluate the effects of repeated firing cycles and thickness of veneer on the final color and translucency parameter of zirconia based ceramic restorations, and the influence of artificial aging on their color stability.

The first null hypothesis tested was that the number of firing cycles and veneer thickness would not significantly affect color and translucency of zirconia-based ceramic restorations. While second null hypothesis stated that, both color and translucency have a non-significant color change after artificial aging.

MATERIALS AND METHODS

This in vitro study was done after getting the approval of Local Research Ethics Committee, Faculty of Dentistry, Mansoura University. It followed its guidelines of clinical trials with approval no. A0207024FP. Firstly, based on Fathi et al.,[2] A power analysis test was conducted to calculate the sample size using G*Power version 3.0.10; sample size = 10/subgroup, α error = 0.05, power = 80.0% and effect size = 1.4.

Eighty disc-shaped zirconia cores (Nacera Pearl, Dental Direkt Gmbh, Germany) were fabricated in A2 shade and 1 mm thickness x 10 mm diameter using CAD/CAM technology (CORiTEC 250i touch, imes-icore GmbH, Germany). They were fully sintered following manufacturer's guidelines. After sintering, their proper dimensions were verified using digital caliper. All discs were sandblasted using 50 µm alumina particles at 4 bar, 10 mm distance for 10 seconds on one surface to enhance bonding between the zirconia core and the veneering ceramic material. According to veneer thickness, zirconia specimens were divided into two main groups (n=40); Group (A): 0.5 mm veneer thickness and Group (B): 1 mm veneer thickness.

A special custom-made circular mold was constructed for standardized building of the veneering ceramic material (IPS e.max Ceram, Ivoclar Vivadent, Liechtenstein) onto zirconia cores with the required thickness (0.5 mm or 1 mm). IPS e.max Ceram layering ceramic material powder was combined with its liquid buildup to create a thin slurry composition. Then, it was applied onto the sintered zirconia core in a thin layer using a brush. This complex was carefully transferred into suitable firing furnace (Programat EP 3010, Ivoclar Vivadent, Liechtenstein) and fired following manufacturer's recommendations.

After cooling to room temperature, the glaze material (IPS e.max Ceram Glaze, Ivoclar Vivadent, Liechtenstein) was mixed and applied on the veneered surface with a fine brush and glaze firing was done following the recommended manufacturer's guidelines. After glazing, all specimens thickness was rechecked using digital caliper to ensure the required total thickness (1.5mm for group A specimens and 2 mm for group B specimens). According to number of glaze firing cycles, each main group was further subdivided into four subgroups (n=10); 1, 3, 5, and 7.

After completing the glaze firing cycles for specimens of each subgroup, the color measurements were performed. Color coordinates in the CIE L*a*b* color space were measured and calculated through spectrophotometric reflection apparatus. For repeatability under standardized conditions, a portable spectrophotometer (Vita Easyshade V, Germany) was used after calibration before each measurement following manufacturer's gudelines.[1,2] Specimens of each subgroup were firstly numbered from 1 to 10 then measured consecutively. The probe measuring tip was applied perpendicularly at each specimen center. Measurements of the color parameter L*, a* and b* were conducted against neutral grayish background, while translucency parameters were taken against backgrounds of both black and white. Measurements for each specimen were taken three times and the mean values of L*, a* and b* were conducted. This was done by one investigator at the same time of the day.[1,2]

The color differences for all subgroups between color coordinates after repeating glaze firing cycles were calculated using CIELAB (ΔE) color difference formula:

$$\Delta E=[(\Delta L^2)^2+(\Delta a^2)^2+(\Delta b^2)^2]^{1/2}$$

Where: ΔE represent color difference, while ΔL^*, Δa^* and Δb^* represent the differences in L* (lightness-darkness), a* (redness-greenness) and b* (yellowness-blueness) coordinates, respectively.

Translucency parameter was conducted by calculating color difference of each specimen against black and white backgrounds according to following formula:

$$TP=[(LB^*-LW^*)^2+(aB^*-aW^*)^2+(bB^*-bW^*)^2]^{1/2}$$

Where: TP represent translucency parameter (from 0 to100); the higher TP value means more translucent material. L* indicates lightness-darkness, a* indicates the red-green axis and b* indicates the yellow-blue axis, B for color coordinate against the black background, W: for color coordinate against the white background.

The fatigue testing was carried out for all studied specimens through established separate and consecutive thermal and mechanical fatigue methods. To mimic the thermal cycling fatigue that occurs in oral environment, all numbered specimens were exposed to accelerated artificial aging process using a thermal cycling device (Thermo Scientific, Thermo Fisher Scientific Inc., USA). In this study, thermal cycling was performed for 10000 cycles (the temperature ranges from 5 °C to 55 °C, with a transfer time of 5 seconds and a dwell time of 30 seconds.) To approximate the duration of one year of service within the oral cavity.[12-14]

Following the thermal cycling procedure, all specimens were exposed to artificial mechanical cycling fatigue simulating 1 year of clinical service using a computer-controlled dual-axis chewing simulator machine (Chewing Simulator CS-4.4, SD Mechatronik, Germany). All specimens were submitted to 240,000 load cycles with 1.6 Hz frequency to simulate an intermittent unidirectional axial load of 50 N. The load was imposed using a steatite-ceramic, enamel-type antagonist. Then, the integrity of air-dried specimens was monitored at regular intervals visually under good illumination and tactilely with a dental probe to detect any mode/sign of early failure (chipping, crack, debonding, or fracture).[15]

After completion of all fatigue cycles successfully, the second color measurements were performed for all specimens using the same protocol under the same conditions as previously followed for the initial measurements.

SPSS software version 22 was used for data analysis. Quantitative data assuming normal distribution after conducting the Shapiro-Wilk test to assess the normality. Qualitative data were described using number and percentage. The obtained results were deemed significant at the (≤0.05) level. The paired t-test was utilized to assess two paired tests for data that follows a normal distribution. The One Way ANOVA test was employed to compare multiple independent groups, while the Post Hoc Tukey test was utilized to identify pairwise comparisons.

RESULTS

Influence of repeated firing cycles on color coordinates

It was found that, when firing cycles number increased from 1 to 3, 5, and 7 for both groups this resulted in decreasing the mean values of L* (darker), increasing the mean values of a* color coordinate (more reddish) and increasing the mean values of b* color coordinate (more yellowish). One-way ANOVA analysis revealed that there was statistical significant difference for all measured coordinates after repeated firing cycles tested (P<0.001). Tukey HSD post hoc test found that there were statistically significant differences between all subgroups regarding L*, a*, and b* coordinates except for the L*, a*, and b* values for A5 and A7, and for B5 and B7 subgroups. Also, the a* and b* values for A3, A5, and A7 subgroups and the b* values for B3, B5, and B7 subgroups showed no statistically significant difference.

Influence of veneer thickness on color coordinates:

One-way ANOVA test revealed that increasing the veneer thickness for all tested subgroups resulted in statistically significant increasing in of L*, a* and b* mean values producing a lighter, more reddish and more yellowish behavior.

Influence of repeated firing cycles on color deference:

For group A, the highest mean color difference value (3.34±0.35) was recorded between 1 and 7 firing cycles subgroups, while the lowest mean value (0.26±0.21) was found from 5 to 7 firing cycles subgroups. For group B, the highest mean color difference value (2.72±0.19) was recorded between 1 and 7 firing cycles subgroups, while the lowest mean value (0.27±0.13) was found between 5 and 7 firing cycles subgroups. The highest mean value for group B expressed undetectable color change less than 3.3 threshold. For both groups, One-way ANOVA test represented statistical significant difference between ΔE values (P<0.001 for both groups). For group A, Tukey HSD post hoc test found no statistical significant difference in mean ΔE values for (A1-A5 and A1-A7) and for (A3-A5 and A3-A7). For group B, it revealed non-statistical significant difference between the mean ΔE values for (B1-B3 and B1-B5), for (B1-B5 and B1-B7), and for (B3-B5, B3-B7, and B5-B7). (Table 1)

TABLE (1) Mean values, One-way ANOVA and Tukey post hoc test for comparison of color difference (ΔE) measured between all subgroups of the same veneer thickness.

	ΔE								
Subgroup	**A1**	**A3**	**A5**	**A7**	**B1**	**B3**	**B5**	**B7**	**Test of significance**
A1									F=110.54 P<0.001*
A3	ΔE1= 2.58 ± 0.17								
A5	ΔE2=3.12 $\pm 0.25^{A}$	ΔE4=0.81 $\pm 0.18^{B}$							
A7	ΔE3=3.34 $\pm 0.35^{A}$	ΔE5=1.07 $\pm 0.26^{B}$	ΔE6= 0.26 ±0.21						
B1									F=121.11 P<0.001*
B3					ΔE1=2.20 $\pm 0.14^{a}$				
B5					ΔE2= 2.45 $\pm 0.16^{ab}$	ΔE4= 0.27 $\pm 0.20^{c}$			
B7					ΔE3= 2.72 $\pm 0.19^{b}$	ΔE5= 0.53 $\pm 0.17^{c}$	ΔE6= 0.27 $\pm 0.13^{c}$		

Mean values (±SD) with the same superscripted letters represent non-significant difference (uppercase letters for group A and lowercase letters for group B), where ΔE1 between 1 and 3 firing cycles, ΔE2 between 1 and 5 firing cycles, ΔE3 between 1 and 7 firing cycles, ΔE4 between 3 and 5 firing cycles, ΔE5 between 3 and 7 firing cycles, and ΔE6 between 5 and 7 firing cycles. *significance at p-value ≤ 0.05

Influence of veneer thickness on color deference:

The highest color difference value between both main groups was found after the first firing cycle (4.79±0.30), while the lowest value was recorded after making three firing cycles (3.78±0.27). All calculated ΔE values between both groups after application of different firing cycles refers to unacceptable detectable color difference that all values were more than the 3.3 threshold. One-way ANOVA analysis revealed statistical significant difference between ΔE values calculated between both main groups at different firing cycles (P<0.001). (Table 2)

Influence of repeated firing cycles and veneer thickness on translucency parameter:

For group A, the TP mean values were 6.98±0.15, 6.79±0.13, 7.10±0.10, and 7.17±0.09 after 1, 3, 5, and 7 firing cycles, respectively. For group B, the TP mean values were 4.11±0.08, 4.30±0.11, 4.36±0.12, and 4.41±0.08 after 1, 3, 5, and 7 firing cycles, respectively. Generally, increasing firing cycles number increases TP. One- way ANOVA analysis revealed statistical significant difference between all subgroups considering TP (P<0.001*). For group A, Tukey HSD post hoc test revealed non-statistical significant difference between TP mean values (P=0.063) except between A3 and both A5 and A7 subgroups. On contrary for group B, it revealed statistical significant difference between the TP mean values (P=0.018) except between B3, B5 and B7 subgroups. Regarding veneer thickness influence on the TP, it was revealed that that increasing the veneer thickness of zirconia significantly decreased TP regardless firing cycles number.

Influence of fatigue aging on color stability and translucency:

It was found that the applied fatigue aging protocol has decreased L* (darker) and increased both a* (more reddish) and b* (more yellowish) for the specimens of all subgroups. Paired *t*-test revealed that there were statistically significant differences for all color coordinates among all tested subgroups (p<0.001).

Following fatigue aging, it was found that specimens of group A had ΔE mean values more than the values calculated for specimens of group B. It was found that the highest color deference (ΔE) was for A7 subgroup (4.90±0.18) that is counted as unacceptable color change (more than the 3.3 threshold). The lowest ΔE value was found for B1 subgroup (1.59±0.10) that is considered an acceptable color change with ΔE less than 3.3. One-way ANOVA test showed that there was a statistically significant difference between ΔE values of all subgroups (P<0.001). Tukey HSD post hoc test revealed no statistically significant

TABLE (2) Mean values (±SD) and One-way ANOVA for comparison of color difference (ΔE) between different subgroups of the same number of firing cycles.

	ΔE				
Subgroup	**A1**	**A3**	**A5**	**A7**	**Test of significance**
B1	4.79±0.30				F=27.88 P<0.001*
B3		3.78±0.27			
B5			4.38±0.29		
B7				4.43±0.24	

significance at p-value ≤ 0.05

difference between the ΔE mean values for A1 and A3, A5 and A7, and B5 and B7 subgroups. (Table 3) With regard to the influence of fatigue aging on TP, it was found that the TP mean values had increased for all subgroups. Paired t-test showed that there were statistically significant differences for all subgroups (p<0.05) except for A1 (P=0.851). (Table 4)

Table (3). Mean values (±SD), One-way ANOVA and Tukey post hoc test for comparison of color difference (ΔE) between all subgroups, measured after fatigue aging.

Subgroup	ΔE		Test of significance
	Mean	SD	
A1	3.78^{A}	0.19	F= 398.56 P<0.001*
A3	3.93^{A}	0.09	
A5	4.84^{B}	0.21	
A7	4.90^{B}	0.18	
B1	1.59	0.10	
B3	2.99	0.13	
B5	3.40^{a}	0.06	
B7	3.52^{a}	0.08	

Mean values with the same superscripted letters represent non-significant difference (uppercase letters for group A and lowercase letters for group B). SD: Standard Deviation. *significance at p-value ≤ 0.05

Table (4). Mean values (±SD) and Paired t-test for comparison of translucency parameter (TP) measured before and after fatigue aging for all subgroups.

Group (A)					Group (B)				
Subgroup	TP	Mean	SD	Test of significance	Subgroup	TP	Mean	SD	Test of significance
A1	Pre	6.98	0.15	t=0.10	B1	Pre	4.11	0.08	t=2.95
	Post	7.05	0.19	p=0.851		Post	4.43	0.11	p=0.021*
A3	Pre	6.79	0.13	t=8.55	B3	Pre	4.30	0.11	t=6.85
	Post	7.29	0.11	p<0.001*		Post	4.74	0.14	p<0.001*
A5	Pre	7.10	0.10	t=11.05	B5	Pre	4.36	0.12	t=9.05
	Post	7.71	0.12	p<0.001*		Post	4.95	0.07	p<0.001*
A7	Pre	7.17	0.09	t=11.22	B7	Pre	4.41	0.08	t=9.25
	Post	7.83	0.10	p<0.001*		Post	5.08	0.10	p<0.001*

SD: Standard Deviation. *significance at p-value ≤ 0.05

DISCUSSION

According to results of current study, the first null hypothesis was not supported as both firing cycles number and veneer thickness had a significant influence on optical properties of zirconia-based ceramic restorations. In addition, the second hypothesis was also rejected because applied protocol of artificial fatigue aging had a significant effect on their color stability and translucency.

The current results showed that, regardless of veneer thicknesses, increasing firing cycles number from 1 to 3, 5, and 7 resulted in decreasing the mean values of L* (darker), increasing the mean values of a* (more reddish) and increasing the mean values of b* (more yellowish). Bachhav and Aras[16] found that increasing firing cycles number with 0.5 mm-thick specimens, was significantly decreased a* but increase both L* and b*. Moreover, Ozturk et al.[17] utilized DC-Zirkon specimens and they found that increasing firings cycles number led to increase in L* and b* values while decrease in a*. In addition, Celik et al.[18] and Fathi et al.[2] showed that increasing firings cycles number led to lighter, greenish and yellowish color of specimens. These results are not completely in agree with our results. Our findings are only consistent with those of these studies regarding the increased b* value. This inconsistency may be resulted from the tested core materials optical properties. Moreover, change of color as result of multiple firings probably due to metal oxides color instability.[2, 17]

On contrary, the findings of this study align with previous studies. Uludag et al.[19] found that increasing number of firings cycles led to decrease L* and increase both a* and b* of IPS Empress and In-Ceram. Salary et al.[20] found that increasing firing cycles number led to zirconia based porcelain discoloration in vita system with L* decreased while the a* and b* increased. Moreover, Sahin et al.[21] noted reddish and yellowish specimens after repeated firings.

This study found that increasing the veneer thickness for all tested subgroups; 1, 3, 5, and 7 firing cycles resulted in statistically significant increasing in the mean values of L*, a* and b* parameters producing a lighter, more reddish and more yellowish behavior. This may be attributed to, behavior of material changes in response to light by increasing its thickness; as more amount of light is absorbed and scattered, resulting in a reduced amount of light being reflected and transmitted throughout material.[2] The findings align with those of Montero et al.[4] who revealed that thinner ceramic specimens had lower L*, a* and b* than thicker ones. Also, they align with with Jalalian et al.[22] and Fathi et al.[2] who concluded that increasing the veneer thickness (0.5 mm, 1 mm, and 1.5 mm thicknesses) of zirconia based ceramic restorations led to increasing the L*, a* and b*. In addition, several studies[6,16,17,23] found that the a* and b* increased with increasing veneer thickness.

In current study, the highest mean color difference (ΔE) value for group (A) specimens (3.34±0.35) was recorded between 1 and 7 firing cycles, while the lowest mean value (0.26±0.21) was found from 5 to 7 firing cycles. For group (B) specimens, the highest mean color difference value (2.72±0.19) was recorded between 1 and 7 firing cycles, while the lowest mean value (0.27±0.13) was found between 5 and 7 firing cycles. These findings are in agreement with those of Fathi et al.,[2] who detected the highest ΔE value in both zirconia core used between firing cycles 1 and 7, while the ΔE between 5 and 7 firings was the least.

Typically, minimum of 3 firing cycles are required for construction of ceramic restorations.[2] If ΔE values between two specimens is below 1 unit, then the specimens are deemed to be matched. ΔE value between 1 and 3.3 units exhibited significant variances, nevertheless deemed clinically satisfactory. ΔE values exceeding 3.3 can be detected by individuals without training, such as patients, and are considered clinically unacceptable.[24] The current study found that, ΔE values between all firing cycles were clinically unacceptable except between 1 and 7 firing cycles for 0.5 mm veneer thickness. All mean ΔE values for second group expressed clinically acceptable color difference except for A1-A7 where detectable color change was measured. Therefore, a little clinical concern should be taken for color change after repeated firings for restoration with thicker veneers.

In this study, for both veneer thicknesses, ΔE from 3 to 5, 3 to 7, and 5 to 7 firings was significantly lower than that from 1 to 3, 1 to 5, and 1 to 7 firings. These findings may be expressed in compliance with the results of Bayinder and Ozbayram study.[6] Uludag et al.[19] found that color difference decreased with multiple firing cycles, especially following firing cycle number five. That's resulted from stability of color of metal oxides after repetitive firings. In line with the current findings that the lowest mean ΔE values was found between 5 and 7 firing cycles, Celik et al.[18] found the least ΔE value in veneering porcelain shade when it was fired 7 to 9 times.

The highest color difference value between both main groups was found after the first firing cycle (4.79±0.30), while the lowest value was recorded after making three firing cycles (3.78±0.27). All calculated ΔE values between both groups after application of different firing cycles refers to unacceptable detectable color difference that all values were more than the 3.3 threshold. This means the veneer thickness had a significant influence on optical properties of zirconia-based ceramic restorations.

Edge loss phenomenon can affect the translucency measurements, that is, in accordance, influenced by size of specimen; smaller specimens are susceptible to edge loss. In current study this was avoided by utilizing 3-mm measuring tip spectrophotometer with 10-mm dimension specimen.[2] Regarding veneer thickness influence on the translucency parameter TP, it was revealed that, increasing thickness of zirconia veneer significantly decreased TP mean values at any number of firing cycles. In current study, 1 mm thickness of veneer showed lower TP than that of 0.5 mm thickness. That is agreed with results of Fathi et al.,[2] and Kursoglu et al.,[3] who found higher translucency with lower veneer thickness. Jeong et al.[25] also found increased transmittance value with decreasing thickness of veneer. Utilizing thicker veneer layer led to accumulation of more crystal content. Light reflection occurred within the range of veneering and framework, explaining translucency decrease by increasing the veneer thickness.[2,26]

This study showed that with increase of number of firing cycles, TP values increased. Bayinder et al[6] and Li et al.[27] concluded that the translucency was increased with increasing firing cycles number. The marked increase in translucency can be credited to pore volume changes resulted from repetitive firings.[2, 27]

Similar to what was found by Altan and Cinar,[1] the current study concluded that thin specimens are influenced more by multiple firings. For specimens with 0.5 mm veneer thickness, translucency first lowered with number of firings reached from 1 to 3, but then raised with firing cycles increased to 5 and 7. On contrary for 1 mm veneer thickness, the translucency increased from 1 to 3 firing cycles then no significant change occurred when firing cycles increased to 5 and 7. This refers to increasing the thickness of veneering material to 1 mm reduced the impact of repetitive firings on the translucency of zirconia-based restorations.

Success of prosthetic dentistry can be obtained by achieving high esthetics. Moreover, the esthetic success of restorations depends mainly on its color stability.[10] Accelerated Artificial Aging (AAA) had been evidenced to become an effective procedure to replicate the clinical environment, because of different conditions which the material is subjected to.[28, 29]

Specimens underwent thermal cycling and an artificial chewing simulation to replicate oral conditions. Standardized thermal cycling protocol seems to be lacking when comparing various studies. However, the International Organization for Standardization (ISO TR 11405) in 1994 recommended that thermos-cycling from 5°C to 55°C is as an accepted accelerated aging test. This method replicates the natural temperature range experienced in the mouth when consuming hot or cold beverages. Thermal cycling is recommended in range between 3000 and 100000 cycles. It is supposed that 10000 cycles simulate one year of oral life according to hypothesis that such thermal cycles may happen from 20 to 50 times per day.[12, 14] Therefore, to simulate one year of clinical service, 10000 thermal cycles from 5°C to 55°C were applied in this study.

Likewise for chewing simulation part, a consecutive separate exposure to loading cycles imitating also a one year wearing period, was performed. It was described that five years wearing period can be imitated using 1200000 chewing cycles.[31] Consequently, all specimens were subjected to 240000 cycles to simulate a one year wearing period. A mechanical load of 50 N was used corresponding to the average physiological chewing pressure, with steatite-ceramic antagonists because of their similar wear behavior with natural teeth.[32]

It was found that the applied fatigue aging protocol has decreased L* (darker) and increased both a* values (more reddish) and b* (more yellowish) for the specimens of all subgroups. In addition, it was found the specimens of group A had ΔE mean values more than the values calculated for specimens of group B. The highest color deference (ΔE) was observed for A7 subgroup (4.90±0.18) that is counted as unacceptable color change (more than the 3.3 threshold). The lowest ΔE value was found for B1 subgroup (1.59±0.10) that is considered an acceptable color change with ΔE less than 3.3.

The outcome of current study is in a partial accordance with outcome of a comparative in vitro study,[33] in which the maximum color change has occurred in the specimens with 0.5 mm thickness whereas, the minimum color change has occurred in the specimens with 2 mm thickness. However, these color changes were beyond clinically perceptible threshold for all tested thicknesses showing high color stability after exposure to a protocol of fatigue aging. Similarly, Koseoglu et al.[34] examined the impact of artificial aging on optical properties of monolithic zirconia fabricated with different thicknesses (0.5 mm, 1 mm, 1.5 mm and 2 mm). They found that L*, a *, b* reduced with all thicknesses and the highest ΔE was produced with 0.5 mm thicknesses, whereas lowest ΔE was noticed with 2 mm thicknesses.

With regard to the influence of fatigue aging on the translucency, the TP mean values had increased for all subgroups of our study. This result is compatible with Putra et al.[11] who also examined the impact of hydrothermal aging on zirconia-based ceramic restorations translucency. In contrast, Koseoglu et al.[34] and Fathy et al.[35] revealed that the translucency reduced with all tested thicknesses and the highest TP was noticed with specimens of 0.5 mm thickness, while the lowest TP was noticed with 2 mm thickness specimens. This incompatibility with our study could be as a result of variations in the study design including the tested zirconia type and the applied aging protocol. Also, the measuring protocol and the used measuring device might have an impact on these incompatible results.

There are certain limitations to be considered in this study. The study utilized specimens with disk-shape rather than specimens with tooth-shape. Vita Easyshade spectrophotometer was used but repeatability and reliability of it did not match those of some similar devices.[36] Using other brands of zirconia and other spectrophotometer devices is advisable for the upcoming research to determine color stability and translucency parameter of zirconia-based ceramic restorations with different veneer and core thicknesses after multiple firings. Clinical studies are important to examine color change under different clinical conditions, rejecting or confirming the results of this current in vitro study.

CONCLUSIONS

The conclusions drawn were based on the limitations of this in vitro study:

1. Both firing cycles and veneer thickness had a significant influence on optical properties of zirconia ceramic restorations.
2. Increasing number of firing cycles for both tested veneer thicknesses resulted in increased translucency with an acceptable darker, more reddish and more yellowish behavior of zirconia ceramic restorations.
3. Increasing veneer thickness for all tested firing cycles resulted in decreased translucency with unacceptable lighter, more reddish and more yellowish picture of zirconia ceramic restorations.
4. Artificial fatigue aging had a significant effect on optical properties of zirconia ceramic restorations. 1 mm veneer thickness yielded a minimal color change at different firing cycles, while the translucency increased for both 0.5 mm and 1 mm veneer thicknesses after repeated firings.

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