THE COLOR STABILITY OF MULTILAYERED SUPER TRANSLUCENT MONOLITHIC ZIRCONIA (STM-ZR) CEMENTED TO DIFFERENT IMPLANT-ABUTMENT SUBSTRATES AFTER ACCELERATED AGEING IN VITRO

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ABSTRACT

INTRODUCTION: As the color of super translucent monolithic zirconia (stm-Zr) cemented to underlying substrates were not widely studied, the purpose of this in vitro study was to investigate the color stability of (stm-Zr) cemented to different implant-abutment substrates after accelerated ageing.

MATERIALS & METHODS: Multilayered CubeX (5mol%Y2O3) was milled in discs (n=24) and was divided into three groups cemented to different substrate materials (n=8); titanium grade-V (group-A), IPS e.max ZirCAD-MT (4mol%Y2O3) (group-B), and IPS e.max ZirCAD-LT (3mol%Y2O3) (group-C), to simulate commonly used implant abutment materials. Cemented samples were characterized for their color before and after accelerated ageing.

RESULTS: After ageing significant decrease in color stability in (group A) compared to the other two groups, B and C ($p<0.015$) & ($p<0.001$).

CONCLUSION: 3Y-TZP zirconia showed a more negligible ageing effect with low-temperature degradation compared to the 5Y-TZP

KEYWORDS: Super-translucent zirconia; implant abutment; accelerated ageing; color stability; phase transformation.

RUNNING TITLE: Color stability of multilayered zirconia cemented on abutments after ageing

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INTRODUCTION

The optical behavior of STM-Zr must be similar to that of natural teeth in order to create an appealing look. Nonetheless, particle size, heat rate, sintering temperature, and sintering holding time all have an impact on their color appearance during fabrication processes (1, 2). Since human perceptibility of color appears to be subjective, the color appearance is primarily determined by the spectral reflectance generated by light scattering at the surface, which has a strong influence on the color appearance of ceramic and can be scientifically quantified using the Commission International de l'Eclairage (CIE) system (3).

Dental implants have become a successful treatment option for the prosthetic rehabilitation of total and partial edentulism and better serve patients concerning function, phonetics, and esthetics (4). However, their use to replace missing teeth in the esthetic zone is challenging (5). Because of their well-documented biological and mechanical advantages, prefabricated titanium abutments are considered the gold standard for both implant-supported fixed and partial prostheses (4, 6, 7). Despite many advancements in the production and design of metal abutments, the metallic component remains a drawback. Because they induce grayish discoloration under the peri-implant mucosa, these titanium abutments cannot match the appearance of natural teeth (4-6, 8). To address this esthetic issue, all-ceramic abutments constructed of aluminium oxide or yttrium-stabilized zirconium oxide have been developed (4, 5, 9).

When more fine ceramics are utilized in thin sections approaching 1.5 mm, clinicians must be careful in selecting substrates because the background type has a significant impact on the color of ceramic systems (1, 9-11).

Several ceramic material systems are now available for implant-supported restorations. However, the phase instability of 3Y-TZP ceramics causes low-temperature deterioration (LTD), also known as ageing. When the material is exposed to moisture at rather higher temperatures, the tetragonal granules on the surface begin to shift spontaneously to the monoclinic phase. The volume expansion associated with the t-m transformation causes surface roughening, grain pull-outs, and extensive microcracking, all of which can lead to strength loss in the long run (12).

LTD is temperature-dependent, with the fastest progress occurring between 200 and 300 ° C. (13). It has also been shown that it happens at a much lower rate at human body temperature (14). The t-m phase transformation is affected by chemical and phase composition, microstructure, surface topography, and testing conditions (15, 16).

The use of 4 mol % Y2O3 and 5 mol % Y2O3 to stabilize monolithic translucent zirconia led to the development of new materials for clinical use, indicating the need for more research to validate the color stability of monolithic translucent zirconia over longer periods of time when exposed to moisture and different oral conditions.

The purpose of this study was to assess the effect of accelerating ageing on three different types of implant-abutment materials: titanium grade V, IPS e.max ZirCAD 4mol%Y2O3 and IPS e.max ZirCAD LT 3mol%Y2O3 on the color of STM-Zr (Multilayered CubeX zirconia-5mol% Y2O3)

This study's null hypothesis was no difference in the color stability of the multilayered type of the STM-Zr when cemented to different substructures and subjected to accelerated ageing.

MATERIALS AND METHODS

2.1 Specimens designing and Preparation: Zirconia and titanium blocks were used to mill crowns and substrate specimens. First, two designs were made using AutoCAD software to produce discs (10mm diameter x 1mm thickness) (for crown specimens), and the other design was (10mm diameter x 2mm thickness) (for abutment specimens). Both designs were saved as (.STL) files to be read by the CAD/CAM machine software.

2.1.1. For Ceramic Crown Specimens: Multilayered CubeX STM-Zr of shade (A2) was milled to the prepared disc-shaped design (n=24). Specimens were then sintered according to the manufacture's recommendations.

2.1.2. For Substrate Specimens: three groups were prepared (n=8) according to the substrate material used: titanium grade V (group A), IPS e.max ZirCAD MT A2 (group B), and IPS e.max ZirCAD LT A2 (group C) to simulate commonly used implant abutment materials. A schematic diagram presenting the study design is shown in (Fig. 1), and a summary of zirconia materials used and their compositions are seen in (Table 1)

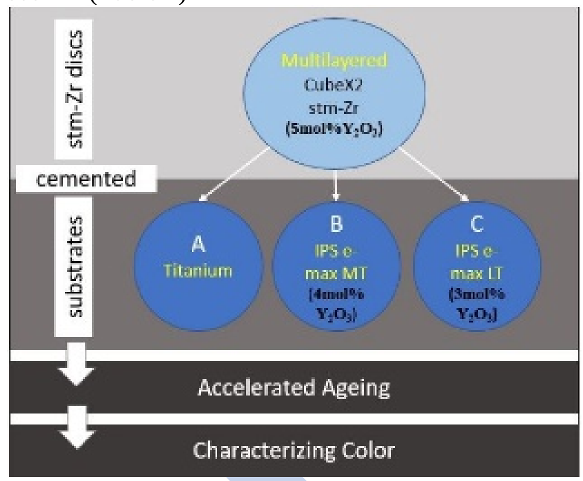

Fig. 1. Schematic diagram showing the study design

Table (1): Summary of Zirconia materials used and their compositions

Material/Produc	Multilayered CubeX	IPS e.max ZirCAD MT	IPS e.ma ZirCAD LT
Zirconium oxide (ZrO2)	< 90 %	86.0 – 93.5%	88.0 – 95.5 %
Yttrium oxide (Y2O3)	< 10 %	> 6.5 % – ≤ 8.0 %	> 4.5 % – ≤ 6.0 %
Hafnium oxide (HfO2)	< 5 %	≤ 5.0%	≤ 5.0%
Aluminium oxide (Al2O3)	< 0.5%	≤ 1.0%	≤ 1.0%
Other oxides	< 1 %	≤ 1.0%	≤ 1.0%
TYPE	5Y-TZP	4Y-TZP	3Y-TZP

2.2. Cementation: All specimens (crowns and substrates) were sandblasted by aluminum oxide particles (110um) for 20 seconds under the pressure of 0.2 MPa by sandblasting machine and then dried with an air stream (17). Consecutively, the ceramic primer was applied to the substrate's adherent surfaces followed by the adhesive dual cured resin cement (Panavia V5, Universal shade (A2)) for each group and placed under a static load of 3kgs for two minutes (18). Excess resin cement was removed, and specimens were light-cured for 10 seconds from each surface to ensure complete curing of the resin cement according to the manufacturer's instructions. (Fig.2)

2.3. Aging of the Specimens: Specimens underwent accelerated aging after cementation of materials to mimic how they are presented in the oral cavity in a steam autoclave (Hygenius Fona- Slovak Republic) at 134°C, 0.2 MPa (19). After setting the autoclave to the needed temperature and pressure values, ageing effects were evaluated after 5 hrs. (10 cycles-30min/cycle) in correspondence to the standard ISO

13356 (20). Previous researches have shown that ageing for 1 hour in an autoclave is similar to 3-4 years of actual ageing (21, 22). As a result, the study's ageeing parameters are comparable to 15-20 years of actual ageing, which is the projected lifespan of zirconia restorations (23).

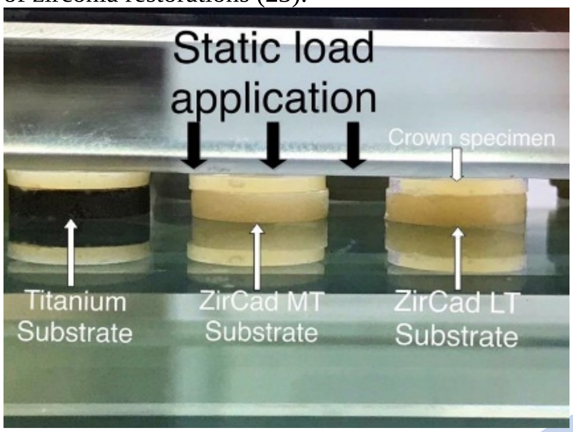

Fig. 2: Stm-Zr discs while being cemented on Titanium and Zr-based substrates with applied static load.

2.4. Testing: Specimens of all the groups were tested before and after aging accordingly for:

Color: The color of the stm-Zr was measured against the three different substrates using Vita Easy shade before ageing. The spectrophotometer was calibrated by using a white tile before each measurement. The measurements were performed by placing the spectrophotometer's tip in contact with the center of the disk. The mean value of 3 sequential measurements of L*, a*, and b* were recorded. (24, 25). Color measurements were recorded once again after ageing. ΔE was calculated using the following equation: $\Delta E = (\Delta L)2+ \Delta a2+(\Delta b)2$

ΔL (lightness), Δa, and Δb (representing red and yellow tinges, respectively) are the individual differences in the L, a, and b color parameters between the two colors measured for each specimen before and after aging (26).

2.5 Statistical analysis: IBM SPSS software version 20.0 (IBM Corporation, Armonk, NY) was used to input data into the computer and analyze it. The Kolmogorov-Smirnov test was employed to ensure that the distribution was normal. A range (minimum and maximum), mean, standard deviation, and median were used to describe quantitative data. F-test (ANOVA) for normally distributed quantitative variables to compare between more than two groups and Post Hoc test (Tukey) for pairwise comparisons were used to determine the significance of the obtained results at the 5% level.

RESULTS

3.1 Color Analysis: Descriptive statistics as means of ΔE and standard deviations, min-max, and median for all the studied groups were calculated, and the p-value for each group was compared with each other. (Table 2)

Table (2): Comparison between ΔE of different groups of Multilayered CubeX zirconia-5mol%Y_2O_3

	Multilayered CubeX Zirconia			**F**	**P**
	A (n = 8)	**B (n = 8)**	**C (n = 8)**		
Min. – Max.	1.27 – 5.42	0.42 – 2.59	0.14 – 1.03		
Mean ± SD.	3.30 ± 1.69	1.57 ± 0.93	0.49 ± 0.27	12.772*	<0.001*
Median	3.44	1.64	0.43		
Sig. bet. Grps.	p_1=0.015*,p_2<0.001*,p_3=0.158				

F: F for ANOVA test, Pairwise comparison between each 2 subgroups was done using Post Hoc Test (Tukey)
p: p value for comparing between the different subgroups
p_1: p value for comparing between A and B
p_2: p value for comparing between A and C
p_3: p value for comparing between B and C
*: Statistically significant at $p \le 0.05$

The highest mean ΔE was recorded in group-A (3.30 ± 1.69), followed by group-B (1.57 ± 0.93), while group-C showed the least mean value of ΔE (0.49 ± 0.27). The F-test (ANOVA) for statistical analysis showed significant differences between group-A (Titanium substrate) and the other two groups (B: ZirCAD MT substrate, C: ZirCAD LT substrate), (p<0.015) & (p<0.001), respectively. A summarizing bar chart for ΔE of all groups is illustrated in (Fig. 3).

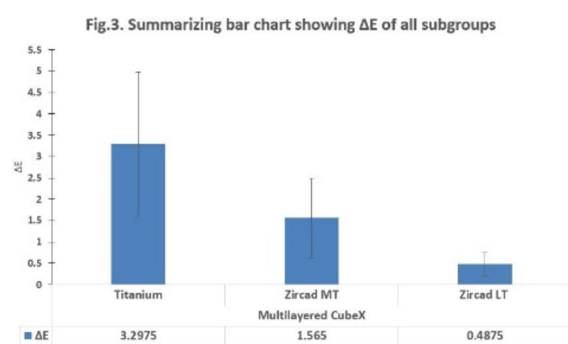

Fig. 3: Summarizing bar chart showing ΔE for all groups showing significance.

DISCUSSION

According to the results of this study, the null hypothesis was rejected;

Vita Easy shade V was the color measurement instrument of choice as it exhibits higher reliability, shade reproducibility, and accuracy (27-29).

Group-A (Titanium substrate) had the highest mean ΔE. In contrast, group-C (ZirCAD LT substrate) was the least mean value of ΔE. Thus, and could assume that using zirconium abutments resulted in a whiter appearance while titanium abutments caused a darker appearance after ageing. This finding is well documented in the literature (1, 11).

Using different substrate materials lead to variations, where titanium substrate showed the highest variation as its ΔL values were more significant than other zirconia substrates. This is probably because the ΔL values show light reflection from the surface of the metal background. Also, the Δa and Δb values did differ for specimens. Both Δa and Δb values were greater on titanium substrate than on zirconia, suggesting that red and yellow coloration shows through the titanium background giving a noted variation in ΔE.

The structure and amount of crystal content inside the core matrix, as well as the chemical nature and particle size, influence the incident light wavelength (ƛ) , which defines the translucency-opacity character of dental porcelain (30 ,31). The findings of this study revealed that implant abutment materials had a greater impact on the final color of translucent ceramic systems than opaque ceramic systems. A number of studies have backed up this conclusion (9, 29, 32-34).

The new stm-Zr is made by increasing the Y2O3 content, which results in two crystalline materials: 4Y-TZP and 5Y-TZP. Both types of grains are larger than 3Y-TZP, resulting in fewer grain boundaries, less birefringence, and light scattering (35). There is no significant light scattering because the scattering center (or grain boundary) is smaller than the wavelength of the light being scattered (36).These materials are thus more translucent and color stable than 3Y-TZP, with a two-fold increase in translucency (37).

This is true for the thermal treatments used here, but for longer sintering times or higher temperatures, equivalent behavior cannot be assured.

Pigments breaking down (burning the coloring metallic oxides) during heat exposure could be another cause of zirconia's color change (38-40). Because most oxide ceramics, such as alumina and related compounds, are made up of small particles, they produce a fine-grained polycrystalline microstructure filled with scattering centers with wavelengths comparable to visible light. In this study, the manufacturer of zirconia brands did not disclose the exact percent of the type and color of metallic oxides. Nevertheless, from the information given by the manufacturer, it can be claimed that the (Multilayered CubeX zirconia-5mol%Y2O3) have less aluminum oxide content (<0.5%) than the (ZirCAD LT-3mol%Y2O3) (≤ 1.0%); hence they scatter lightless, resulting in more color stability.

The findings of this study agree with those of Fathy, S.M. et al.(41) and Volpato et al. (42), who concluded that 3Y-TZP has a higher risk of low-temperature degradation, which could have a significant impact on the esthetic appearance and translucency of translucent Y-TZP and thus its durability. The results also support Alghazzawi's (43) conclusion that ageing affects zirconia's optical qualities, with the effects growing with time and the extent of change being affected by different brands of dental zirconia.

The findings of this work, however, differed with those of Hamza TA et al. (44), who evaluated the influence of artificially accelerated ageing on the color stability of three recently released CAD/CAM materials. They claimed that artificial accelerated ageing had no effect on the color stability of any of the three ceramic groups. This could be owing to difference in the study designs, measurement methods, and equipment.

After thermocycling, Koseoglu et al. (45) found that the color and translucency values in the 0.5 mm thickness group showed statistically significant alterations; no statistically significant differences were seen in the other thickness groups. However, this insignificance may be due to using different zirconia, ageing methodology, and light measuring equipment. Furthermore, Koseoglu recommended similarity in clinical conditions, where a single surface of the restoration is exposed to fluids in the mouth; In this case, the change in color values obtained from their study may vary from the values of color change obtained in other studies that simulate the clinical conditions, the thing which was done in this study.

Because localized t–m transformation may prevent a crack from propagating, the metastability of the Y-TZP tetragonal grains at body/mouth temperature appears perfect for utilizing zirconia as a dental restorative material. This could help Y-TZP devices last longer while they are under load (46) However, for long-term clinical success of esthetic restorations, the color must be stable to assure accurate color matching.

Increased yttria content increases the translucency of yttria-stabilized zirconia but decreases the strength (little or no phase transformation toughening), limiting the use of high yttria content zirconia to low stress-bearing areas (47, 48).

In this study, accelerated hydrothermal ageing, simulating the oral environment, was done after cementation of materials to mimic how they are present in the oral cavity, where the crown material is cemented to the underlying abutment substructure. As the monoclinic phase increases after ageing, the low-temperature degradation increases, and the aging resistance decreases.

The results of this study are in agreement with Kim, H.-K., & Kim, S.-H. (49), who concluded that hydrothermal ageing affected pre-colored monolithic zirconia ceramics' optical properties and microstructure.

The findings of this work contradict those of Ahmed et al. (50), who investigated the optical properties of ultra-translucent tetragonal/cubic zirconia after artificial ageing. The optical characteristics and flexural strength of tetragonal/cubic zirconia are not affected by hydrothermal aging, they claim. This is most likely owing to the study design differences.

Although the novelty of this paper, the authors consider that it has few different limitations. First of all, the authors suggest that other color measurements such as translucency parameter, contrast ratio and opalescence parameter can be tested. Moreover, more than one commercial brand of translucent zirconia (5mol%Y2O3) can be compared to see if the manufacturer has an effect on the color stability.

CONCLUSION

Within the limitation of this study, it can be concluded that:

1-In order to achieve a better esthetic outcome for implant-supported ceramic restorations, zirconia is preferable over titanium as an abutment material.

2- The final color of more translucent ceramic systems was influenced by implant abutment materials more than opaque ceramic systems, since translucent materials reflect the underlying material's color more than opaque ones.

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REFERENCES

1. Nakamura T, Saito O, Fuyikawa J, Ishigaki S. Influence of abutment substrate and ceramic thickness on the colour of heat-pressed ceramic crowns. Journal of oral rehabilitation. 2002; 29: 805-9.
2. Azer SS, Ayash GM, Johnston WM, Khalil MF, Rosenstiel SF. Effect of esthetic core shades on the final color of IPS Empress all-ceramic crowns. The Journal of prosthetic dentistry. 2006; 96:397-401.
3. Massoud YA. A method for fabricating a cast post and core that is esthetic when used under an all-ceramic crown. The Journal of prosthetic dentistry. 2002; 88:553-4.
4. Kohal RJ, Att W, Bächle M, Butz F. Ceramic abutments and ceramic oral implants. An update. Periodontology 2000. 2008; 47:224-43.
5. Bressan E, Paniz G, Lops D, Corazza B, Romeo E, Favero G. Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: a prospective multicenter study. Clinical oral implants research. 2011; 22:631-7.
6. Jung RE, Sailer I, Hammerle C, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. International Journal of Periodontics and Restorative Dentistry. 2007; 27:251.
7. Dede DÖ, Armaganci A, Ceylan G, Çankaya S, Çelık E. Influence of abutment material and luting cements color on the final color of all ceramics. Acta Odontologica Scandinavica. 2013; 71:1570-8.
8. Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. Clinical oral implants research. 2007; 18: 569-74.
9. Uzun G, Keyf F. Effect of different cement colors on the final color of IPS Empress ceramic restorations. Biotechnology & Biotechnological Equipment. 2007; 21:501-5.
10. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque posts. The Journal of prosthetic dentistry. 2000; 83:412-7.
11. Jalali H, Alizadeh ES, Sadighpour L, Shabestari G, Fard M. The effect of background and ceramic thickness on the color of an all-ceramic restorative system. Journal of the California Dental Association. 2010; 38:179-86.
12. Flinn BD, Raigrodski AJ, Singh A, Mancl LA. Effect of hydrothermal degradation on three types of zirconias for dental application. The Journal of prosthetic dentistry. 2014; 112:1377-84.
13. Yoshimura M. Phase stability of zirconia. Am Ceram Soc Bull. 1988; 67:1950-5.
14. Keuper M, Berthold C, Nickel KG. Long-time aging in 3 mol.% yttria-stabilized tetragonal zirconia polycrystals at human body temperature. Acta biomaterialia. 2014; 10:951-9.
15. Lawson S. Environmental degradation of zirconia ceramics. Journal of the European ceramic society. 1995; 15:485-502.

16. Chevalier J, Gremillard L, Virkar AV, Clarke DR. The tetragonal-monoclinic transformation in zirconia: lessons learned and future trends. Journal of the American Ceramic Society. 2009; 92:1901-20.
17. Su N, Yue L, Liao Y, Liu W, Zhang H, Li X, et al. The effect of various sandblasting conditions on surface changes of dental zirconia and shear bond strength between zirconia core and indirect composite resin. The journal of advanced prosthodontics. 2015; 7:214-23.
18. Aboushelib MN, Feilzer AJ, Kleverlaan CJ. Bonding to zirconia using a new surface treatment. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2010; 19:340-6.
19. Standardization. IOf. ISO13356. Implants for surgery Ceramic materials based on yttria stabilized tetragonal zirconia (Y-TZP). ISO: Geneva, Switzerland,2008.
20. Wille S, Zumstrull P, Kaidas V, Jessen LK, Kern M. Low temperature degradation of single layers of multilayered zirconia in comparison to conventional unshaded zirconia: phase transformation and flexural strength. Journal of the mechanical behavior of biomedical materials. 2018; 77:171-5.
21. Nakamura K, Harada A, Kanno T, Inagaki R, Niwano Y, Milleding P, et al. The influence of low-temperature degradation and cyclic loading on the fracture resistance of monolithic zirconia molar crowns. Journal of the mechanical behavior of biomedical materials. 2015; 47:49-56.
22. Chevalier J, Cales B, Drouin JM. Low-temperature aging of Y-TZP ceramics. Journal of the American Ceramic Society. 1999; 82:2150-4.
23. Sanon C, Chevalier J, Douillard T, Cattani-Lorente M, Scherrer SS, Gremillard L. A new testing protocol for zirconia dental implants. Dental Materials. 2015; 31:15-25.
24. Dede DÖ, Armağanci A, Ceylan G, Celik E, Cankaya S, Yilmaz B. Influence of implant abutment material on the color of different ceramic crown systems. The Journal of Prosthetic Dentistry. 2016; 116:764-9.
25. Dozić A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color-measuring devices. Journal of Prosthodontics. 2007; 16:93-100.
26. l'Eclairage CId. Colorimetry Publication CIE, No. 15.3. Central Bureau of the CIE Vienna, Austria; 2004.
27. Derdilopoulou FV, Zantner C, Neumann K, Kielbassa AM. Evaluation of visual and spectrophotometric shade analyses: a clinical comparison of 3,758 teeth. International Journal of Prosthodontics. 2007; 20:414.
28. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. The Journal of prosthetic dentistry. 2009; 101:193-9.
29. Klotz A-L, Habibi Y, Hassel AJ, Rammelsberg P, Zenthöfer A. How reliable and accurate is the shade determination of premolars by spectrophotometry? Clinical Oral Investigations. 2019:1-6.
30. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part I: core materials. The Journal of prosthetic dentistry. 2002; 88:4-9.
31. Brodbelt R, O'brien W, Fan P. Translucency of dental porcelains. Journal of Dental Research. 1980; 59:70-5.
32. Barath VS, Faber F-J, Westland S, Niedermeier W. Spectrophotometric analysis of all-ceramic materials and their interaction with luting agents and different backgrounds. Advances in dental research. 2003; 17:55-60.
33. Li Q, Yu H, Wang Y. Spectrophotometric evaluation of the optical influence of core build-up composites on all-ceramic materials. Dental Materials. 2009; 25:158-65.
34. Chang J, Da Silva JD, Sakai M, Kristiansen J, Ishikawa-Nagai S. The optical effect of composite luting cement on all ceramic crowns. Journal of dentistry. 2009; 37:937-43.
35. Zhang F, Reveron H, Spies BC, Van Meerbeek B, Chevalier J. Trade-off between fracture resistance and translucency of zirconia and lithium-disilicate glass ceramics for monolithic restorations. Acta Biomaterialia. 2019; 91:24-34.
36. Shen J. Advanced ceramics for dentistry: Butterworth-Heinemann; 2013.
37. Klimke J, Trunec M, Krell A. Transparent tetragonal yttria-stabilized zirconia ceramics: influence of scattering caused by birefringence. Journal of the American Ceramic Society. 2011; 94:1850-8.
38. Bachhav VC, Aras MA. The effect of ceramic thickness and number of firings on the color of a zirconium oxide based all ceramic system fabricated using CAD/CAM technology. The journal of advanced prosthodontics. 2011; 3:57-62.
39. Gonuldas F, Yılmaz K, Ozturk C. The effect of repeated firings on the color change and surface roughness of dental ceramics. The Journal of Advanced Prosthodontics. 2014; 6:309-16.
40. Yılmaz K, Gonuldas F, Ozturk C. The effect of repeated firings on the color change of dental ceramics using different glazing methods. The journal of advanced prosthodontics. 2014; 6:427-33.

41. Fathy SM, El-Fallal AA, El-Negoly SA, El Bedawy AB. Translucency of monolithic and core zirconia after hydrothermal aging. Acta biomaterialia odontologica Scandinavica. 2015; 1:86-92.
42. Volpato CÂM, Cesar PF, Bottıno MA. Influence of accelerated aging on the color stability of dental zirconia. Journal of Esthetic and Restorative Dentistry. 2016; 28:304-12.
43. Alghazzawi TF. The effect of extended aging on the optical properties of different zirconia materials. Journal of prosthodontic research. 2017; 61:305-14.
44. Hamza TA, Alameldin AA, Elkouedi AY, Wee AG. Effect of artificial accelerated aging on surface roughness and color stability of different ceramic restorations. Stomatological Dis Sci. 2017; 1:8-13.
45. Koseoglu M, Albayrak B, Gül P, Bayindir F. Effect of Thermocycle Aging on Color Stability of Monolithic Zirconia. Open Journal of Stomatology. 2019; 9:75-85.
46. Garvie RC, Hannink RH, Pascoe RT. Ceramic steel? Nature. 1975; 258:703.
47. Camposilvan E, Leone R, Gremillard L, Sorrentino R, Zarone F, Ferrari M, et al. Aging resistance, mechanical properties and translucency of different yttria-stabilized zirconia ceramics for monolithic dental crown applications. Dental Materials. 2018; 34:879-90.
48. Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, et al. Strength, toughness and aging stability of highly-translucent Y-TZP ceramics for dental restorations. Dental Materials. 2016; 32:e327-e37.
49. Kim H-K, Kim S-H. Effect of hydrothermal aging on the optical properties of precolored dental monolithic zirconia ceramics. The Journal of prosthetic dentistry. 2019; 121:676-82.
50. Ahmed DMA, Mandour MH, El-Sharkawy ZR. Optical Properties and Flexural Strength of Artificially Aged Tetragonal/Cubic Ultra-Translucent Zirconia. Al-Azhar Dental Journal for Girls. 2020; 7:135-42.