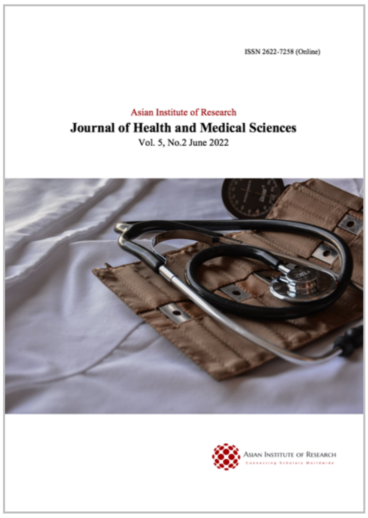

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Evaluation of Discoloration After Thermocycling in CAD/CAM Blocks of Different Thicknesses

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Abstract

The study aims to evaluate the color of CAD/CAM blocks of different thicknesses after thermocycling as in-vitro. A total of 180 samples (n=10) were prepared in 2 thicknesses (0.5mm, and 1.0 mm) from various CAD/CAM blocks of different structures (Katana UTML, Prettau® 4 Anterior® Dispersive, IPS e-max Cad, Vita YZ-XT, Vita YZ-T, Vita Suprinity PC, Vita Enamic, Shofu HC, G-Ceram). The color values of the samples (L*, a*, b*) were measured before and after thermocycling. The discoloration (ΔE) data obtained were statistically compared with two way-ANOVA, Tukey HSD posthoc tests, and Paired Sample T-Test ($p<0.05$). The highest average discoloration was found in the Katana group (ΔE=3.07) with a thickness of 1 mm, while the lowest was found in the Shofu HC group (ΔE=0.49) with a thickness of 0.5 mm. In contrast, the ΔE value was significantly different in samples with a thickness of 1 mm and 0.5 mm ($p<0.05$), there was no difference in the ΔE values in the groups in themselves. Discoloration values of test materials depending on thickness varied, but the difference of thickness in the same material did not affect the color change. All the color changes were clinically accepted.

Keywords: Computer-Aided Design, Prosthesis Coloring, Dental Materials

1. Introduction

The undesirable features of metal-ceramic restorations and the increasing aesthetic demands of dentists and patients have led to all-ceramic systems as an alternative. A wide range of ceramic products was introduced in terms of content, starting with John Mclean's introduction of aluminous core porcelain materials in 1965 and then with improvements in the aesthetic, durability properties, and production methods of all ceramic materials (Conrad et al., 2007; McLean & Hughes, 1965; Ueda et al., 2015). When current all-ceramic materials were examined, it was observed that the mechanical properties of ceramics, which usually have excellent aesthetic properties, were inadequate, and the aesthetic properties of ceramics with good mechanical properties were insufficient (Zarone et al., 2011). Feldspathic porcelain and glass ceramics exhibit excellent optical properties. Although aesthetic restorations close to the surface features of the natural tooth can be obtained, its mechanical properties are inadequate in posterior region restorations (Matsuzaki et al., 2015; Sen & Us, 2018). Hence high durability zirconium oxide ceramics were developed in the early 1990s, and full ceramic restorations were allowed in posterior regions with high chewing forces (Harianawala et al., 2014). Since zirconium ceramics have an opaque structure, they need to be coated (veneering) with feldspathic porcelain to achieve natural-looking restorations. However, fractures in veneer porcelain (chipping) have been a severe problem (Guess et al., 2008). Thanks to the developing computer-aided design and computer-aided production (CAD/CAM) technologies, monolithic zirconium restorations have been achieved in a more light-passing (translucent) and color-layered (polychromatic) structure with improvements in production processes and sinterization temperatures. Thus, an important alternative has been created to solve the problem of fracture seen in traditional zirconium cor infrastructure restorations (Jiang et al., 2011; Zhang et al., 2013). Studies aimed at increasing the translucent properties of zirconia ceramics and monolithic zirconium blocks with polychromatic properties similar to the color transitions of the tooth between enamel dentin look very promising for restoration production brings mechanical and aesthetic properties together. The thickness of the restorative material, surface properties, color of the tooth structure, the cement used, the final color of the ceramic materials of the translucent feature can affect the result, as well as the long-term exposure of restoration to the oral environment (Dede et al., 2013).

CAD/CAM technology has become frequently used in dentistry today. With the advances in technology and materials, CAD/CAM technology will play an essential role in producing dental restorations in the future. This technology makes it possible to make high-quality and error-accurate restorations. It also requires less laboratory work than other techniques used (Douglas, 1997). The biggest challenge encountered in aesthetic restorations is achieving color harmony with natural teeth. Obtaining the final color of a ceramic restoration as planned is a highly complex phenomenon. It depends on many factors such as the color, light source, ceramic variety, ceramic thickness, coping color, adhesive cement color, and opacity perceived in ceramic restorations. These factors can change the final restoration color (Terzioğlu et al., 2009). Another factor that affects the final color of restorations is the color of the infrastructure. The color and thickness of the infrastructure material, the number and thickness of the porcelain used in the superstructure, glazing processes, and the selected cementation agent affect the color in all-ceramic systems (Chu et al., 2007).

Studies have shown that material thickness affects the optical properties of its material (Kim et al., 2016). As the thickness of the material increases, the path of light in the material increases. As a result, the light is further absorbed and emitted, reducing the amount of light passing through the material (O'Keefe et al., 1991). This causes the material to have different optical properties of different thicknesses. The fact that the optical properties of restoration remain stable after aging is also one of the main factors determining the success of the material used. This study aims to evaluate the effect of thermocycling on the color of samples of two different thicknesses prepared with different types of CAD/CAM ceramic blocks.

2. Method

This study evaluated color changes after thermocycler of 0.5 and 1-mm thick samples obtained from different types of CAD/CAM blocks (Table 1). Partially sintered zirconia blocks were sintered, and blocks of the green stage of lithium disilicate glass-ceramics were heated according to the manufacturer's specifications. Test specimens (n=10) each were prepared with 10 mm (length) x 10 mm (width) x 0.5 or 1.0 mm (thicknesses). The color chosen for the samples was A2. These sample thicknesses were chosen based on the recommended 0.5 mm margin and 1.0 mm occlusal thickness for monolithic zirconia restorations. Samples were cut with a diamond disc from each block, ground with a surface grinding plate (#100, #600) on a grinding machine (MINITEC-333 ;Presi Eybens; France), and polished with water-resistant sandpapers #1000 and #2000 (Figure 1a). For producing 0.5mm and 1.0mm thicknesses. The thickness of the samples was measured and verified with a digital caliper.

2.1 Aging in Thermal Cycle (Cycle)

Universal-Testing Machine MTE-100 (Mod Dental; Turkey) is a thermal cycle device used for thermal cycle testing (Figure 1b). A thermal cycle was applied to all groups at 5°- 55° C de 10000 times.

2.2 Making Color Measurements before and after Aging of Samples

The color measurements of the samples, which are produced from 9 different materials and aged in 2 different thicknesses, were re-calibrated with the Lovibond RT Series Reflectance Tintometer UK spectrophotometer (Lovibond; Germany) before each measurement and made before and after aging.

2.3 Calculation of Color Changes of Samples

Measurements were recorded before and after aging, ΔE color differences were made to the 3D International Commission on Illumination International Lighting Bordu CIE Lab specifications by detecting the L* a* b* coordinates of 3 locations in the CIE Lab color space. ΔE value, change in L* a* b* coordinates before and after aging $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ formula. ΔE value, mean and standard deviations were calculated from L* a* b* values for ten samples in each group tested.

2.4. Statistical Analysis

Bi-directional variance analysis was used for repeated measurements in comparison of ΔE color change values. In contrast, ANOVA analysis, a parametric test, was performed in the IBM SPSS 20.0 package program. The Tukey multi-comparison test and paired sample T-Test were applied to compare groups. The results for $p<0.05$ were considered statistically significant. ΔE values below 3.0 are clinically undetectable, ΔE values between 3.0 and 5.0 are clinically acceptable, and ΔE values above 5.0 are clinically unacceptable. These ΔE values are based on previous studies' mean acceptability and detectability thresholds (Nogueira & Della Bona, 2013).

Table 1: Used test materials

Yttrium stabilized Zirconia	Katana UTML	Noritake Dental Co, Nagoya, Japon	$(ZrO_2 + HfO_2 + Y_2O_3)$> 99.0%, Y2 O3 > 4.5-≤6.0%, HfO_2 ≤5.0%, other oxits ≤1.0%
Yttrium stabilized Zirconia	Prettau® 4 Anterior® Dispersive	Zirkonzahn GmbH, Bruneck,Italy	<12% Y_2O_3, <1% Al_2O_3, max. 0.02% SiO2, max. 0.01% Fe_2O_3, max. 0.04% Na_2O
Lithium distilled glass ceramic	IPS e-max Cad	İvoclar Vivadent, Schaan, Liechtenstein	SiO_2 57-80%, Li_2O 11-19%, K_2O 0-13%, P_2O_5 0,-11%, ZrO_2 0–8%, ZnO 0–8% with other oxides and ceramic pigments 0≤10%
Extra translucent zirconia	Vita YZ-XT	Vita Zahnfabrik H. Rauter GmbH, Bad Sackingen, Germany	Zro_2 86-91%, Y_2O_3 8-10%, HfO_2 1-3%, Al_2O_3 0-1%, Pigments 0-1%
Translucent zirconia	Vita YZ-T	Vita Zahnfabrik H. Rauter GmbH, Bad Sackingen, Germany	ZrO_2 90-95%, Y_2O_3 4-6%, HfO_2 1-3%, Al_2O_3 0-1%, Pigments 0-1%
Lithium silicate reinforced with zirconia	Vita Suprinity PC	Vita Zahnfabrik H. Rauter GmbH, Bad Sackingen, Germany	SiO_2 56–64 % ,Li_2O 15–21%, K_2O 1 – 4%, P_2O_5 3–8%, Al_2O_3 1–4%, ZrO_2 8–12%, CeO_2 0–4%, La_2O_3 %0.1, Pigments 0 – 6%
Feldspar ceramic enriched with aluminum oxide	Vita Enamic	Vita Zahnfabrik H. Rauter GmbH, Bad Sackingen,Germany	UDMA, TEGDMA 86.0 (75.0)
Hybrid ceramic	Shofu HC	Shofu Inc., Kyoto, Japan	UDMA, TEGDMA Silica powder, micro fumed silica, zirconium silicate 61.0
Feldspathic monochromatic glass ceramic	G-Ceram	Atlas-Enta Dental A.Ş., İzmir, Turkey	SiO_2 56-58%, Al_2O_3 18-25%, Na_2O 8-12%, K_2O 8-14%, CaO 0,2-1%, TiO_2 0,1-0,2%
Bis-GMA, bisphenol A di glycidyl ether methacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-EMA, ethoxylated bisphenol-A dimethacrylate			

Table 2: Overall discoloration values

Descriptive Statistics
Dependent Variable: Discoloration

Thickness	Groups	Mean	Std. Deviation	N
0.5-mm	VİTA YZ-T	1.24	0.20	10.00
	SUPRİNTY	0.90	0.29	10.00
	VİTA YZ-XT	1.34	0.33	10.00
	G-CERAM	1.97	0.79	10.00
	KATANA	1.92	0.15	10.00
	PRETTAU	1.11	0.09	10.00
	E-MAX	2.81	0.40	10.00
	SHOFU	0.49	0.09	10.00
	VITA ENAMIC	1.05	0.31	10.00
1-mm	VİTA YZ T	1.25	0.14	10.00
	SUPRİNTY	0.98	0.26	10.00
	VİTA YZ XT	1.44	0.24	10.00
	G-CERAM	1.76	0.58	10.00
	KATANA	3.07	0.61	10.00
	PRETAU	1.27	0.08	10.00
	E-MAX	2.93	0.71	10.00
	SHOFU	0.56	0.12	10.00
	VITA ENAMIC	0.96	0.29	10.00
	Total	1.50	0.83	180.00

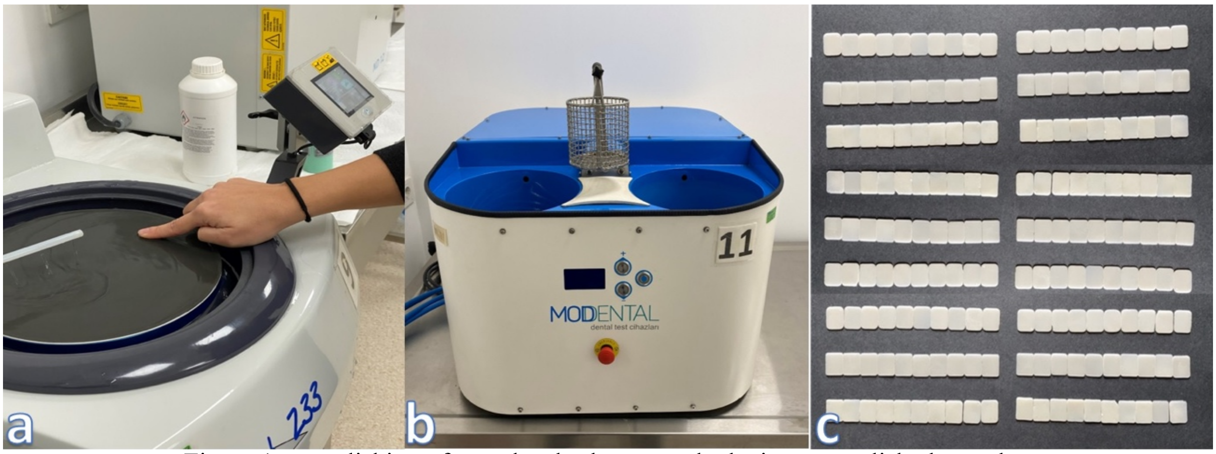

Figure 1: a: polishing of samples; b: thermocycle device, ; c: polished samples

3. Results

There was a difference in the values of discoloration between the groups. It was found that the highest color changes were in the Katana group (3.07) (Table 2) and that the different material thicknesses did not make a statistical difference in the color change of the materials (Table 3 and 4). All values were clinically accepted ($2.1< \Delta E < 3.5$) (Figure 2).

Table 3: Tests of Between-Subjects Effects

Dependent Variable: Discoloration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	101.208[a]	17	5.953	40.907	0.000
Intercept	406.231	1	406.231	2791.298	0.000
thickness	1.100	1	1.100	7.557	0.007
groups	93.960	8	11.745	80.702	0.000
thickness * groups	6.148	8	0.768	5.280	0.000
Error	23.577	162	0.146		
Total	531.015	180			
Corrected Total	124.784	179			

a. R Squared = .0811 (Adjusted R Squared = 0.791)

Table 4: Levene's Test of Equality of Error Variances[a]

Dependent Variable: Discoloration

F	df1	df2	Sig.
6.969	17	162	0.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + thickness + group+ thickness * groups

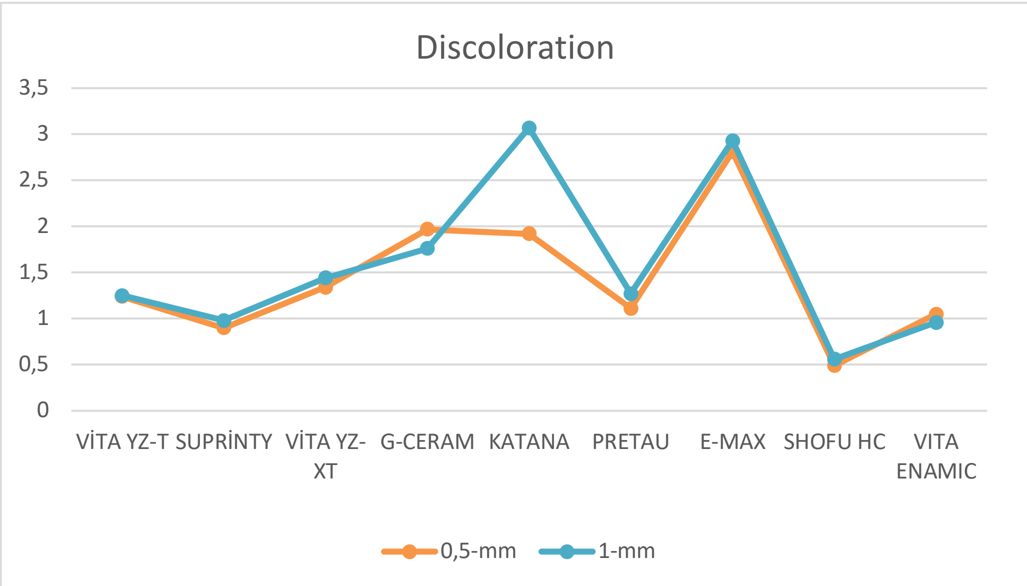

Figure 2 : Discoloration values of samples

4. Discussion

As the ceramic thickness increases, the opacity of the material increases. Furthermore, the effects of light reflection from the bottom tooth decrease. (Turgut, Bagis, & Ayaz, 2014) This increases the masking feature of the material. Material thicknesses affect the final color (Terzioğlu et al., 2009). ΔE values of sample groups with a thickness of 1mm are higher than 0.5 mm thickness groups. We think this result results from decreased light permeability and increased opacity of the material as the material thickens, as mentioned in the studies. Restorations are requested to maintain their physical, mechanical, and optical properties throughout their lifespan. However, the oral environment is dynamic, and restorations are subject to wear, heat differences, and dyeing agents. These factors affect the color change of the restoration and, accordingly, the duration of use (Bagis & Turgut, 2013). Accelerated aging methods are also used in studies to evaluate the color change of materials. These methods mimic clinical and living conditions by exposing materials to ultraviolet light (UV), heat, continuous humidity, and variations (De Oliveira et al., 2014).

H.-Y.Jeong and his colleagues examined the mechanical properties of CAD/CAM materials after aging procedures (Jeong et al., 2018). Lava Ultimate, Vita Enamic, Cerasmart, IPS E.max CAD, IPS E.max Zir CAD materials were applied to 22,000 thermocycling procedures and aging procedures in the autoclave bending resistance, surface roughness, and SEM image. The Lava Ultimate group reported that silica and zircon particles of various sizes, visible in the resin matrix before aging decreased after aging. Compared to Lava Ultimate and Cerasmart, ceramic fillers, evenly distributed in all groups, reported no significant change even after aging. The IPS e.max CAD group reported that rectangular lithium dioxide particles were well observed, but some irregular shapes were observed after aging, especially in the group aging with autoclave, and there was much fragmentation. On the other hand, they reported that small-sized particles exhibit changes in distribution due to the decrease of particles after aging, which may be related to changes in the surface. The IPS E.max values (2.93 and 2.81) in this study may depend on this change in the surface.

Gürdal et al. evaluated the color differences by cementing CAD/CAM (Lava Ultimate, Cerasmart, Cerec Bloc, IPS e.max CAD, VITA Suprinity, Brilliant Crios, IPS Empress CAD) block material samples with two different thicknesses and three different types of resin types of cement (Gürdal et al., 2018). They applied it after 5000 thermal cycles and examined color changes. They stated that aging has a significant effect on color values. They noted that the lowest ΔE values were observed in Vita Suprinity and Cerasmart, followed by Lava Ultimate, IPS e.max CAD, and Brilliant Crios, due to the material contents.

Acar et al. evaluated color differences between materials that applied coffee and aging to hybrid dental ceramics (Vita Enamik), resin nano ceramic (Lava Ultimate), lithium disilicate glass-ceramic (IPS e.max CAD), and nanocomposite resin (Filtek Supreme Ultra Universal) materials of different thicknesses (Acar et al., 2016). ΔE values for IPS e.max CAD material have been reported below the perceptible threshold regardless of thickness. They said that ΔE values for Vita Enamic material were above the detectable threshold and below the threshold for clinical acceptability. Filtek Supreme Ultra Universal and Lava Ultimate reported that ΔE values are above the point of clinical acceptability and are declining as their thickness increases. They attributed this result to the colorability of materials associated with monomer hydrophobicity and water absorption properties. They reported that Vita Enamik's pores contain a porous ceramic matrix filled with polymer materials, while Lava Ultimate has nano-ceramic particles embedded in the cross-linked resin matrix, which should be considered composite resins. They stated that the materials contain both hydrophobic UDMA and hydrophilic TEGDMA that TEGDMA has much water absorption so that the materials can be sensitive to discoloration. The results of this study are consistent with previous results for similar materials.

Alp et al. investigated the effects of different surface treatments (polishing and glazing) and coffee and aging (5000 thermocyclers) on the color and translucence of monolithic (zircon glass-ceramic and lithium disilicate glass-ceramic) CAD/CAM blocks (Alp et al., 2018). They stated that only the color change of polished lithium disilicate glass-ceramic samples is detectable but clinically acceptable, and color changes in all other groups are not detected. They reported that the surface of glass-ceramic material with zircon content has a homogeneous, thin, bar-like crystal structure with a crystal size of approximately 0.5 μm and that the surface of the lithium disilicate glass-ceramic material has a needle-shaped crystal size of approximately 1.5 μm. Hence, the glass-ceramic material with zircon content is less colored than the glass-ceramic material with lithium disilicate (Belli et al., 2017). Consistent with the findings of this study.

Quek et al. investigated the effects of beverages containing dyes (cola, tea, coffee, red wine, distilled water) on various composite materials (direct composite (Filtek Z350), indirect composite (Shofu Ceramage), and CAD/CAM composite blocks (Shofu HC, Lava Ultimate, Vita Enamic) color and translucency. They stated that there were differences in color changing and translucence between direct, indirect, and CAD/CAM composites and that CAD/CAM composites showed more color changes in red wine than direct and indirect composites. They noted that most materials show a detectable discoloration (ΔE>3.3) when exposed to red wine, tea, and coffee. They reported that this was due to Bis-GMA, UDMA, TEGDMA content, and water absorption in the material contents.

In another study, Eğmez et al. examined surface roughness, topography, and SEM images by applying different aging methods to Cerasmart, Lava Ultimate, and Vita Enamic CAD/CAM materials (Turgut & Bagis, 2011). When SEM images of the materials tested in each aging group were examined, Cerasmart showed smoother surface textures with small particles distributed properly, while lava ultimate showed larger clustering filler particles protruding from the surface. When the surface topography of the aging groups was examined, Cerasmart aged groups and control groups had similar surface patterns. They stated that lava ultimate has different surface characteristics and irregularities from the control group in some aged groups; micropores and pits are seen in these groups. Cerasmart and Lava Ultimate reported that surface roughness values were in the clinically recommended range after aging methods.

The optical properties of resin-containing materials may vary due to aging (Egilmez et al., 2018). The color changes resulting from aging are often associated with deterioration of the polymer matrix, unrestrained monomers of polymerization agents, and outer painting agents (Albuquerque et al., 2013). The resin-containing materials include monomers such as Bis-GMA, Bis-EMA, TEGDMA, UDMA. Bis-GMA increases the viscosity of materials and disadvantages color stability. TEGDMA and UDMA are added to the material to reduce viscosity. These monomers reduce the viscosity of Bis-GMA while enhancing cross-linking and mechanical properties. However, the color stability of the material is still controversial (Karaokutan et al., 2016). The water absorption properties of bis-GMA, TEGDMA, and UDMA monomers can cause differences in the degree of color stability of the material (Turgut, Bagis, Turkaslan, et al., 2014). The addition of TEGDMA to the material increases water absorption and prevents color stability. TEGDMA-based materials release monomers in larger quantities than Bis-GMA and UDMA-based materials into aqueous environments. Water absorption of bis-GMA-containing materials increases due to TEGDMA concentration and increases proportionately but decreases with the displacement of TEGDMA with UDMA. UDMA is less susceptible to painting than Bis-GMA (Turgut, Bagis, Turkaslan, et al., 2014). Gajewski et al. reported that Bis-GMA causes the highest, TEGDMA and Bis-EMA lowest, and UDMA causes water absorption similar to other monomers. Their resolutions were observed in UDMA, Bis-GMA, and Bis-EMA after the highest TEGDMA. They reported that these contents could be hydrolyzed by filtering out their unrestrained monomers or low molecular weight oligomers when exposed to oral fluids (Gajewski et al., 2012). In our study, UDMA, TEGDMA, Vita Enamic material with content, UDMA, TEGDMA, Shofu HC material with content showed more ΔE changes in the resin structure of approximately 86% after aging thermally. We believe that the ΔE change in Vita Enamic and Shofu HC hybrid materials is due to their content and structural differences. The contents of CAD/CAM materials may cause them to be resistant to long-term aging procedures. Exposing materials of this solid structure for longer-term aging processes and measuring them by adding dyeing agents can make color change differences clinically noticeable. When we look at the contents of CAD/CAM materials used in our study, after aging without dyeing agents in as little as one year (aging process with 10,000 cycle thermals), color changes are not expected to reach the clinically "acceptable" threshold value and exceed this threshold value. ΔE values are below the clinically acceptable threshold in our study as in previous studies compared to before the aging process with thermal cycles (Alp et al., 2018; Lauvahutanon et al., 2017; Turgut & Bagis, 2011).In the new studies, color changes of materials can be examined by increasing aging time with dyeing agents and functional adhesion processes. In addition, the addition of detailed color parameters and SEM reviews can contribute to the new studies.

References

Acar, O., Yilmaz, B., Altintas, S. H., Chandrasekaran, I. & Johnston, W. M. (2016). Color stainability of CAD/CAM and nanocomposite resin materials. *The Journal of Prosthetic Dentistry*, *115*(1), 71–75. https://doi.org/10.1016/j.prosdent.2015.06.014

Albuquerque, P. P. A. C., Moreira, A. D. L., Moraes, R. R., Cavalcante, L. M. & Schneider, L. F. J. (2013). Color stability, conversion, water sorption and solubility of dental composites formulated with different photoinitiator systems. *Journal of Dentistry*, *41*(SUPPL. 3). https://doi.org/10.1016/j.jdent.2012.11.020

Alp, G., Subasi, M. G., Johnston, W. M. & Yilmaz, B. (2018). Effect of surface treatments and coffee thermocycling on the color and translucency of CAD-CAM monolithic glass-ceramic. *Journal of Prosthetic Dentistry*, *120*(2). https://doi.org/10.1016/j.prosdent.2017.10.024

Bagis, B. & Turgut, S. (2013). Optical properties of current ceramics systems for laminate veneers. *Journal of Dentistry*, *41*(SUPPL. 3). https://doi.org/10.1016/j.jdent.2012.11.013

Belli, R., Wendler, M., de Ligny, D., Cicconi, M. R., Petschelt, A., Peterlik, H. & Lohbauer, U. (2017). Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. *Dental Materials*, *33*(1). https://doi.org/10.1016/j.dental.2016.10.009

Chu, F. C. S., Chow, T. W. & Chai, J. (2007). Contrast ratios and masking ability of three types of ceramic veneers. *Journal of Prosthetic Dentistry*, *98*(5). https://doi.org/10.1016/S0022-3913(07)60120-6

Conrad, H. J., Seong, W. J. & Pesun, I. J. (2007). Current ceramic materials and systems with clinical recommendations: A systematic review. *Journal of Prosthetic Dentistry*, *98*(5), 389–404. https://doi.org/10.1016/S0022-3913(07)60124-3

De Oliveira, A. L. B. M., Botta, A. C., Campos, J. Á. D. B. & Garcia, P. P. N. S. (2014). Effects of immersion media and repolishing on color stability and superficial morphology of nanofilled composite resin. *Microscopy and Microanalysis*, *20*(4). https://doi.org/10.1017/S1431927614001299

Dede, D. Ö., Armaganci, A., Ceylan, G., Çankaya, S. & Çelk, E. (2013). Influence of abutment material and luting cements color on the final color of all ceramics. *Acta Odontologica Scandinavica*, *71*(6). https://doi.org/10.3109/00016357.2013.777114

Douglas, R. D. (1997). Precision of in vivo colorimetric assessments of teeth. *Journal of Prosthetic Dentistry*, *77*(5). https://doi.org/10.1016/S0022-3913(97)70137-9

Egilmez, F., Ergun, G., Cekic-Nagas, I., Vallittu, P. K. & Lassila, L. V. J. (2018). Does artificial aging affect mechanical properties of CAD/CAM composite materials. *Journal of Prosthodontic Research*, *62*(1). https://doi.org/10.1016/j.jpor.2017.06.001

Gajewski, V. E. S., Pfeifer, C. S., Fróes-Salgado, N. R. G., Boaro, L. C. C. & Braga, R. R. (2012). Monomers used in resin composites: degree of conversion, mechanical properties and water sorption/solubility. *Brazilian Dental Journal*, *23*(5), 508–514. https://doi.org/10.1590/s0103-64402012000500007

Guess, P. C., Kuliš, A., Witkowski, S., Wolkewitz, M., Zhang, Y. & Strub, J. R. (2008). Shear bond strengths between different zirconia cores and veneering ceramics and their susceptibility to thermocycling. *Dental Materials*, *24*(11). https://doi.org/10.1016/j.dental.2008.03.028

Gürdal, I., Atay, A., Eichberger, M., Cal, E., Üsümez, A. & Stawarczyk, B. (2018). Color change of CAD-CAM materials and composite resin cements after thermocycling. *Journal of Prosthetic Dentistry*, *120*(4). https://doi.org/10.1016/j.prosdent.2017.12.003

Harianawala, H. H., Kheur, M. G., Apte, S. K., Kale, B. B., Sethi, T. S. & Kheur, S. M. (2014). Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. *Journal of Advanced Prosthodontics*, *6*(6). https://doi.org/10.4047/jap.2014.6.6.456

Jeong, H. Y., Lee, H. H. & Choi, Y. S. (2018). Mechanical properties of hybrid computer-aided design/computer-aided manufacturing (CAD/CAM) materials after aging treatments. *Ceramics International*, *44*(16). https://doi.org/10.1016/j.ceramint.2018.07.146

Jiang, L., Liao, Y., Wan, Q. & Li, W. (2011). Effects of sintering temperature and particle size on the translucency of zirconium dioxide dental ceramic. *Journal of Materials Science: Materials in Medicine*, *22*(11). https://doi.org/10.1007/s10856-011-4438-9

Karaokutan, I., Yilmaz Savas, T., Aykent, F. & Ozdere, E. (2016). Color Stability of CAD/CAM Fabricated Inlays after Accelerated Artificial Aging. *Journal of Prosthodontics*, *25*(6). https://doi.org/10.1111/jopr.12353

Kim, H. K., Kim, S. H., Lee, J. B., Han, J. S., Yeo, I. S. & Ha, S. R. (2016). Effect of the amount of thickness reduction on color and translucency of dental monolithic zirconia ceramics. *Journal of Advanced Prosthodontics*, *8*(1). https://doi.org/10.4047/jap.2016.8.1.37

Lauvahutanon, S., Shiozawa, M., Takahashi, H., Iwasaki, N., Oki, M., Finger, W. J. & Arksornnukit, M. (2017). Discoloration of various CAD/CAM blocks after immersion in coffee. *Restorative Dentistry & Endodontics*, *42*(1), 9. https://doi.org/10.5395/rde.2017.42.1.9

Matsuzaki, F., Sekine, H., Honma, S., Takanashi, T., Furuya, K., Yajima, Y. & Yoshinari, M. (2015). Translucency and flexural strength of monolithic translucent zirconia and porcelain-layered zirconia. *Dental Materials Journal*, *34*(6). https://doi.org/10.4012/dmj.2015-107

McLean, J. W. & Hughes, T. H. (1965). The reinforcement of dental porcelain with ceramic oxides. *British Dental Journal*, *119*(6).

Nogueira, A. D. & Della Bona, A. (2013). The effect of a coupling medium on color and translucency of CAD-CAM ceramics. *Journal of Dentistry*, *41*(SUPPL. 3). https://doi.org/10.1016/j.jdent.2013.02.005

O'Keefe, K. L., Pease, P. L. & Herrin, H. K. (1991). Variables affecting the spectral transmittance of light through porcelain veneer samples. *The Journal of Prosthetic Dentistry*, *66*(4). https://doi.org/10.1016/0022-3913(91)90501-M

Sen, N. & Us, Y. O. (2018). Mechanical and optical properties of monolithic CAD-CAM restorative materials. *Journal of Prosthetic Dentistry*, *119*(4). https://doi.org/10.1016/j.prosdent.2017.06.012

Terzioğlu, H., Yilmaz, B. & Yurdukoru, B. (2009). The effect of different shades of specific luting agents and IPS empress ceramic thickness on overall color. *The International Journal of Periodontics & Restorative Dentistry*, *29*(5). https://doi.org/10.11607/prd.00.0882

Turgut, S. & Bagis, B. (2011). Colour stability of laminate veneers: An in vitro study. *Journal of Dentistry*, *39*(SUPPL. 3). https://doi.org/10.1016/j.jdent.2011.11.006

Turgut, S., Bagis, B. & Ayaz, E. A. (2014). Achieving the desired colour in discoloured teeth, using leucite-based cad-cam laminate Systems. *Journal of Dentistry*, *42*(1). https://doi.org/10.1016/j.jdent.2013.10.018

Turgut, S., Bagis, B., Turkaslan, S. S. & Bagis, Y. H. (2014). Effect of Ultraviolet Aging on Translucency of Resin-Cemented Ceramic Veneers: An In Vitro Study. *Journal of Prosthodontics*, *23*(1). https://doi.org/10.1111/jopr.12061

Ueda, K., Güth, J. F., Erdelt, K., Stimmelmayr, M., Kappert, H. & Beuer, F. (2015). Light transmittance by a multi-coloured zirconia material. *Dental Materials Journal*, *34*(3). https://doi.org/10.4012/dmj.2014-238

Zarone, F., Russo, S. & Sorrentino, R. (2011). From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. *Dental Materials*, *27*(1), 83–96. https://doi.org/10.1016/j.dental.2010.10.024

Zhang, Y., Lee, J. J. W., Srikanth, R. & Lawn, B. R. (2013). Edge chipping and flexural resistance of monolithic ceramics. *Dental Materials*, *29*(12), 1201–1208. https://doi.org/10.1016/j.dental.2013.09.004