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Color Stability of Three Different Types of Monolithic CAD/CAM Esthetic Restorations After Exposure to Artificial Accelerated Aging (An In-vitro study)

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ABSTRACT

Background: CAD/CAM Composite is one of the esthetic milled restorations. It has high esthetic properties and modulus of elasticity close to that of dentin. The color stability of composite CAD/CAM restorations is still under investigation. ***Aim:*** To evaluate the color stability of milled nano-hybrid composite and hybrid ceramic compared to lithium disilicate after Artificial Accelerated Aging. ***Materials and Methods***: Twenty seven disc-shaped samples (10mm X 2mm) were fabricated in standardized manner. Samples were divided into three equal groups (n=9) according to the material type: Lithium disilicate ceramic (IPS e.max CAD), Hybrid Ceramic (Vita Enamic) and Nano-hybrid CAD/CAM composite (Tetric CAD). Color measurements of the three milled materials were assessed before and after Artificial Accelerated Aging (AAA) in weathering machine for 300 hours using a spectrophotometer based on CIE L*a*b* relative to the standard illumination D65. Color difference was obtained by calculating the difference in color measurements of the specimens before and after accelerated aging using the formula $\Delta E=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{½}$. ***Results:*** There was a statistically significant difference between ΔE of different ceramic types. Tetric CAD showed the highest mean DE (4.29) while there was no statistical significance difference between Vita Enamic and IPS e.max CAD (3.02 and 2.94 respectively). ***Conclusion:*** Artificial accelerated aging caused clinically unacceptable color changes in Tetric CAD, while it caused perceptible but clinically acceptable color changes in Vita Enamic and IPS e.max CAD. Color changes after artificial aging is related to the chemical composition of the material.

Keywords: Artificial Accelerated Aging, Color Stability, Monolithic Esthetic Restorations, CAD/CAM

INTRODUCTION

Dental esthetics has become the main concern of most of patients as it is important for their self-esteem and quality of life.[1] At the end of the last century the idea of

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presence of metal prosthesis inside the patient's mouth became not accepted among dentists, which led them to focus more on esthetic dentistry in response to patient demand.[2] These factors have prompted the creation of novel all-ceramic prosthetic rehabilitations, with the goal of replacing metal ceramic restorations with all ceramic one of comparable mechanical strength and better esthetics.[2,3]

The introduction of CAD/CAM technology has recently facilitated fabrication of milled esthetic restorations that are easier and less time consuming.[4,5] Monolithic chair-side prostheses are presented in the dental market as CAD/CAM blocks that are manufactured in a repeatable, standardized manner.[4] With great advantage of being conservative in tooth preparation, monolithic chair side restorations have higher fracture strength than bilayered one, less manufacturing steps and fewer laboratory work are required as they are produced by CAD/CAM. In addition, they are easily polished and can be delivered in a single session.[6,7]

IPS e.max (Ivoclar – Vivadent), a lithium disilicate glass ceramic with enhanced translucency, toughness, and durability is one of the most widely used ceramic materials. Clinically, it has performed significantly better in terms of optical behavior and flexural strength.[8] Recently, Polymer infiltrating ceramic network (PICN) material "Vita Enamic, VITA Zahnfabrik", has been developed. It is a hybrid ceramic which is made up of a polymer organic phase which comprises 14% infiltrated into feldspathic ceramic matrix that comprises 86% of its volume.[9] This dual network structure decreased the material's brittleness and surface hardness, allowing for faster and easier milling.[10]

Resin composites have progressed from being a direct restorative material to becoming laboratory processed blocks that can be utilized in CAD/CAM systems to fabricate indirect restorations.[11] CAD/CAM processed composite blocks have many advantages over ceramics and direct composites: they are more polymerized, less porous, more homogeneous, and require less milling time compared to ceramics, and therefore, less wear of cutting equipment.[11] Additionally, they are more resilient and could be easily repaired compared to indirect ceramics.[11,12]

Tetric CAD (Ivoclar – Vivadent) is a new material that has been introduced recently to the dental market by Ivoclar company.[13] It consists of nano-hybrid composite with resin matrix composed of

Bisphenol A-glycedyl dimethacrylate (Bis-GMA), Bisphenol A diglycidyl methacrylate ethoxylated (Bis-EMA), Triethylene glycol dimethacrylate (TEGDMA), and Urethane dimethacrelate (UDMA) nano-filled 70% with barium glass and silicon dioxide.[13] As provided by the manufacturer, Tetric CAD was introduced as aesthetic composite blocks. In addition, they have chameleon effect so they can blend to the surrounding natural tooth structure resulting in a pleasant esthetic restoration.[13]

CIE L*a*b* system is the most widely used method for measuring the color differences. It was developed by the Commission International de l'Eclairage (CIE) in 1976. Color is represented in this system by three coordinates: L* Coordinate indicates the degree of whiteness/ blackness of an object. The a* and b* coordinates indicate redness – greenness and yellowness – blueness respectively. Color difference is calculated by using the formula $D E= [(D L^*)^2+(D a^*)^2+(D b^*)^2]^{½}$.[3,14]

In dentistry, the DE values are used to describe whether or not the change in the overall shade are perceivable to the human observer. A perceptible color match is one that is at or below the perceptibility level, whereas an acceptable color match is one that is at or below the acceptability threshold.[15] According to **Vichi et al.,**[16] DE values less than 1unit are regarded as not perceivable by the human eye; DE values ranging between 1 and 3.33 are perceptible by skilled experienced operators (well-trained eye) but clinically acceptable, while DE values more than 3.33 are considered detectable by the untrained observers and thus it is clinically unacceptable. Many authors considered DE more than 3.33 clinically unacceptable.[17–20]

Discoloration of dental materials in the oral environment is caused by a variety of factors.[21,22] Extrinsic factors such as ultraviolet irradiation, heat, water, and food colorants can all cause discoloration. Discoloration can be also caused by intrinsic factors such as the composition of the resin matrix, which contains Bis-GMA, Bis-EMA, and TEGDMA, and UDMA which have higher water sorption and thus are more susceptible to staining agents and discoloration.[23,24]

Artificial accelerated ageing is an experimental method for simulating oral environmental conditions outside of the patient's mouth.[25,26] A lot of methods were proposed in the literature to artificially age prosthetic dental materials to evaluate its color stability. These methods include placing materials in beverages solutions such as coffee, tea, and red wine.[1,27] Other methods of aging including thermocycling, autoclaving (hydrothermal aging) were used in previous studies.[28-30]

Artificial Accelerated Aging using weathering process that involves exposure to ultraviolet light (UV), increased temperatures, and variable humidity has been widely used in previous research.[3,25,26,31] According to the manufacturer of the artificial ageing weathering machine, 300 hours inside it is equivalent to one year of clinical service.[3,8,32,33]

Therefore, the purpose of this study was to evaluate the color stability of Tetric CAD, and Vita Enamic compared to IPS e.max CAD after artificial accelerated aging by means of weathering process. The null hypothesis was that there was no significant difference between the three investigated materials in terms of color change after artificial accelerated aging.

MATERIALS AND METHODS

Materials used in this study are shown in **Table (1).**

A total of 27 disc-shaped samples were milled out of three types of monolithic CAD/CAM ceramic blocks: Nano-hybrid CAD/CAM composite (Tetric CAD; Ivoclar Vivadent, Liechtenstein), Hybrid Ceramic (Vita Enamic; VITA Zahnfabrik, Bad Sakingen, Germany) and Lithium disilicate glass ceramic (IPS e.max CAD; Ivoclar Vivadent, Liechtenstein), 9 specimens for each material. Shade A2 MT was chosen for IPS e.max CAD& Tetric CAD, and 2M2 T for Vita Enamic.

Samples preparation

To convert CAD/CAM blocks to cylinders, a cylindrical shape with 10mm diameter and 14mm long was designed using Z brush software.[34] The designed cylinder was exported as standard tessellation language (STL) file and then imported into CORiTEC SmartControl™ software.[34] The design was nested into CAD/CAM blocks and milled using CORiTEC 250i CAD/CAM milling machine.[34] After that, the cylinders were cut into discs with uniform thickness of

Table (1): Materials used in the study.

Material	Brand Name	Chemical Composition	Manufacturer
Nano-hybrid CAD/CAM composite	Tetric CAD	Monomers: Bis-GMA, Bis-EMA, TEGDMA, UDMA. Fillers: Barium aluminum silicate glass, Silicone dioxide.	Ivoclar Vivadent, Liechtenstein
Hybrid Ceramic	Vita Enamic	86% ceramic (SiO_2 58-63%, Al_2O_3 20-23%, Na_2O 9-11%, K_2O 4-6%, ZrO2 0-1%). 14% polymer (UDMA, TEGDMA).	VITA Zahnfabrik, Bad Sakingen, Germany
Lithium disilicate	IPS e.max CAD	SiO_2 (57.0-80.0wt%), Li_2O (11.0 – 19.0 wt%), K_2O (0.0 – 13.0 wt%), P_2O_5 (0.0- 11.0 wt%), ZrO_2 (0.0 –8.0 wt%), ZnO (0.0-8.0 wt%), Coloring oxides (0.0 – 8.0), Others (0.0 – 10.0).	Ivoclar Vivadent, Liechtenstein

2mm using electric diamond cutting saw (IsoMet 4000 Linear Precision Saw, Buehler, USA) under constant water coolant **(Figure 1).**[27] Dimensions of samples were verified using digital caliber (INSIZE digital caliber, Insize measuring tool, India).

Figure (1): Cutting ceramic discs using Isomet 4000 Linear precision saw machine.

Crystallization and glazing of Ips e.max CAD samples

IPS e.max CAD samples were glazed and crystalized in a single step. Ivocolor glazing paste (Ivoclar Vivadent, Lichtenstein) was used to apply a single coat of glazing paste using a brush to be applied in a uniform thickness. After that, all samples were placed inside a porcelain furnace (Programat EP 3010, Ivoclar Vivadent, Lichtenstein) to be tempered at 850 °C for 25 minutes under a vacuum to reach its fully crystallized form.[8]

Polishing of Vita Enamic and Tetric CAD Samples

As polishing is a critical step, Tetric CAD and Vita Enamic samples were polished in a standardized manner. PVC tubes were used to construct a mold “holder” containing self-cure acrylic resin to hold ceramic sample, and a T-Shape attachment to hold the low-speed hand piece.[30] A parallellometer (BEGO Paroskop M, USA) was used for polishing procedure. A holder containing embedded sample was fixed on the horizontal table of the paralellometer while the T-shape attachment holding the low-speed handpiece was fixed to its vertical arm to be parallel to the holder containing the disc sample **(Figure 2)**.

Figure (2): Parallellometer used for polishing procedure holding the mold containing ceramic sample and T-shape attachment with low-speed handpiece fixed inside it.

OptraPol Polishing kit (Ivoclar Vivadent, Liechtenstein) was chosen to polish Tetric CAD samples and Vita Enamic Polishing set technical (Vita zahnfabrik spitalgasse 3.D-79713 Bad sachingen, Germany) for polishing the Vita Enamic one. All samples were polished at speed of 7000 rpm for 60 seconds in one direction under constant water spray. After that, samples of each group were cleaned separately for 10 seconds in ultrasonic cleaner (PT Dent Ultrasonic Cleaner, China) containing distilled water.[25]

Base line color measurements

The samples 'base line color measurements were recorded using a portable reflective spectrophotometer (RM200QC; X-Rite, Neu- Isenburg).[30] The aperture size was set to 4mm and the samples were exactly aligned within the device over a white background, measurements were done according to the CIE L*a*b* color space system relative to the CIE standard illuminant D65.[30] Each sample was measured three times at three different points and CIE L*a*b* parameters were calculated and saved.

Artificial Accelerated Aging (AAA) Test

All the specimens were then subjected to AAA test using QUV accelerated weathering testing machine (Q – Lab Corporation, USA).[8] Samples were attached to custom aluminum sheets **(Figure 3)**; only polished and glazed surfaces were exposed to the AAA for 300 hours.[8] Samples inside the weathering machine were subjected to 150 cycles of aging; each cycle was 2 hours long.[8] During each cycle, the samples were exposed to UV light for 1 hour and 42 minutes and distilled water spray for 18 minutes and under temperature of 50°C.[8]

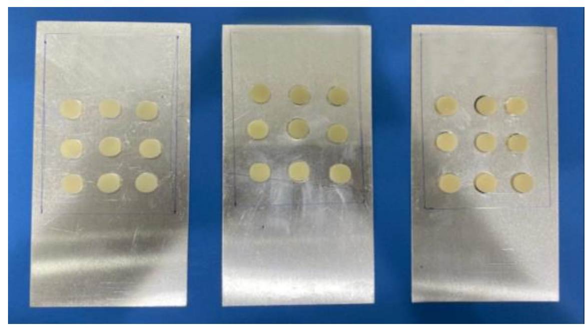

Figure (3): Samples attached to aluminum sheets to be placed inside the weatherometer device.

Color measurements after Artificial Accelerated Aging

Color of the samples was measured again by the same spectrophotometer after AAA and color difference was calculated using the formula $\Delta E= [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$.

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Data were presented as mean, standard deviation (SD) or median and range values. For parametric data, one-way ANOVA was used to compare between the groups. Bonferroni's post-hoc test was used for pair-wise comparisons as ANOVA test was significant. For non-parametric data, Kruskal-Wallis test was used to compare between the groups. Dunn's test was used for pair-wise comparisons as Kruskal-Wallis test was significant. The significance level was set at P ≤ 0.05.

RESULTS

A) Color Change (ΔE)

One way ANOVA test showed that there was a statistically significant difference between (ΔE) of different ceramic types (*P*-value = 0.002, Effect size = 0.396) as shown in **Table (2)**. Pair-wise comparisons between ceramic types revealed that Tetric CAD showed the statistically significant highest mean ΔE. There was no statistically significant difference between Vita Enamic and IPS e.max CAD; both showed the statistically significant lowest mean (ΔE) values represented by bar chart **(Figure 4)**.

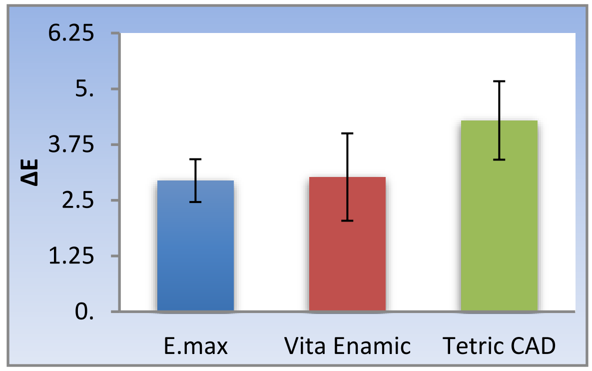

Figure (4): Bar chart representing mean and standard deviation values for ΔE of the three ceramic types.

B) ΔL, Δa and Δb

Kruskal-Wallis test showed that there was a statistically significant difference between ΔL, Δa and Δb of different ceramic types **(Table 3)**. Pair-wise comparisons between ceramic types revealed that Tetric CAD showed the statistically significant highest median ΔL, Δa and Δb. There was no statistically significant difference between Vita Enamic and IPS e.max CAD; both showed the statistically significant lowest median ΔL, Δa and Δb.

Table (2): The mean, standard deviation (SD) values and results of one – way Anova repeated measures ANOVA test for comparison between ΔE of the three ceramic type.

E.max		Vita Enamic		Tetric CAD		*P*-value	Effect size *(Eta squared)*
Mean	SD	Mean	SD	Mean	SD		
2.94 [B]	0.48	3.02[B]	0.98	4.29 [A]	0.88	0.002*	0.396

**: Significant at P ≤ 0.05.*
Different superscripts indicate statistically significant difference between ceramic types.

Table (3): Descriptive statistics and results of Kruskal-Wallis test for comparison between ΔL, Δa, and Δb values of the three ceramic types.

Materia	**E.max**		**Vita Enamic**		**Tetric CAD**		***P*-value**	**Effect size *(Eta squared)***
Color Paramet	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)	Mean (SD)	Median (Range)		
ΔL	-0.69 (0.97)	-0.7^{B} (-2.03 – 0.6)	-0.72 (0.87)	-0.8^{B} (-2.07 – 0.93)	-2.63 (0.63)	-2.73^{A} (-3.67 – -1.6)	<0.001*	0.554
Δa	-0.67 (0.64)	-0.77^{B} (-1.4 – 0.2)	-0.91 (1.34)	0.7^{B} (-3.87 – 0.63)	0.77 (1.16)	0.6^{A} (-1.5 – 2.27)	0.012*	0.282
Δb	-0.77 (1.23)	-0.73^{B} (-2.37 – 1.2)	-0.88 (1.28)	-0.6^{B} (-2.93 – 0.77)	-2.65 (1.05)	-2.77^{A} (-4.47 – -1.43)	0.007*	0.334

**: Significant at P ≤ 0.05.*
Different superscripts indicate statistically significant difference between ceramic types.

DISCUSSION

Null hypothesis was rejected because there was a significant difference in color change between Tetric CAD, Vita Enamic, and IPS e.max CAD after Artificial Accelerated Aging (AAA).

Discoloration of hybrid ceramics and hybrid composites inside the oral cavity after a long time of use is considered a major problem and may affect its esthetics longevity.[27] Therefore, this study was conducted to evaluate the color stability of the new Tetric CAD restorative material and Vita Enamic when compared to IPS e.max CAD after being exposed to AAA by means of weathering process.

Samples in this study were manufactured in a standardized manner according to previous studies.[25,27] In this study, 10mm ceramic disc diameter was selected to be compatible with the spectrophotometer's aperture size while 2mm thickness as it is the maximum thickness recommended for monolithic fixed dental prosthesis.[27] Paralellometer, T-shape attachment holding the straight handpiece, and holder to the samples were used in polishing procedure to avoid any influence on samples' color stability and to make them highly polished in a standardized manner. A spectrophotometer was selected over visual inspection as it provides accurate, reliable, and statistically useful results.[8] A white background was selected for color measurements as it reflects light produced from the reflective light spectrophotometer. D65 is the color temperature corresponding to outdoor daylight and it is the true color temperature of white light as perceived by the human eye.

Also, it is frequently used in dental shade matching.[35]

Restorations in the oral cavity that are vulnerable to color changes are affected by a variety of factors, including humidity, dietary habits, and temperature.[31] If the color change is obvious, the restoration may become unsatisfactory and need to be replaced. In the current study, samples were exposed to 300 hours in a weathering machine to high temperature, water spray, and UV light. The main environmental factors that influence the hydrolysis and degradation of dental restorations and affect their appearance are UV light, temperature changes, and water.[31] According to manufacturer of the weatherometer, 300 hours inside the weathering machine is equivalent to one-year clinical service.[3,8,25,31] This method of AAA is practical, convenient, standardized and can provide more realistic expectations of the long-term outcome of restorations.[8,25,31]

In the present study, hybrid composite “Tetric CAD” showed the highest color change (ΔE 4.29) compared to the hybrid ceramic “Vita Enamic” (ΔE 3.02) and Lithium disilicate “IPS e.max CAD” (ΔE 2.94) after AAA. The color change of Tetric CAD was clinically unacceptable ($\Delta E > 3.33$), while that of Vita Enamic and IPS e.max CAD was perceptible but clinically acceptable ($\Delta E < 3.33$). IPS e.max showed the least color change among the three materials.

Results of this study agree with previous studies who stated that composites showed higher discoloration than ceramic materials, while hybrid ceramics like Vita Enamic showed intermediate color change between them but it is more color stable than composites.[31,36-38] Numerous studies reported that the resin matrix used in the composite materials have an obvious impact on discoloration. This may be attributed to monomer hydrophilicity and water sorption properties.[24,37,39] Both Tetric CAD and Vita Enamic consists of hydrophobic UDMA and hydrophylic TEGDMA.[37] TEGDMA exhibits high water absorption property which permit water into the resin matrix.[37,38] Therefore, both Tetric CAD and Vita Enamic may be susceptible to color changes.[37]

However, discoloration of these two materials were not the same in this study, Tetric CAD discolored more than Vita Enamic which agreed with a previous study.[24] Additionally, Tetric CAD contains Bisphenol A-glycidyl methacrylate (Bis-GMA) and its ethoxylated version (Bis-EMA) in its composition.[24] According to **Karaoukutan et al.,**[31] High viscosity and color stability are two drawbacks of Bis-GMA, this attributed to the presence of hydroxyl group in its composition. TEGDMA and UDMA were added to reduce its viscosity and to increase crosslinking; however, color stability of the material is controversial.[31] **Gajewski et al.**[40] showed that Bis-GMA caused the highest water sorption compared with UDMA, TEGDMA, and Bis-EMA. Previous studies showed that monomers containing UDMA like Vita Enamic which had no hydroxyl group have low water sorption and better stain resistance compared to those contain Bis-GMA, so it is associated with less color change.[37-39] Therefore, Bis-GMA may be the reason behind why color change of Tetric CAD is higher than that of Vita Enamic. Additionally, most polymers have functional groups in their molecular chains that absorb UV light.[31,34,41] AAA leads to the degradation of the matrix/silane/filler, as the composite absorbs the water that penetrates the filler/resin interface. This leads to hydrolysis of the silane, reducing the retention of the filler particles and therefore color change "discoloration" of the material.[31,34,41]

IPS e.max CAD showed the least color change among the three investigated materials, and this agreed with previous studies.[8,39,42] Color change of IPS e.max may be attributed to the metal oxides which added to ceramic to obtain the color shades and under the UV light these metal oxides can very easily break down and peroxides compound may develop and result in color change.[6,39,43]

AAA caused all the three milled ceramic materials to become darker in color (negative ΔL values), Tetric CAD showed the greatest decrease in ΔL value and this agreed with previous studies.[26,31] IPS emax and Vita enamic showed slight decrease in Δa "negative values" (color shifted to green) while Tetric CAD showed more increase in Δa "positive values" (color shift to red). All materials showed decrease in Δb values "negative values" (Color shifted to blue), Tetric CAD showed the most decrease in Δb values compared to IPS e.max and Vita Enamic. Higher changes of L* a* b* values in Tetric CAD after artificial aging may be attributed to the presence of Bis-GMA in its composition.[33]

The limitation of this study that was conducted in–vitro and not in–vivo as in clinical situation the restoration is bonded to the tooth structure and exposed to solutions and beverages with different temperatures and light. Further clinical and in-vitro studies are recommended to evaluate the color stability and surface roughness of Tetric CAD by using other means of artificial aging like thermocycling and presence in saliva, and different beverages to better reflect the clinical situation.

CONCLUSIONS

Within the limitations of this in-vitro study, the following points were concluded:

1. Tetric CAD showed clinically unacceptable color changes (DE > 3.33), while both IPS e.max CAD and Vita Enamic showed perceptible but clinically acceptable color changes (DE < 3.33) after artificial accelerated aging.

2. Color changes after accelerated aging is related to intrinsic factors within the material, i.e., chemical composition of the material.

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