

Effect of Common Staining Beverages on Color Stability of Polymer-infiltrated Ceramics and Extra Translucent Zirconia: An *In Vitro* Study

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ABSTRACT

Aim: The current study aims to assess the color change of polymer-infiltrated ceramic Vita Enamic (VE) and extra translucent multilayer zirconia (XTML) after being immersed in different types of beverages, which are coffee, tea, and cola in comparison to distilled water as control.

Materials and methods: A total of 80 rectangular-shaped specimens were prepared with fixed dimensions (14 × 12 × 0.5 mm) and then were divided into two groups ($n = 40$) according to ceramic material (VE, XTML). Specimens were sliced as each slice measures about 0.5 mm thick. Each group specimens were divided into four subgroups ($n = 10$) based on the immersion solutions in which specimens were stored (water, coffee, tea, and cola) for 28 days. The color parameters (L-a-b) of the specimens were recorded before immersion and at the end of the 7th (T1), 14th (T2), 21st (T3) and 28th (T4) days after immersion. Color measurements were statistically analyzed with a significance threshold of $p < 0.05$.

Results: There was a significant difference in color change between VE and XTML in all periods of tea and coffee immersion subgroups and in T3 and T4 in cola immersion subgroups ($p < 0.001$). Vita Enamic showed the highest differences in ΔE through all storage periods after 28 days of tea immersion (ΔE of VE = 8.06 ± 1.04). Extra translucent multilayer zirconia showed the highest differences in ΔE through all storage periods after 28 days of tea immersion (ΔE of XTML = 3.0 ± 0.33).

Conclusion: Commonly consumed staining beverages influenced the color stability of the polymer-infiltrated ceramics more than extra translucent zirconia ceramics.

Clinical significance: This study may provide guidance for clinicians to select the appropriate ceramic restorative material with high color stability and low tendency for color change by common staining beverages to achieve long-lasting esthetic results for the patients.

Keywords: Ceramics, Color change, Polymer-infiltrated, Spectrophotometer, Translucent zirconia.

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INTRODUCTION

Ceramic restoration use has increased recently as it can simulate the visual character of the tooth substance and meet the patients esthetic demands in addition to its high mechanical properties. However, a wide range of ceramic materials are available in the market.^{1,2}

In 2012 hybrid ceramics or polymer-infiltrated ceramics started to make their entry into the world of computer-aided design/ computer aided manufacturing (CAD/CAM). It's worth mentioning that these materials require no further heat treatment after the milling process, thus speeding the delivery process which serves one of the purposes of CAD/CAM technology.³

In 2013 the appearance of hybrid machinable ceramic made it to the market of dentistry which is Vita Enamic (VE) resin-infiltrated hybrid ceramic. The resin infiltrated ceramic according to microstructure seems to be the total opposite of the LAVA ultimate nano-ceramic, having the matrix being the ceramic and the resin infiltrated to reinforce it.⁴

Vita Enamic has been reported to yield combined characteristics between porcelains and resin-based composites which are related to its microstructure. Such a property makes it a good candidate for inlays, onlays, laminate veneers, crowns, and implant superstructures.⁵

Zirconia-based dental ceramics are more durable and reliable. To decrease the substructure zirconia material from fracturing and breaking the veneering porcelain, monolithic yttria-stabilized

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tetragonal zirconia polycrystal (Y-TZP) was introduced. It still exhibits less translucency than glass ceramics, though. Several brands commercialized transparent Y-TZP to eliminate this restriction. Recently, multilayered monolithic Y-TZP zirconia materials that replicate the esthetic effects of dentin and enamel have been introduced. These materials have gradational translucency and gradational Chroma. It has been proposed that the multilayered zirconia material has a 43% light transmittance capability with varying levels of transmittance throughout layers. For more esthetic quality, Extra translucent zirconia materials are introduced where they exhibit more esthetics than translucent zirconia. It consists

Table 1: The materials used in the study

Material	Brand name	Manufacturer
1-extra translucent Zirconia blanks	Cercon XTML	Sirona, Bensheim, Germany
2-polmer infiltrated ceramic	Vita Enamic	VITA Zahnfabrik, Bad Säckingen, Germany

of full cubic stabilized monolithic zirconia (FSZ), which has been synthesized to enhance zirconia's translucency.⁶

The ability of ceramic restorations to withstand discoloration over time is critical to the performance and durability of these restorations, particularly in hostile oral environments. Endogenous or exogenous discoloration may develop in porcelain restorations. The material's chemical instability could cause an endogenous hue shift. The restoration's tendency for absorption stains in the mouth cavity, which may be promoted by surface characteristics like roughness, may result in exogenous staining.^{7,8}

In everyday life, many different drinks and meals are ingested in varied amounts, colors, temperatures, and compositions. Each drink and meal has a distinct influence on the structures in the oral cavity.^{9,10} Beverages consumed by the population have shown a variation in their influence on the color stability of esthetic dental restorations leading to perceptible color changes. These beverages have come to increase the complexity of the oral environment, producing a continuous alteration within the pH value, and are accompanied by colorants and staining pigments like coffee, tea, and cola.¹¹

As a result of the contradiction between research on the influence of different beverages on ceramic restorations, this research aims to evaluate the color change of VE and extra translucent multilayer zirconia (XTML) restorative ceramic materials after soaking in commonly consumed beverages which are coffee, tea, and cola solutions in comparison to distilled water as control. The null hypothesis suggested that the color of the tested materials would not differ after being immersed in different types of beverages.

MATERIALS AND METHODS

Study Design and Sample Grouping

The current *in vitro* study was conducted at the Fixed Prosthodontics Department, Faculty of Dentistry, Minia University, Egypt. The study has been approved by the ethical committee of the Faculty of Dentistry, Minia University, Egypt (Approval number: 461/75).

Eighty rectangular-shaped specimens with fixed dimensions (14 × 12 × 0.5 mm) were assigned into 2 groups (40 each) according to the type of material which is VE (Group I) and XTML (Group II) (Table 1) and then each group was sub-divided into 4 subgroups (10 each) according to the type of solution the immersion solution used (distilled water, coffee, tea, and cola).

Sample Preparation

Cerecon XTML Preparation

3D design rectangular shaped block with dimensions (14 × 12 × 15 mm) was designed using windows 3D builder software to produce an STL file. The final shape was accurately confirmed, saved, and exported to the CAM software system (DentalCam v 6.17.00).

After inserting the blanks into the milling machine, the block was machined in accordance with the imported design. To

compensate for sintering shrinkage, the block was machined with an approximate 20–25% oversize.

Forty Zirconia specimens were machined from their respective blocks by using a low-speed diamond saw (Buchler-Isomet LakeBulff, IL, USA) to approximate 20–25% oversize in thickness to compensate for the sintering shrinkage to reach a uniform standard thickness of (0.5 mm). Verifying the thicknesses of the specimens were done with a digital caliper.

The specimens was sintered according to the manufacturer's temperature and time recommendations.

All slices were then finished using the coarse wheel, then a medium rubber tool, and finally fine rubber tool was used using a straight hand-piece attached to an electric motor with the direction of rotation forward.¹²

Vita Enamic Preparation

Forty slices of VE, and with dimensions (14 × 12 × 0.5 mm) of VE block (VITA Zahnfabrik, Bad Säckingen, Germany) were cut by Isomet 4,000 with precision cut micro-saw 4 at 2,500 rpm cutting speed using a diamond disc 0.5 mm thickness under a cooling system (Water: Anti-corrosive agent) in a ratio of 30:1. All slices were measured using a digital caliper by the same operator to standardize the dimensions of all slices. One surface only was polished by low-speed handpiece with instruments of the Vita Polishing kits (VITA Zahnfabrik) at first using diamond-coated instruments at a speed of 7,000 rpm for 15 seconds in vertical and horizontal motion all over the surface using a water coolant spray to reduce the generation of heat during polishing.¹³

Color Measurement

The color stability of each sample was assessed using a VITA Easyshade V spectrophotometer (VITA Zahnfabrik). To guarantee the accuracy of each measurement, the spectrophotometer was calibrated in the calibration slot in accordance with the manufacturer's instructions. For all groups of samples A and B, the VITA Easyshade spectrophotometer aperture was centered on the center of each sample, and its CIE L* a* and b* were to be measured on a neutral grey background. According to the protocol followed by Al Wadei¹⁴, every sample had three measurements for every coordinate, and the average of those measurements was recorded.

Immersion Solution Preparation

For subgroup A (Distilled water), samples were kept in firmly closed containers filled with 10 mL of distilled water (control medium) in an incubator temperature 37°C for 28 days.

In subgroup B (Cola), about 200 mL of Coca-Cola was distributed into 20 firmly closed containers using plastic syringes and samples were immersed in these firmly closed containers.

In subgroup C (Instant coffee), the instant coffee solution was prepared by dissolving 1.8 grams of coffee instant powder (Nescafe, Nestle, Egypt) in 150 mL of hot water.¹⁴ The samples were stored in firmly closed containers at 37°C.

In subgroup D (Tea), Tea solution was prepared by soaking three pre-fabricated teabags (Lipton-Yellow Label, Egypt) in 200 mL of boiling water for about 5 minutes. The samples were stored in firmly closed containers in an incubator temperature of 37°C for 28 days. All Tested solutions were changed every day. Samples were then washed under running water for ten seconds and then dried using sterile cotton.¹⁵ The color was measured after 7, 14, 21 and 28 days.

Table 2: Mean differences and standard deviations of ΔE for VE and XTML after immersion in beverage solutions at different times

Duration	VE	XTML	t	p
<i>Water (n = 10)</i>				
T1	0.55 ± 0.12	0.40 ± 0.20	1.966	0.065
T2	0.64 ± 0.11	0.50 ± 0.20	1.929	0.070
T3	0.72 ± 0.12	0.77 ± 0.19	0.713	0.485
T4	0.78 ± 0.11	0.60 ± 0.16	2.843	0.011
<i>Cola (n = 10)</i>				
T1	1.19 ± 0.24	1.0 ± 0.29	1.563	0.135
T2	1.70 ± 0.25	1.50 ± 0.27	1.704	0.106
T3	2.32 ± 0.27	1.64 ± 0.23	6.096	<0.001*
T4	3.15 ± 0.28	1.80 ± 0.30	10.304	<0.001*
<i>Coffee (n = 10)</i>				
T1	2.51 ± 0.56	0.90 ± 0.22	8.422	<0.001*
T2	3.36 ± 0.54	1.47 ± 0.22	10.275	<0.001*
T3	3.50 ± 0.66	2.42 ± 0.30	4.708	<0.001*
T4	5.73 ± 0.99	2.20 ± 0.41	10.404	<0.001*
<i>Tea (n = 10)</i>				
T1	3.52 ± 0.73	1.50 ± 0.28	8.145	<0.001*
T2	4.68 ± 0.78	1.91 ± 0.21	10.832	<0.001*
T3	6.13 ± 0.97	2.70 ± 0.23	10.846	<0.001*
T4	8.06 ± 1.04	3.0 ± 0.33	14.618	<0.001*

Data was expressed using Mean ± SD. SD, standard deviation; t, student t-test; p, p-value for comparing between VE and XTML. *Statistically significant at p ≤ 0.05

Color evaluation was repeated at the end of immersion period in different storage media to assess the color change or stability by the equation:

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

L* for the color-opponent dimensions of lightness
 a* for the color-opponent dimensions of redness–greenness
 b* for the color-opponent dimensions of blueness–yellowness

Statistical Analysis of the Data

IBM SPSS software version 20.0 was utilized to perform statistical analysis of the obtained data. (IBM Corp, Armonk, NY). Collected data was explored for normality using Shapiro–Wilk and Kolmogorov Smirnov tests. One-way ANOVA test was used to compare the four studied groups followed by Tukey’s *Post Hoc* test for pairwise comparison. For comparisons involving more than two periods, an ANOVA with repeated measurements was employed, and for pairwise comparisons, the modified Bonferroni *Post Hoc* test was utilized. The significance level was judged at the 5% level.

RESULTS

Table 2 presents the color change of VE and XTML after storage in different beverages (water, cola, coffee, and tea) for four storage periods (7 days, 14 days, 21 days, and 28 days). In water subgroup, Mean and standard deviations of color differences for VE at the end of the 7th (T1), 14th (T2), 21st (T3) and 28th (T4) days were (0.55 ± 0.12, 0.64 ± 0.11, 0.72 ± 0.12, 0.78 ± 0.11; respectively) and for XTML (0.40 ± 0.20, 0.50 ± 0.20, 0.77 ± 0.19, 0.60 ± 0.16; respectively). In the cola subgroup, the mean and standard deviations of color

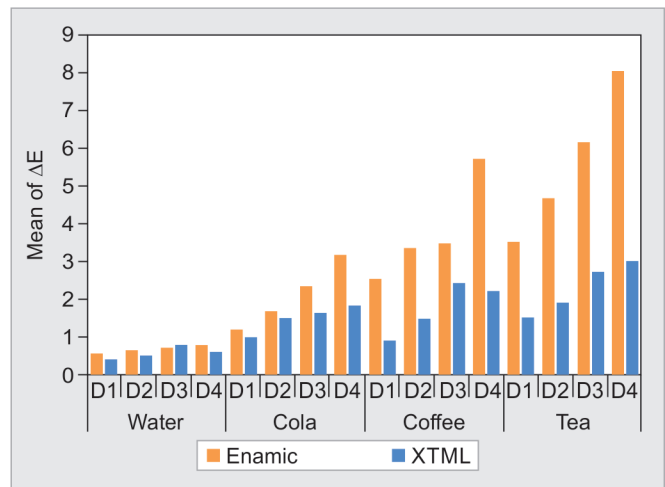


Fig. 1: Mean differences and standard deviations of ΔE of VE and XTML after immersion in beverage solutions

differences for VE at T1, T2, T3 and T4 were (1.19 ± 0.24, 1.70 ± 0.25, 2.32 ± 0.27, 3.15 ± 0.28; respectively) and for XTML (1.0 ± 0.29, 1.50 ± 0.27, 1.64 ± 0.23, 1.80 ± 0.30; respectively). In the coffee subgroup, the mean and standard deviations of color differences for VE at T1, T2, T3 and T4 were (2.51 ± 0.56, 3.36 ± 0.54, 3.50 ± 0.66, 5.73 ± 0.99; respectively) and for XTML (0.90 ± 0.22, 1.47 ± 0.22, 2.42 ± 0.30, 2.20 ± 0.41; respectively). In the tea subgroup, mean and standard deviations of color differences for VE at T1, T2, T3, and T4 were (3.52 ± 0.73, 4.68 ± 0.78, 6.13 ± 0.97, 8.06 ± 1.04; respectively) and for XTML (1.50 ± 0.28, 1.91 ± 0.21, 2.70 ± 0.23, 3.0 ± 0.33; respectively).

Vita Enamic revealed greater color changes than XTML after beverage staining in all periods of the four subgroups. There was a significant difference in color change between VE and XTML in all periods of tea and coffee immersion subgroups and in T3 and T4 in cola immersion subgroups (p < 0.001). Vita Enamic showed the highest differences in ΔE through all storage periods after 28 days of tea immersion (ΔE of VE = 8.06 ± 1.04). Extra translucent multilayer zirconia showed the highest differences in ΔE through all storage periods after 28 days of tea immersion (ΔE of XTML = 3.0 ± 0.33). The differences in the color change (ΔE) in both materials after staining from the highest to the lowest through all storage periods were as follows: Tea > coffee > cola > water (Fig. 1). The results clearly indicate the high influence of staining beverages on the color change of the tested ceramic restorations.

DISCUSSION

Over the past decade, rapid advancements in CAD/CAM materials have demonstrated their efficacy, necessitating thorough investigation of their optical behavior to meet patients’ high esthetic expectations. Gaining color stability and minimum color change is a crucial factor for patient satisfaction and restoration success.^{16,17}

In this study, all specimens were sliced with the Isomet 4,000. To guarantee a standardized thickness for all samples as saws reduce specimen deformation and kerf loss during cutting materials, preventing any potential optical changes caused by changes in thickness.^{18,19}

The use of rectangular specimens instead of discs is used to ensure better light reflectance and eliminate factors affecting

color parameter evaluations, such as surface curvature or natural tooth discoloration, at the same distance and level from the sample surface.²⁰

The thickness of 0.5 mm was chosen to mimic the restoration thickness for better results in color changes. The thickness of all specimens was confirmed by the assistance of a digital caliper to ensure standardization.²¹

Beverages consumed by the population have shown a variation of influence on the color stability of esthetic dental restorations leading to perceptible color changes. These beverages have come to increase the complexity of the oral environment, producing a continuous alteration within the pH value, and are accompanied by colorants and staining pigments. Many studies have evaluated their effect and interaction with the esthetic dental material.²²

Based on the protocol followed by Ertaş et al.,²³ the total time of immersion in beverages solutions was 28 days which equals to 28 months of beverages' consumption. Then samples were maintained at 37° C in an incubator in order to replicate the oral cavity temperature and avoid any temperature fluctuations that might affect the staining potency of the solutions.^{24,25}

The Commission Internationale de l'Éclairage (CIE) L*a*b* system, which has proven its efficacy in detecting any minor color changes as well as its accuracy and repeatability, may be used to precisely evaluate the color shift.²⁶ The color-opponent dimensions of lightness are represented by L*. Color-opponent dimensions of the redness–greenness range are represented by a*, whereas those of the blueness–yellowness range are represented by b*. These three factors were used to measure the color change as ΔE . The utilization of the Vita Easyshade spectrophotometer in our study to obtain the CIELAB coordinates is frequently employed in the dental research field, accordingly it was used in our study to obtain the ΔE for the specimens.²⁷ One study proving the accuracy of the easyshade spectrophotometer was done by Kenović et al.,²⁴ who evaluated the intra-device accuracy and repeatability of dental shade-matching device using both *in vitro* and *in vivo* models. They concluded that the precision of the device tested was 93.75% and that the VITA Easyshade V dental shade-matching device gave dependable and precious measurement.

Various levels of color change were reported in the literatures to indicate the acceptable and perceptible thresholds under *in vitro* and *in vivo* conditions. The perceptible ΔE threshold in different investigations ranges from 1.0 to 3.7, and the acceptable ΔE threshold ranges from 1.7 to 6.8.^{28,29} Several studies have shown that color differences greater than one unit ($\Delta E > 1$) can be visually perceived by 50% of human observers.¹⁹ Others showed that the general person only notices color changes when ΔE * a-b values are higher than 3.3.²⁸ Gupta et al.³⁰ used the $\Delta E > 3.7$ threshold to determine that their results were not clinically differentiable. In this current study the threshold of $\Delta E > 2.3$ was chosen, as an intermediate between different reported values, to be considered as clinically acceptable color difference or in other words, non-clinically perceived.³¹

In the present study, the color change of XTMZ in cola, coffee, and tea subgroups throughout all the storage periods was in the acceptability range except in T3 and T4 in the tea group which were beyond the acceptability range. In VE, color change in T1 and T2 in the cola group was in the acceptability range but color change in T3 and T4 in cola group and in all storage periods in the coffee group and tea group was beyond the acceptability range.

In the present study, the color changes in coffee and tea were found to be more intense than in cola and distilled water after immersion.^{16,28} The greater staining power of tea and coffee in polymer-infiltrated ceramics could be attributed to the yellow pigments' capacity to permeate the porous ceramic structure of these substances, which is penetrated by a polymer. Water and pigments from severely stained chromogenic food are reported to be absorbed by the polymer. Studies show that color absorption in polymer-infiltrated ceramics is caused by the hydrophilic nature of the TEGDMA component.¹⁶ Tea and coffee have different tannin content, with tea containing more tannins, which enhance the binding capacity of chromogens to material surfaces, promoting staining.³² Both the coffee and tea solutions' low polarity can cause color changes by enabling pigments to penetrate the resin matrix more deeply.^{16,18} The color change of XTMZ zirconia is due to the breakdown of metal oxides which causes the formation of peroxide compound that would likely change the color of the pre-shaded ceramic material.³³ Furthermore, cola drinks have a higher acidity (pH value of cola drinks is about 2.7) which can result in filler particle surface erosion and resin matrix degradation. It has also been demonstrated that cola drinks are more titratable acidic than other popularly used acidic beverages and it contributes to the fastening of saliva neutralization and causing a less staining effect on teeth restoration.^{16,34} In addition, Cola drinks have high polarity which diminishes their absorption effect and decreases their ability to adhere or stick to the teeth surface when washed and be more easily removed with washing. Also, the presence of phosphate ions in cola drinks appeared to have comparable effects on teeth surfaces.^{16,35} So, the null hypothesis of this study was rejected due to storage with various combinations of water, tea, coffee, and cola had a significant influence on color change of polymer infiltrated ceramics in comparison to XTMZ ceramic materials.

This study's findings agree with that of Eldwakhly et al.,¹⁶ who studied the influence of various staining solutions (coffee, cola, ginger, and water) on the color stability of five ceramic materials including polymer infiltrated ceramic and they verified that the highest color difference of polymer infiltrated ceramics was caused with coffee immersion. In addition, this result is in harmony with the study performed by Saba et al.,³⁶ who studied the effect of various staining solutions (water, red wine, and coffee) on the color stability of hybrid ceramic after 28 days and they found unacceptable color change for VE ($\Delta E = 4.9$) after coffee solution immersion. Also in agreement with the finding of Stamenković et al.,³⁷ who studied the influence of artificial aging as well as staining solutions (coffee and wine) on the color stability of five ceramic materials including polymer infiltrated ceramics and they found highly unacceptable color change after artificial aging and immersion of VE samples in coffee solution for 120 hours ($\Delta E = 3.9$). Finally in accordance with that of Yerliyurt and Sarıkaya,³⁸ who studied the effect of artificial aging of polymer-infiltrated ceramics and immersion in different beverage combinations including water, cola, coffee, and tea. They found significant color changes after immersion of VE specimens in a coffee-tea beverage ($\Delta E = 12.68$) followed by coffee ($\Delta E = 7.63$) followed by coffee-coke beverage ($\Delta E = 3.09$).

The method of application of staining beverages and the length of application time is a limitation in our study as the staining beverages do not remain continuously in contact with the restorative ceramic material in the oral cavity and might be

interrupted by brushing and also contaminated and washed by human saliva. Long-term clinical trials are needed for a better understanding of the full effect on patients.

CONCLUSION

Regarding the limitations of the present study, staining beverage solutions had a distinct influence on the color stability of the tested ceramic restorative materials. Commonly consumed staining beverages influenced the color stability of the polymer-infiltrated ceramics more than extra translucent zirconia ceramics. Practitioners should take into consideration the staining susceptibility of the polymer-infiltrated ceramics.

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