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Color Stability of Resin Hybrid Ceramic Materials in Comparison to Zirconia-Reinforced Lithium Silicate Ceramic

Reza Eftekhar Ashtiani[1], Elaheh Beyabanaki[1*], Mahshid Razmgah[2], Alma Salazar[3], Marta Revilla-León[3], Amirali Zandinejad[3]

1. Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
2. Private Practice, Tehran, Iran
3. Comprehensive Dentistry Department, College of Dentistry, Texas A&M University, Dallas, TX

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**** Corresponding author:***
Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Email: e.beyabanaki@gmail.com

ABSTRACT

Objectives: This in vitro study aimed to compare the effect of external staining agents (black tea and grape juice) on the color change of three hybrid ceramics including a new material in comparison to zirconia-reinforced lithium silicate.

Materials and Methods: Ten samples of two hybrid dental ceramics including Vita Enamic (Vita Zahnfabrik) and Crystal Ultra (Digital Dental) in addition to a resin nanoceramic, Lava Ultimate (3M ESPE); and a zirconia-reinforced lithium silicate glass ceramic, Vita Suprinity (Vita Zahnfabrik) were prepared and immersed in black tea or grape juice for 30 days. A spectrophotometer was used to evaluate color change. All samples were carefully chosen in A3 shades or their equivalent. Two-way ANOVA and Bonferroni tests were used to analyze the color differences ($\Delta E00$) among the materials and the staining solutions at a significant level of 0.05.

Results: Significant color changes were observed in Vita Enamic and Lava Ultimate groups after immersion in both solutions ($P<0.001$). The least color changes ($\Delta E00$) belonged to the Vita Suprinity (1.34) and Crystal Ultra (1.92) groups, respectively.

Conclusion: The color changes of Vita Enamic and Lava Ultimate materials were beyond clinical acceptability. However, the mean color changes of Vita Suprinity and Crystal Ultra groups were clinically acceptable.

Keywords: Color; Computer-Aided Design; Ceramics

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INTRODUCTION

Recently, a variety of monolithic dental ceramic materials has been introduced for fabrication of aesthetic tooth-colored fixed dental prostheses. Hybrid ceramics (HC), polymer-infiltrated ceramic network (PICN), and resin nano-ceramics (RNC)computer-assisted design/computer-assisted manufacturing (CAD/CAM) materials are the most recent generation of restorative materials developed and presented for fabrication of indirect restorations such as veneers, inlays, onlays, partial, and single crowns for dental or implant restorations [1,2]. Development of these materials involves infiltration of a porous ceramic with resin-based polymers. This novel generation of materials has similar physical properties to natural teeth including hardness, rigidity, flexural strength and microshear bond strength [3,4].
Although proper shade selection and translucency are the main factors at the time

of aesthetic dental materials selection, their color stability should also be considered for the long-term success of aesthetic restorations. The color stability of selected restorative materials would be critical in the oral environment due to their constant exposure to potential colored and staining fluids from different foods and drinks such as black tea, coffee, colored juices and carbonated drinks. Direct resin composites are widely used in dentistry, however their lower resistance to discoloration is considered as one of their shortcomings when compared to dental ceramics [5-10]. In addition to material compo-sition, exposure time to staining mediums and final surface treatment of composite restora-tions also play important roles in the discoloration of composite resin materials [11,12]. There are some concerns about the discoloration of hybrid ceramics and nano-ceramics due to their resin polymer composition regarding their indications for indirect restorations. Based on their composition and fabrication method they might demonstrate different susceptibility to discoloration, which should be considered before their selection especially for the aesthetic zone restorations [13].

Most previously published studies on stainability of HC and RNC materials involves evaluating Vita Enamic [5,14-20] and Lava Ultimate [21-23]. Furthermore, few studies on color stability of zirconia-reinforced lithium silicate glass-ceramic (ZLS) materials such as Celtra Duo or Vita Suprinity exist [2,7,10]. Crystal Ultra is a newly introduced hybrid ceramic with a 70% ceramic-like inorganic silicate glass fillers infiltrated with 30% cross-linked polymer mixture [24] and recommended for use in a wide range of restorations from laminates to implant-supported/retained prostheses according to its manufacturer. However, there is very limited scientific data on the color stability of this newly introduced hybrid ceramic which makes it difficult to judge this material especially in comparison to well-known resin-based CAD/CAM blocks including Vita Enamic and Lava Ultimate which have been frequently investigated by numerous scientific studies [5,14-23]. Therefore, the purpose of this study was to analyze and compare the color changes of Vita Enamic, Crystal Ultra, Lava Ultimate, and Vita Suprinity when immersed in black tea and grape juice for 30 days. The null hypothesis was that there would be no significant color changes exceeding the clinically acceptable levels after immersion of the resin-based and ZLS CAD/CAM blocks when immersed in different staining solutions.

MATERIALS AND METHODS

Ten 12×14×1.5mm samples were prepared for four CAD/CAM blocks in A3 or equivalent shades. These included Vita Enamic (VE), Crystal Ultra (CU), Lava Ultimate (LU) and Vita Suprinity (VS) (Table 1). The blocks were cut with a low-speed diamond blade and a ground section machine (Accutom, Struers, Germany) under water irrigation. Both sides of the samples were polished using a diamond polishing kit (Clearfil Twist Dia, Kururay, Japonya) based on the

Table1. Characteristics of the materials evaluated in this study.

Material	Composition	Manufacturer
Crystal Ultra	Hybrid ceramic material composed of 70% wt ceramic-like inorganic silicate glass fillers infiltrated with 30% wt cross-linked polymer mixture	Digital Dental, Scottsdale, USA
Lava Ultimate	Resin nano-ceramic material consisting of 80% wt nano-ceramic and 20% wt resin (Bis-GMA, UDMABis-EMA, TEGDMA)	3M ESPE, St. Paul, MN, USA
Vita Enamic	Hybrid ceramic material consisting of 86% wt feldspar ceramic and 14% wt cross-linked polymer (UDMA, TEGDMA)	VITA Zahnfabrik, Bad Sackingen, Germany
Vita Suprinity	Zirconia-reinforced lithium silicate material with a composition of SiO2 (56-64%), ZrO2 (8-12%), Li2O (15-21%), and La2O3 (0.1%)	VITA Zahnfabrik, Bad Sackingen, Germany

Bis-GMA: Bisphenol A diglycidyl methacrylate; UDMA: Urethane dimethacrylate; Bis-EMA: Bisphenol A ethoxylate dimethacrylate; TEGDMA: Triethylene glycol dimethacrylate manufacturer's instructions. Samples presenting inaccurate size or chipping were replaced with new ones. All samples were cleaned with deionized water (US Water Systems, Indianapolis, US) for 3 minutes ultrasonically (Patterson Dental, Saint Paul, USA) and then incubated in distilled water at 37°C for 24 hours [7]. Samples of each material were randomly allocated into two groups (N=5) and immersed in either black tea (Shahrzad, Tehran, Iran) or grape juice (Sunich, Tehran, Iran) [2]. The black tea solution was prepared by dissolving 2 g of tea powder in 200 mL of boiling distilled water according to the manufacturer's instructions. All samples were stored in a dark environment inside an incubator (Heal Force Bio-meditech, Shanghai 201706, China) at 37°C for 30 days to simulate 2.5 years of consumption of staining agents [7]. Solutions were changed every 24 hours and storage containers were covered to prevent evaporation of the fluids [25]. Spectrophotometric analyses were performed on the 1st (before immersion) and 30th days using a spectrophotometer (Vita Easy shade Advance, Germany) against a grey background [2]. All the specimens were rinsed for 15s with distilled water and air-dried prior to color measurements [1,12]. For each sample, measurements were repeated three times in a central area and the average scores were recorded by a blinded trained operator. The CIEL*a*b color system was used to determine color differences in this study [24-28].

The before and after color differences in the black tea and grape juice media were calculated using the CIEDE2000 (DE00) color-difference formula [26,27] on gray backing and it calculated as following:

$$\Delta E_{2000}\sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2+\left(\frac{\Delta C\prime}{k_C S_C}\right)^2+\left(\frac{\Delta H\prime}{k_H S_H}\right)^2+R_T\left(\frac{\Delta C\prime}{k_C S_C}\right)\left(\frac{\Delta H\prime}{k_H S_H}\right)}$$

Different acceptability (1.8-2.25) and perceptibility (0.8-1.3) thresholds for discoloration are introduced in the literature [28-30]. In this study the parametric coefficients; KL, KC, and KH were set to 1.0, the perceptibility threshold was set toDE00=1.30 units, and the clinical acceptability threshold was set toDE00=2.25 units [29,30].

Color change differences noted in the specimens due to their immersion in the staining agents were calculated using the SPSS Statistics 22.0 program (SPSS, Inc, Chicago, Illinois). The Kolmogorov-Smirnov test was implemented to assess the normality of the data distribution. A parametric analysis of variance test (two-way ANOVA) was applied to determine whether significant differences existed among the groups. The Bonferroni test was used for paired comparison at a significant level of 0.05.

RESULTS

The color changes examination of the evaluated CAD/CAM materials caused by exposure to 2staining solutions presented significant differences between both, the restorative materials and the colorant beverages ($P<0.05$). The restorative materials used in this study displayed color changes above the clinical significance perceptibility ($\Delta E00>1.30$) level at the end of the 30thday in both staining solutions. Furthermore, clinically unacceptable color differences ($DE00>2.25$ units) were noticed for all materials except for CU and VE in grape juice, and VS after immersion in either Solutions ($\Delta E00<2.25$). Moreover, LU displayed the highest overall $\Delta E00$ value ($\Delta E00=8.53$) and VS showed the lowest overall $\Delta E00$ value, ($\Delta E00=1.34$) (Table 2). The highest level of discoloration was observed for LU immersed in grape juice ($\Delta E00=10.62$).

No statistically significant differences were recorded between the two staining solutions for VS and CU samples ($P>0.05$). However, immersion in grape juice resulted in greater color change than in black tea for LU ($P<0.001$).

Also, significant discoloration was observed for VE samples submerged in black tea as compared with those in grape juice ($P=0.001$). In addition, a considerable difference between LU and all the other used materials ($P<0.001$) (Table 3) was observed (Figure 1).

Table 2. Mean and standard deviation (SD) of color change (ΔE00) of four CAD/CAM materials in tea and grape juice solutions after 30 days.

Materials	Solution	Mean	SD
Crystal Ultra	Grape juice	1.31	0.66
	Tea	2.54	1.15
	Total	1.92	1.1
Lava Ultimate	Grape juice	10.62	3.03
	Tea	6.43	0.91
	Total	8.53	3.05
Vita Enamic	Grape juice	1.42	0.53
	Tea	4.36	0.52
	Total	2.89	1.62
Vita Suprinity	Grape juice	1.32	0.23
	Tea	1.37	0.22
	Total	1.34	0.21

Table 3. P values of pair comparison of total color change between four different CAD/CAM materials.

Sample	Sample	P
Crystal Ultra	Lava Ultimate	<0.001
Crystal Ultra	Vita Enamic	0.571
Crystal Ultra	Vita Suprinity	1
Lava Ultimate	Vita Suprinity	<0.001
Lava Ultimate	Vita Suprinity	<0.001
Vita Enamic	Vita Suprinity	0.057

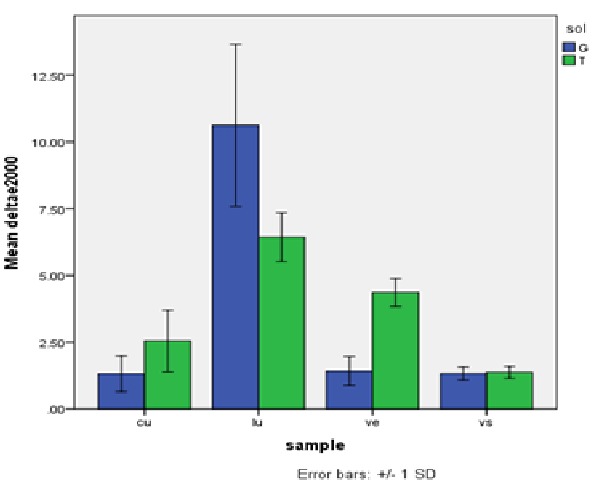

Fig. 1. Color change of different CAD/CAM materials in two colorant solutions (G; grape Juice and T;tea). The materials include: CU, Crystal Ultra; LU, Lava Ultimate; VE, Vita Enamic; and VS, Vita Suprinity.

DISCUSSION

Along with the initial color matching process, predictable long-term color stability should be considered as important at the time of restorative material selection, particularly when using newly introduced hybrid ceramic and resin nano-ceramic materials. Consumption of potential staining beverages such as black tea and fruit juices is part of the daily routines for most people which were also used as staining media in this study. The null hypothesis of this study was rejected because the evaluated polymer containing restorative materials (VE, CU and LU) presented significant color changes in comparison to VS as a dental ceramic material after a 30-day exposure to black tea and grape juice.

Based on the results of this in vitro study, although color changes due to immersion in tea and juice beverages were perceivable for all materials (ΔE> 1.30),VS and CU showed acceptable color changes(1.30<ΔE00<2.25), especially in grape juice. Since the lowest color changes was generally observed for zirconia-reinforced lithium silicate material, this study supports the idea that dental ceramic materials exhibit better color stability than resin containing materials. [5,6]. Other studies comparing the color stability of glass-ceramic materials and polymer-infiltrated ceramics also reported better color stability for the glass-ceramic materials such as zirconia-reinforced lithium silicate material (Celtra Duo, Dentsply Sirona) [7-10].

Furthermore, the color change of the VE in black tea was above the clinical acceptability level, the LU presented the highest level of color changes in either solutions, especially in grape juice (ΔE00=10.62). This is consistent with similar studies that reported higher stainability for LU [13,15,16,18]. Clinically unacceptable color change of LU was also reported when stained with coffee in comparison to VE [13,16]. Furthermore, in a study by Liebermann [18], it was noted that colorant solutions at 55 °C caused greater discoloration changes than those at 37 °C, and

LU displayed more stainability than VE. Both, PICN and RNC materials, could be considered composite resins due to their composition of a porous ceramic matrix filled with a polymer material or embedded nano-ceramic particles in a highly cross-linked resin matrix, respectively [31,32]. Furthermore, both materials contain hydrophobic urethane dimethacrylate (UDMA) and hydrophilic triethylene glycol dimethacrylate (TEGDMA) [22]. Hydrophilic monomers in the composite resin could result in the absorption of staining agents; therefore, TEGDMA might be responsible for the penetration of colorants into both, the HC and RNC materials [20,21]. However, the higher values in color changes noted in the RNC (LU) material could be explained by its bisphenol A-glycidyl methacrylate (Bis-GMA) and its ethoxylated version (Bis-EMA) content [5,22,23]. According to Gajewski et al [33] Bis-GMA exhibits the highest water sorption when compared with other hydrophilic monomers. Although, the effect of the size and chemical and morphological features of the including monomers and polymers in a material should not be neglected, generally there is a higher chance for hydrolytic degradation by water sorption in the materials with a higher resin content [10,34]. Gouveia et al [35] ranked the most common monomers used in the composition of hybrid ceramics and nanoceramics from the highest to the lowest level of hydrophilicity as TEGDMA, Bis-GMA, Bis-EMA, and UDMA. Furthermore, the type, shade, and thickness of the CAD/CAM hybrid ceramic and nanoceramic materials affect their stainability [19].

Although the color change values of the CU specimens were perceivable, these were below or nearly close to clinically acceptable levels ($\Delta E00=1.31$ in grape juice and $\Delta E00=2.54$ in black tea). However, the ΔE of CU and LU were the only statistically significant color change differences ($P<0.001$). Surprisingly, CU despite being a hybrid ceramic material delivered the least color changes after the VS in this study. The improved color stability of this material is probably justified by its different composition and the inclusion of hydrophobic characteristics of the monomer 1, 4-butanediol dimethacrylate (BUDMA) [24] of this material in comparison to VE. BUDMA which is only found in the composition of CU, is a cross-linking monomer that its chemistry could strongly affect the morphological properties of the material such as pore size distribution and permeability [36]. Moreover, the yet unknown exact composition, fabrication, and polymerization procedures of this newly introduced PICN material in comparison to VE as another PICN material could also explain the increased resistance to tea and juice discolorations seen in CU. Therefore, considering the lower values of stainability of CU in both solutions, it could be considered as an alternative to VE as a PICN, and LU as a nanoceramic material in cases with daily habits of drinking tea or juice. Although the manufacturer emphasizes the high optical properties for CU, there is only one in vitro research [24] on this restorative material. Different results found for the Al shade of this material in a study by Al Amri [24] might be attributed to different study designs such the use of thermocycling in coffee or different thickness and shades of the materials used. Nevertheless, in order to draw a definitive conclusion regarding this novel material, further investigations are required.

It has been reported that coffee induces greater discoloration changes than tea, since it contains yellow staining molecules with low polarity and high affinity to the polymer network [37]. Therefore, coffee could cause greater color changes than tea especially in methacrylate-based materials such as LU [14]. Moreover, coffee discoloration is the result of both, adsorption on the surface and absorption of the colorants into the organic phase of the material; while tea discoloration is mainly due to the surface adsorption of polar colorants [20,37,38]. Therefore, it could be concluded that if tea could cause color changes in a resin containing ceramic material, then there would be a higher probability that coffee could also result in stainability of that material. This also

indicates that staining resulting from tea could probably be more easily removed by surface polishing than staining caused by coffee [5,39].
One limitation of this in vitro study was using both sides of the specimens for testing stainability while in clinical situations one side would be bonded to the tooth surface. In future studies, new techniques, the effects of other staining agents, thermocycling and other material thicknesses and shades should be evaluated.

CONCLUSION

Within the limitations of this study, it was determined that ZLS, as a ceramic material, exhibits the highest resistance to color change when exposed to black tea and grape juice. Additionally, HC materials demonstrated less color change compared to RNCs. However, both VE and LU exhibited color changes that exceeded the clinical acceptability threshold. In the comparison between the two hybrid ceramics, CU demonstrated a slightly lower degree of discoloration, although this difference did not reach statistical significance. Notably, the color changes observed in ZLS when subjected to both staining agents and CU in grape juice were perceptible but remained within clinically acceptable limits.

CONFLICT OF INTEREST STATEMENT

None declared.

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