ORIGINAL ARTICLE

Effects of beverage colorants and accelerated aging on the color stability of indirect resin composites

Sakineh Nikzad [a], Abbas Azari [b*], Mohsen Poursina [c]

[a] *Department of Fixed Prosthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran*
[b] *Department of Removable Prosthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran*
[c] *Private Practice, Nekka-Mazandaran, Iran*

Abstract *Background/purpose:* Discoloration of resin-based restorations is considered a common obstacle in restorative dentistry. Several studies assessed the color stability of direct resin composites; however, little is known regarding indirect/laboratory composite resins (ICRs). The purpose of this study was to investigate the color stability of two ICRs (Gradia, Gradia, GC Dental Products) and (SR-Adoro, SR Adoro, Ivoclar Vivadent) compared to a feldspathic porcelain (Ceramco II, DENTSPLY Ceramco) following immersion in different beverages or subjected to accelerated aging.
Materials and methods: Using a machine-made metal mold, 20 disc samples (10 mm in diameter and 2 mm thick) were fabricated from each proposed material. Discs were randomly divided into four groups. The baseline measurements of CIELAB metric parameters were performed on all specimens with a spectrophotometer. Three groups then underwent an immersion process in different media (coffee, tea, and cola) for 2 weeks. The last group was subjected to UV aging for 300 hours. The color coordinates and their corresponding color changes (ΔE) were measured.
Results: The greatest color changes were seen in the coffee solution ($\Delta E = 13.34$ for SR-Adoro and $\Delta E = 16.01$ for Gradia), while tea was responsible for the greatest color change in porcelain ($\Delta E = 4.21$). The UV aging test caused the lowest discoloration effects on all three samples ($\Delta E = 3.42$ for SR-Adoro, $\Delta E = 3.01$ for Gradia, and $\Delta E = 1.29$ for Ceramco II).
Conclusion: Under the limitations of this *in vitro* study, the color stability of commonly used ICRs appeared to be significantly affected by the staining materials used. Standardized methodologies like the one described in this paper may be very reliable for assessing clinical properties of ICR materials.
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 * Corresponding author. Department of Removable Prosthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Quds Street, Tehran, Iran.
    E-mail address: azari@sina.tums.ac.ir (A. Azari).

Introduction

Tooth-colored restorative materials have evolved in order to fulfill the aesthetic requirements of restorative dentistry. Nowadays, many practitioners tend to more extensively use these attractive materials than before in clinical practice. This is mainly because of the conservative nature of the restorative techniques involved, minimal preparation requirements, shorter chair times, and increasing patient knowledge of the varieties of material options available to dentists.

Although outstanding aesthetic properties and excellent biocompatibility of dental porcelain as an aesthetic material were never in doubt, the brittle nature of ceramic materials and the large shrinkage which occurs during processing have raised questions, and trends are to use modern polymeric/composite counterparts. Unfortunately, the tendency for gradual discoloration of polymeric dental materials over time is relatively high, and replacement of the entire restoration soon after treatment is often necessary.[1] It was clearly indicated that polymer-based materials may undergo discoloration due to intrinsic and extrinsic factors.[2-4] Chemical dissociation of the resin matrix itself and/or matrix-filler interface over time are reported to be the main causes of intrinsic discoloration,[5] while surface tainting and sorption of common colored foods and drinks, and/or smoking, were proposed to be the main causes of extrinsic color changes.[1,6-8] Other factors reported to affect discoloration of resin restorations are the light intensity of the curing device,[9] the light-curing type,[10] ultraviolet (UV) light-accelerated aging,[11] vital bleaching,[12,13] and the polishing method.[14] Those investigations however, were mostly carried out on direct filling composite restorative materials, and data on some newly developed indirect/laboratory composites are still very scarce.

These types of composite resins were introduced in order to overcome some limitations of ceramic materials (such as brittleness and reparability) in fixed partial restorations. Several reports pointed out the beneficial biomechanical properties, excellent aesthetics, easy handling, easier laboratory procedures and optimal hardness properties of these types of restoration materials.[15-18] It was also claimed by some manufacturers that the aesthetics of some of these materials can endure for a lifetime. However, in recent studies, changes in the color of laboratory composites during the curing cycle were reported.[19] In this study, we attempted to determine the *ex vivo* color stability and color coordinate changes of two indirect/laboratory composite resins (ICRs) compared to one feldspathic porcelain, after storage in different drinking media and/or after UV light-accelerated aging.

Materials and methods

Two groups of ICR discs of a light-cured micro-ceramic-composite (Gradia, GC Dental Products, Aichi, Japan), a micro-filled, light/heat-cured veneer composite (SR Adoro, Ivoclar Vivadent AG, Schaan, Liechtenstein), and a commercial feldspathic dental porcelain (Ceramco II, DENTSPLY Ceramco, New York, NY, USA) were prepared following the manufacturers' instructions. Each group consisted of 20 discs of 10 mm in diameter and 2 mm thick. In order to better control the disc dimensions, a custom made (laboratory made) metal mold was used. All of the materials used and their specifications are presented in Table 1.

In both ICR groups, a thin layer of separator was first applied to the mold surfaces. For the Gradia group, a layer of Gradia separator (GC Dental Products) and for the SR-Adoro group, a layer of SR-Link (Ivoclar Vivadent AG) were, respectively, applied to the molds. Then 2 × 1 mm layers of each ICR material were added followed by 40 seconds of light curing. In order to control the flow of ICR materials, a glass slide covered with a celluloid matrix was used at the bottom and top of each mold sample during the curing phase. The Gradia prepared mold was placed in an oven (GC lab-o-light LV-II/ LV-III, GC Dental Products) for an additional 5 minutes. SR-Adoro samples were placed in a Lumamat 100 furnace (Ivoclar Vivadent AG) for an additional 11 minutes as instructed by the manufacturer. All of the prepared discs were polished by 240-, 400-, and 600-grit silicon carbide abrasive (Struers A/S, Rodovre, Denmark) with a low-speed handpiece and under water irrigation.

In the feldspathic porcelain group, 1.3 g of ceramic powder was mixed with 0.3 mL of modeling fluid and inserted into the mold using a condensation technique. Specimens were then fired in a porcelain furnace (Vacumat 200, Vita Zahnfabrik, H.Rauter GmbH&Co.KG 79704 Bad Säckingen) according to the manufacturer's recommendations. All fired ceramic specimens were then ground flat on both sides with the same polishing discs described above and glazed.

All of the discs (60 discs in total) were cleaned in an ultrasonic cleaner (Sonorex, Bandelin, Berlin, Germany) for 10 minutes, rinsed with fresh distilled water for another 20 minutes, and then randomly divided into four groups (A–D) of 15 pieces comprising equal numbers for the three sample tests.

Table 1 General composition details and batch numbers for all materials used.

Product	Material type	Manufacturer	Batch No.	Brand
GC-Gradia®	light-cured micro- ceramic- composite	GC Dental Products Corp., Aichi, Japan	4700148800	E13
SR-Adoro®	micro-filled, light/heat-curing veneering composite	Ivoclar Vivadent AG, Schaan / Liechtenstein	PC01233	TS2
Ceramco® II	Feldspathic Porcelain	DENTSPLY Ceramco 570 West College Avenue York, USA	PC265122	A2

Before proceeding to next step, it was necessary to calculate the baseline color of each specimen according to the Commission Internationale de l'Eclairage (CIE) 1976 [L*, a*, b*] (CIELAB) coordinate metric color space. Initially, the white balance settings for the color testing procedures were calibrated and certified. Then, with a special white calibrating tile (SP-64, Atlas Material Testing Technology, Linsengericht, Germany), the color scale relative to the standard illuminant D65 illumination settings which corresponds to natural daylight was determined. Then, the color measurement was carried out with a spectrophotometer (Color-Eye 7000A, Gretag Macbeth Instruments, New Windsor, NY, USA). The light source of this spectrophotometer is a high-intensity pulsed xenon lamp which is capable of precisely measuring both translucent and transparent materials. In order to obliterate the reflective effect of each specimen, color testing was performed in a specular-excluded situation. The viewing aperture diameter of the spectrophotometer was 4 mm, with an observer viewing angle of $2°-8°$. This limited the instrument view to the middle of a sample disc. The obtained CIELAB metric values for each specimen were recorded according to the CIELAB color system, and all gathered data were input into a computer and saved for color difference measurements after the disc immersion phase and UV-aging test. In order to further refine the calculations, after each measurement, the calibration process was repeated. Once the color of each specimen was calculated, the grouped specimens were immediately subjected to an immersion test (specifications of the immersion beverages are given in Table 2) as described as follows.

In group A, the selected disc specimens were immersed in a tea solution. This solution was prepared by dipping a tea bag in boiling distilled water 20 times. Specimens were left in the tea solution until the temperature reached $37\,°C$ and then they were put into an incubator. To prevent possible chemical changes in the solution material, this process was repeated every 48 hours. At the end of week 2, samples were retrieved from the solution, washed for 20 seconds with distilled water, and carefully wiped and dried using water/oil-free compressed air.

In group B, discs were immersed in coffee. The coffee solution was prepared by adding 5 g of coffee to 200 mL of boiling distilled water. Specimens were left in this solution until the solution temperature reached $37°C$, and then they were put into an incubator. This process was repeated every 48 hours. At the end of 2 weeks, all of the discs were removed, washed (20 seconds), and carefully blow-dried.

In group C, specimens were immersed in $4°C$ cold cola and then put into a $37°C$ incubator for 2 weeks. The process was repeated every 48 hours with fresh solution. At the end of 2 weeks, specimens were removed and then blow-dried with oil free air.

In group D, specimens were placed into a UV accelerated-aging test machine (SUNTEST CPS/CPS+, Atlas Material Testing Technology, Linsengericht, Germany) and subjected to UV light irradiation from a filtered xenon lamp ($765\ W/m^2$ daylight at 150 klux). The distance of a specimen to the light was fixed, and irradiation continued for 300 hours. The test conditions were according with ISO 7491:2000, under 80%−100% humidity and 35−37°C temperature control.[20]

At the end of 2 weeks, all of the discs were again put into the spectrophotometer device for the color-change test. Corresponding color changes were determined according to the CIELAB metric color space system and by the same process described above. Mean values of L*, a* and b* were saved and digitally compared to the numerical data gathered before aging. The total color change (ΔE) was calculated for each sample using the following equation:

$$\Delta E = \sqrt{\left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]}$$

Relative values of ΔL*, Δa*, and Δb* corresponded to differences before and after immersion and UV aging. In all cases, when ΔE was > 1, color changes were considered to be detectable with the naked eye, and when ΔE was ≤ 3.3, the change was considered clinically acceptable.[21,22] To determine significant differences between color parametric values (ΔL*, Δa*, and Δb*) among the materials tested, one-way analysis of variance (ANOVA) and Tukey's pair-wise analytical tests were used. Two-way ANOVA was used to assess mean differences in ΔE before and after immersion and UV aging. In all cases, an alpha level of 0.05 was used to indicate statistically significant differences (by Tukey's test, $P > 0.05$).

Results

Changes in each coordinate parameter before and after immersion test are presented in different sections.

ΔL* color parametric value (lightness representative value)

The highest ΔL* values were seen for ICR samples in coffee (ΔL* = -12.19 for SR-Adoro and -15.21 for GC-Gradia), while the lowest values were for these two materials measured after UV aging (ΔL* = -2.33 for SR-Adoro and -2.29 for GC-Gradia). The greatest change in ΔL* for the feldspathic porcelain was seen in tea (ΔL* = -3.03). UV aging changed the ΔL* value of porcelain by about -0.44 (Fig. 1). One-way

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Table 2 Staining solutions detail used in this study.

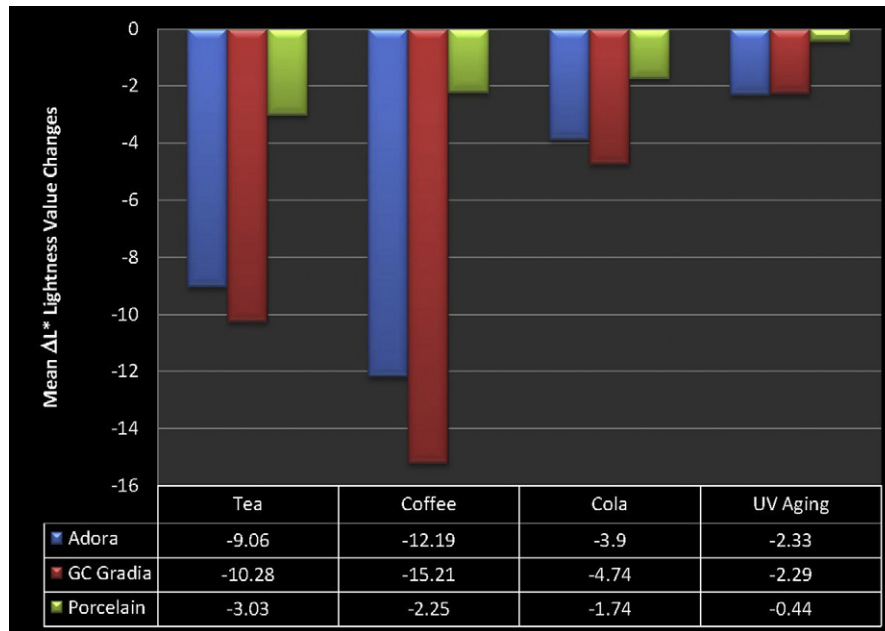| Product	Chemistry	PC/Barcode	Manufacturer	Brand
Tea bag	1 tea bag/200 ml distilled water	PC5792	Lipton/England	Yellow Tea
Nescafe®	5 g coffee/200 ml distilled water	7613030084457	Nestle/Switzerland	Coffee
Cola	Carbonated water, Cola extract, Aspartame, Phosphoric acid	PC382546	Coca Cola/Mashhad- Iran	Cola Zero

Figure 1   Mean ΔL* lightness color value changes of all specimens after immersion in various drinks and UV accelerated aging.

ANOVA showed that there were significant relationships of the immersion type and UV aging with the ΔL* color parametric value ($P < 0.0001$). The type of material tested also had a significant influence on the ΔL* color value change ($P < 0.0001$). Tukey's HSD test showed that significant differences existed among immersion methods, UV aging, and types of materials tested from the standpoint of parameter ΔL* for both ICR systems ($P < 0.0001$).

Δa* color parametric value (color value between red/magenta and green)

The greatest change in the Δa* color value occurred in both ICR samples in coffee (Δa* = 3.32 for SR-Adoro and 3.02 for GC-Gradia), while the lowest values for these two materials occurred after UV aging (Δa* = 0.54 for SR-Adoro and 0.064 for GC-Gradia). The greatest change in Δa* for feldspathic
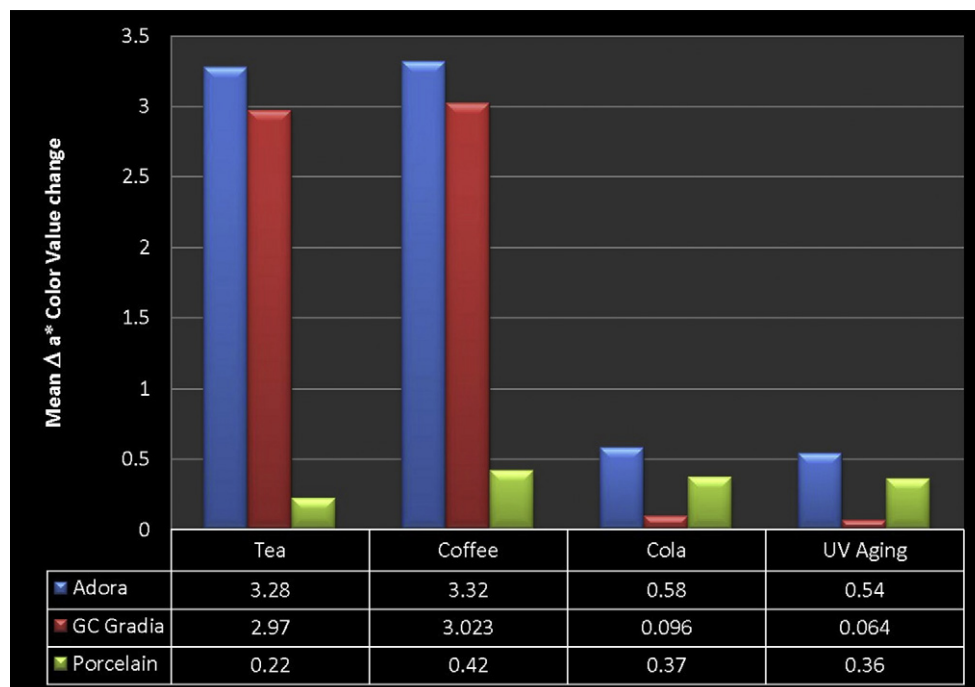

Figure 2   Mean Δa* coordinate color value changes of all specimens after immersion in various drinks and UV accelerated aging.

porcelain was seen in coffee ($\Delta a^* = 0.42$) (Fig. 2; negative values are indicated in green, whereas positive values are indicated in magenta). One-way ANOVA showed that there were significant relationships of the immersion type and UV aging with the Δa^* color parametric value ($P < 0.0001$). The type of material tested also had a significant influence on the change in the Δa^* color value ($P < 0.0001$). Tukey's HSD test showed that significant differences existed among immersion methods, UV aging, and types of materials tested from the standpoint of parameter Δa^* for both ICR systems ($P < 0.0001$).

Δb^* color parametric value (color value between yellow and blue)

The greatest change in the Δb^* color value was seen for both ICR samples in cola ($\Delta b^* = -2.62$ for SR-Adoro and -3.18 for GC-Gradia), while the lowest values for these two materials occurred after UV aging ($\Delta b^* = -1.63$ for SR-Adoro and -0.78 for GC-Gradia). The greatest change in Δb^* for feldspathic porcelain was seen after UV Aging ($\Delta b^* = -0.95$) (Fig. 3; negative values are indicated in blue, whereas positive values are indicated in yellow). One-way ANOVA showed that there were significant relationships of the immersion type and UV aging with the Δb^* color parametric value ($P < 0.0001$), but the type of material tested had no significant influence on the Δb^* color value change. Tukey's HSD test showed that significant differences existed among immersion methods, UV aging, and the type of materials tested from the standpoint of parameter Δb^* for both ICR systems ($P < 0.0001$).

ΔE single color difference value (total color difference)

ΔE is a single value which represents quantitative differences between L*, a*, and b* values of samples before and after the test. Both ICR specimens underwent maximal color changes after immersion in coffee ($\Delta E = 13.34$ for SR-Adoro and 16.01 for GC-Gradia), while changes after UV aging greatly differed ($\Delta E = 3.42$ for SR-Adoro and 3.1 for GC-Gradia). For porcelain specimens, ΔE value changes mostly occurred in the tea solution ($\Delta E = 4.21$) (Fig. 4). The two-way ANOVA showed that the immersion media and material type had a significant effect on the ΔE color value ($P < 0.0001$). One-way ANOVA also indicated that the immersion media had a significant effect on ΔE values ($P < 0.0001$). Results from the pair-wise statistical analysis showed that there was no significant relationship of cola/coffee on porcelain samples or UV-aging/cola on SR-Adora in terms of ΔE color value changes ($P < 0.0001$).

Discussion

ICR materials were introduced to overcome some major drawbacks of their ceramic counterparts in making crowns, bridges, inlays, and veneers. Some of the most important features of these materials are their high toughness and excellent color vitality, which give restorations high strength and life-like color tones. It was stated that these materials have lifetime aesthetics and are free from the so called "paleness" which is commonly seen with traditional dental composite resins. It was clearly indicated, however, that evaluating color changes and differences by a mere visual examination is not useful or even possible.[23] Quantitative assessments of the color stability of dental direct composite resins by means of standardized instruments, such as colorimeters and/or spectrophotometers, and under various test conditions, convinced clinicians to consider these types of material as "color changeable" over time.[2–14] Results of the present study also showed that common beverages have adverse effects on changes in ΔE color values of ICR materials. It was previously indicated that when ΔE is > 1, the color change is considered

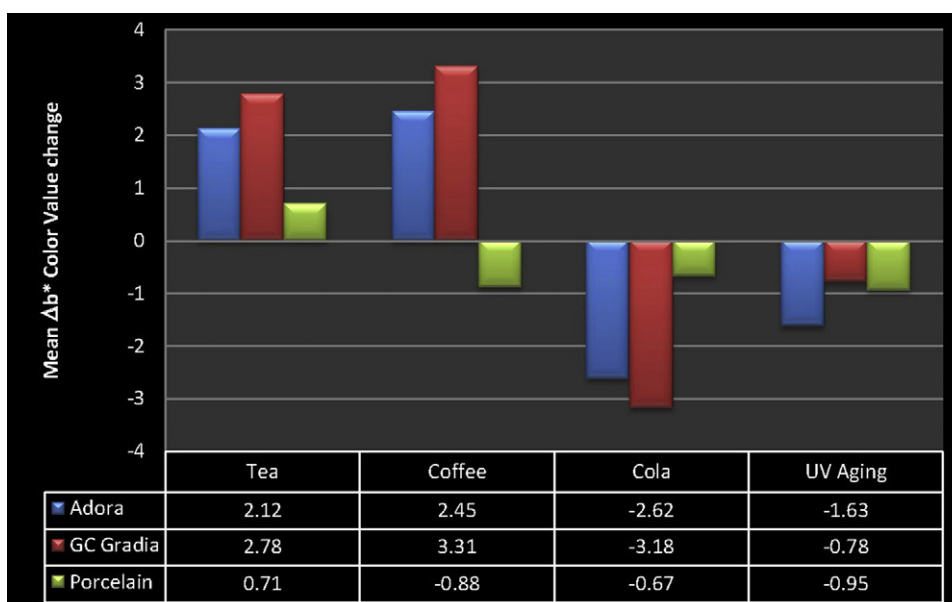|	Tea	Coffee	Cola	UV Aging
Adora	2.12	2.45	-2.62	-1.63
GC Gradia	2.78	3.31	-3.18	-0.78
Porcelain	0.71	-0.88	-0.67	-0.95

Figure 3   Mean Δb^* coordinate color value changes of all specimens after immersion in various drinks and UV accelerated aging.
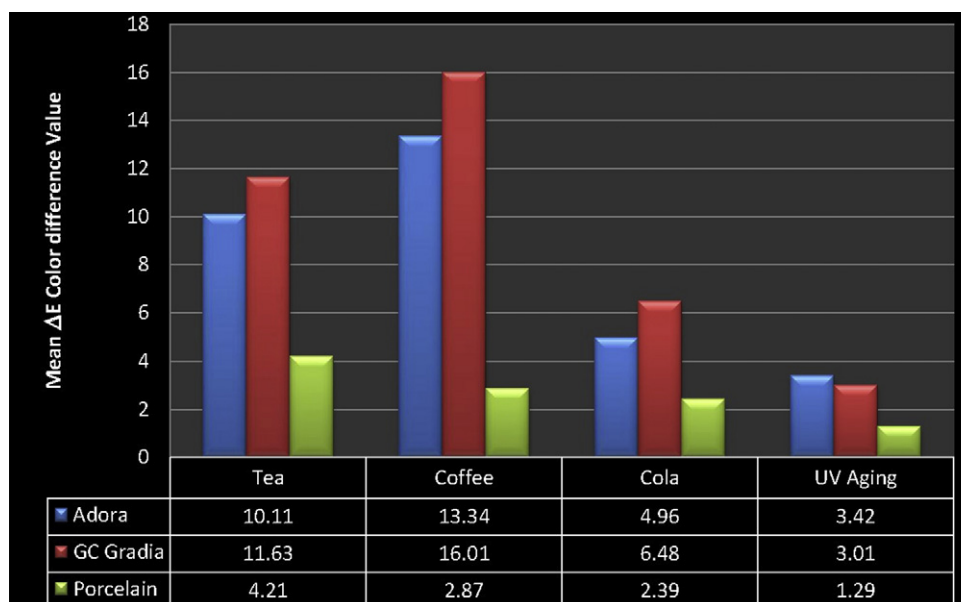
Figure 4 Mean ΔE color difference value changes of all specimens after immersion in various drinks and UV accelerated aging.

detectable to the naked eye, and when ΔE is ≤ 3.3, changes are clinically acceptable.[21,22] According to the color coordinating parameter values achieved in this study, all of the material specimens tested, including porcelain, may lose their "lightness" (i.e., ΔE* < 1) under conditions of immersion and UV aging. The materials showed a color value change to magenta (Δa* >1), but different behaviors were seen between the materials tested in terms of Δb* values. Tea and coffee made specimens yellower, while cola and UV aging made them bluer (based on the Δb* values recorded). Dental porcelain samples in all groups were little affected by the test conditions, and so can be used as a standard for color stability testing of ICR materials; this is in accordance with a recent study.[24] The effect of UV aging on all samples except SR-Adora was not high enough to be considered a factor which affects ΔE (ΔE ≤ 3.3). It was shown that changes in color parameters and ΔE of dental composite materials by UV lighting are clinically acceptable.[11,23] Analysis of quantitative color values achieved in the present study showed that the Δa* and Δb* color coordinates of SR-Adora were most affected. The main medium which had maximum effect on color difference changes was coffee, followed by tea. The mean ΔE change of ICR specimens (ΔE > 13) in this study was much greater than the clinically acceptable limit. The result for porcelain somewhat differed, and specimens made of porcelain showed clinically unacceptable ΔE changes only in tea (ΔE > 4). Previous studies showed that common beverages like red wine, tea, and coffee cause the most significant color changes of composite resins[25] and dental porcelains.[26] Nevertheless, it was noted that these types of beverage only affect the external surface of specimens (external staining), and their effects on the internal structure of ICRs must be further evaluated. In all specimens, stained surfaces of ICRs can be easily polished to ameliorate the discoloration effect. However, the effects of polishing on decreasing the lightness and color stability of ICRs must be comprehensively assessed. An increase in

the wear behavior of composite resins after exposure to alcoholic beverages was previously demonstrated.[27]

In conclusion, within the limitations of this study, the following conclusions were made: immersion media made from common beverages have significant effects on ΔE color space values of ICR materials; coordinate color values were little affected by UV aging, so its importance in future similar studies is under question, but further studies are recommended; and ΔE coordinate color value differences of ICR materials were clinically unacceptable.

The quantitative assessment of tooth-color dental restorative materials through standardized methodologies, like the one described in this paper, can assist clinicians in becoming aware of the actual properties of the materials used.

Acknowledgments

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