Color Stability of Dental Composites after Immersion in Beverages and Performed Whitening Procedures

Stabilnost boje dentalnih kompozita nakon uranjana u napitke i postupaka izbjeljivanja

Abstract

Objectives: The study aimed to compare the color stability of two different light-cured composites after immersion in three liquids and the effectiveness of 16% carbamide peroxide (CP) in removing the discoloration. Material and methods: Color stability of a microhybrid (Z250, 3M ESPE) and nanocomposite (Z550, 3M ESPE) was evaluated after immersion in instant coffee, tea, Coca-Cola, and de-ionized water as a control group (n=5). Samples were kept in liquids for four hours daily at 37°C for 30 days. Furthermore, 16% CP was applied for the following 14 days, simulating night whitening. A digital spectrophotometer was used for color measurement based on the CIE L*a*b* color coordinates. The color changes (ΔE) were measured at baseline, after immersion in the beverages, and also after the teeth whitening procedure. Mixed and factorial ANOVA followed by Bonferroni’s post-hoc test were used for statistical evaluation (p≤0.05). Results: Tested resin composites showed a color change over the acceptability threshold (ΔE* > 3.48) after immersion in coffee and tea. Nanocomposite reported a significant increase in discoloration in coffee after 30 days (p < 0.05). The color of both materials significantly changed (p<0.05) along all three L*,a*,b* axes in coffee and tea to darker, yellow, and red. Whitening with 16% CP was effective in removing external discoloration in both examined composite materials. Conclusion: Coffee and tea induced clinically detectable color changes in dental composites tested, with cumulative effects. Whitening represents an efficient method for the removal of surface discoloration in composite restorations.

Introduction

Growing concerns regarding dental amalgam toxicity, patient requirements for aesthetic fillings, and a minimal invasive treatment approach resulted in the dominance of composite materials in terms of direct restorative dental treatment. Contemporary researchers focus on improving the physical characteristics and clinical longevity as well as esthetic appearance of existing composite materials, along with the introduction of new technologies. Although the quality of composite fillings has improved in recent years, discoloration after exposure to the oral medium continues to be a challenge for composite materials (1). Prolonged exposure of composites to the oral cavity conditions leads to restoration discoloration and a consequent color discrepancy between tooth and restoration. Discoloration causes patient dissatisfaction and the additional cost for the filling replacement (2).

Methods for removing external dental composite discoloration to achieve esthetics restoration include air polishing, bleaching, and other techniques. Contemporary researchers focus on improving the physical characteristics and clinical longevity as well as esthetic appearance of existing composite materials, along with the introduction of new technologies. Although the quality of composite fillings has improved in recent years, discoloration after exposure to the oral medium continues to be a challenge for composite materials (1). Prolonged exposure of composites to the oral cavity conditions leads to restoration discoloration and a consequent color discrepancy between tooth and restoration. Discoloration causes patient dissatisfaction and the additional cost for the filling replacement (2).

Uvod

Sve veća zabrinutost zbog toksičnosti dentalnoga amalga-ma i zahtjeva pacijenata za estetske ispune te minimalno in- vazivne pristupe liječenju, rezultirali su dominacijom kom- pozitnih materijala kad je riječ o izravnom restaurativnom dentalnom tretmanu. Suvremeni istraživači usredotočuju se, uz uvođenje novih tehnologija, na poboljšanje fizičkih obli- ježja i kliničke dugovječnosti te estetskog izgleda postojećih kompozitnih materijala. Iako se kvaliteta kompozitnih ispu- na posljednjih godina poboljšala, promjena boje nakon izla- ganja oralnom mediju i dalje je izazov kada se radi o kom- pozitnim materijalima (1). Dugu trajano izlaganje kompozita u uvjetima u usnoj šupljini rezultira promjenom boje restauracije i posljedičnom razlikom u boji između zuba i restauraci- je. Promjena boje potiče nezadovoljstvo pacijenta i dodatni trošak za zamjenu ispuna (2).

Metode uklanjanja vanjske promjene boje dentalno- ga kompozita radi estetskoga izgleda restauracije obuhvaća-
bleaching or whitening, conventional repolishing, or even replacement of existing highly stained composite. Air polishing may produce roughness on the composite surface, even when using mild glycine-based powder (3). Composite color can be restored by repolishing, although this procedure partially removes material from the restoration surface. However, in the case of deep pigment penetration, it is not possible to completely restore the color of the material to its initial shade by polishing. Therefore, bleaching remains a minimally invasive approach for stain removal from direct resin-based composite restorations. The bleaching effect may be obtained either by using a bleaching agent in different concentrations, or various lamps to speed up the process (4). When used properly under the supervision of a dentist, peroxide-based tooth bleaching products are considered safe and effective (5).

With advancements in nanotechnology in recent years, dental composites with nanoparticles were introduced. Microhybrid composites and nanocomposites are the most commonly used materials for direct dental restorations with microscale/nanoscale, individual/clustered nanoscale glass fillers, respectively (6). As claimed, a high surface/volume ratio in nanocomposites results in improved mechanical, thermal, and optical properties (7). To achieve a longer esthetic appearance of the dental filling, it is important to identify a composite material less susceptible to discoloration. The objective of this study was to assess the color stability of two different composite resins in three frequently used solutions - coffee, tea, and Coca-Cola - and determine if bleaching with 16% carbamide peroxide (CP) gel can remove derived discoloration. The first hypothesis of this study was that beverages affect the discoloration susceptibility of the tested composite materials, and the second hypothesis was that bleaching with 16% CP gel would be effective in the color recovery of tested composites.

Material and methods

Resin dental composites used in this study include microhybrid composite (Filtek Z250 (3M ESPE, St. Paul, MN, USA) and nanohybrid composite (Filtek Z550, 3M ESPE, St. Paul, MN, USA) in shades A2. The characteristics of the composites used in this study are listed in Table 1.

Table 1. Properties of the materials used in this study

| Product       | Manufacturer | Shade | #Batch number | Matrix                      | Filler particle size in μm | Filler weight in % (wt) | Type         |
|---------------|--------------|-------|---------------|-----------------------------|----------------------------|-------------------------|--------------|
| Filtek Z550   | 3M ESPE, St.Paul, MN, USA | A2    | N502352       | Bis-GMA, UDMA, Bis-EMA, TEGMA, PEGDMA | 20 nm silica, 1-10 μm zirconia/silica particles | 82%                      | Nanohybrid   |
| Filtek Z250   | 3M ESPE, St.Paul, MN, USA | A2    | N535897       | Bis-GMA, UDMA, Bis-EMA | 0.01-3.5 μm zirconia/silica particles | 82%                      | Microhybrid  |

Bis-GMA - Bisphenol A-glycidyl methacrylate; UDMA - Urethane dimethacrylate; Bis-EMA - Ethoxylatedbisphenol-A-dimethacrylate; TEGDMA - Triethylene glycol dimethacrylate; PEGDMA - polyethylene glycol dimethacrylate

Bis-GMA-bisfenol A-glicidil metakrilat; UDMA- uretan dimetakrilat; Bis-EMA-etoksiliranikisfenol-A-dimetakrilat; TEGDMA- Trietilen glikol dimetakrilat; PEGDMA - polietilen glikol dimetakrilat
Preparation of Samples

Composite disc samples were prepared using microscopic glass plates covered with Mylar strips and Teflon mold (10 mm in diameter and 2 mm in height). The resin was pressed by a plate to flatten, and it was photopolymerized through the glass and transparent strip from both sides for 20 seconds using a wireless light source with an irradiance of 1200 mW/cm² (Elipar™ FreeLight 2 LED Curing Light, 3M ESPE, St. Paul, MN, USA). The light intensity of the curing lamp was regularly monitored using a radiometer Bluephase Meter (Ivoclar Vivadent, Schaan, Liechtenstein). A total of 40 discs were prepared.

All samples were consequently processed with fine and superfine extra thin (dark orange to yellow) aluminum oxide-impregnated paper discs (Sof-Lex™, 3M ESPE, St. Paul, MN, USA), with average particle size of 24µm, and 8µm respectively, embedded in a low-speed handpiece. The abrasive discs were used with reduced speed under dry conditions and light pressure for 10 seconds to standardize the surface and mimic clinical conditions. The polishing disks were discarded after every specimen. After polishing, the samples were initially stored in distilled water at 37°C to complete the polymerization process.

After 24 hours, the samples were randomly divided into three experimental subgroups and the control group (n=5). Three different beverages used in this experiment were instant coffee, green tea, and Coca-Cola. The samples were immersed in these freshly prepared beverages for four hours during the day to simulate high intakes, then rinsed with distilled water, while in the remaining hours they were stored in deionized water. The samples were kept in experimental liquids at 37°C ± 1°C. The procedures were repeated during 30 days. Considering that 24-hour immersion simulates near one month of coffee consumption (8), the performed intermittent staining protocol mimics clinical exposure to these beverages over six months.

Five samples of both composites were kept in deionized water in the incubator at 37°C for 30 days (control group). Distilled or deionized water was previously used as a control. Five samples of both composites were kept in deionized water in the incubator at 37°C for 30 days (control group). Distilled or deionized water was previously used as a control group due to minimal color change reported (9, 10, 11).

Preparation of Beverages

The contents of the bag (17.5 g) of instant coffee Nescafe 3in1 Classic (Nestle, Hungary, Kft. Szerenczi Gyara) were poured using 150 ml of boiling water. The solution was stirred and allowed to cool for 10 minutes. Tea solution was prepared by immersing prefabricated tea bag (30 gr) Lipton green tea Nature (Unilever, Belgium) into 200 ml of boiling water. After ten minutes of stirring, the bag was removed. A factory-sealed 0.5-liter Coca-Cola package (Coca-Cola HBC, Sarajevo, BiH) at room temperature was used for the third subgroup.

The pH value of every beverage and pH of bleaching gel was determined at room temperature using a digital pH-meter PHWE 13702.93 (Göttingen, Germany). Two-point calibration of pH-meter's electrode was performed using standard buffers at pH=4.0 and 7.0. The electrode was immersed in freshly prepared test beverages. A stable pH reading was...
achieved after 1-2 minutes of immersion, recorded as the pH of the sample. The composition of the immersion solutions (manufacturer's data) and their pH are presented in Table 2.

Composite Samples Bleaching Process

The samples were bleached using 16% carbamide peroxide gel Vivasyle (Ivoclar Vivadent AG, Bendererstrass, Liechtenstein) for seven hours a day over 14-days, mimicking the at-home-night technique. The bleaching agent was carefully removed using a cellulose cloth, rinsed with tap water for one minute, and distilled water consecutively. During the remaining 17 hours, the samples were stored in deionized water at 37°C (12).

Color Evaluation

A Vita Easyshade Compact digital spectrophotometer (Vita Zahnfabrik, Bad Säckingen, Germany) was used for color spectrophotometric determination, previously calibrated with an integrated standard white plate. Color measurements were performed 24 hours after polymerization – on the 7th, 14th, and 30th day of immersion and after whiten ing. At each measurement, the samples were extracted from deionized water, dried with cellulose wadding, and L*a*b* color parameters were evaluated according to the CIEL*a*b* color scale, using white backing. Measurements were repeated three times and the mean L*, a*, and b* values were recorded. The L* vertical parameter refers to the lightness, while a* and b* color coordinates are chromatic axes in the red-green and yellow-blue direction, respectively. Based on the spectrophotometric determination of L*a*b* color values, the total difference between the two shades (ΔE) was calculated. The color shift (ΔE*ab) was calculated using equation $\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. When the ΔE was higher than the acceptability threshold (ΔE > 3.48), it was considered clinically visible, while a value of 1.74 was accepted as the perceptibility threshold (13). The results were statistically analyzed using Statistical Package for the Social Sciences (SPSS) v.20 program package. The values of color changes were analyzed by mixed and factorial ANOVA test (p≤0.05). Subsequently, Bonferroni-corrected t-tests for independent samples were used for comparison (post-hoc analysis).

**Table 2. Main characteristics of the beverages**

| Beverage                     | Main ingredients                                                                 | pH   |
|------------------------------|----------------------------------------------------------------------------------|------|
| Nescafe 3 in 1 Classic       | Coffee powder                                                                     | 6.45 |
| Lipton green tea Nature      | 100% natural, green tea leaves.                                                  | 6.48 |
| Coca-Cola*                   | Carbonated water, sugar, caramel color, phosphoric acid, caffeine, natural flavors.| 2.26 |
| 16% carbamide peroxide       | Glycerin 25-50%, Aqua 10–25%, Urea (Carbamide Peroxide 16%, Carbomer 5 – 10, Potassium Nitrate 1–5, Sodium Hydroxide 1–5, Aroma 0.1–1.0, EDTA 0.1–1.0, Sodium Saccharin 0.1–1.0 | 7.00 |

**Proces izbjeljivanja kompozitnih uzoraka**

Uzorci su izbjeljivani korištenjem 16-postotnoga karbamid-peroksidsnoga gela Vivasyle (Ivoclar Vivadent AG, Bendererstrass, Lihtenštajn) koji je prije toga kalibriran integriranim standardnom bijelom pločom. Mjerenja boje obavljena su 24 sata nakon polimerizacije – sedmog, četvrtaestoga i tridesetoga dana od uranjanja i poslije izbjeljivanja. Pri svakom mjerenju uzorci su ekstrahirani iz deionizirane vode i sušeni celuloznom vatom, a parametri boje L*a*b* ocjenjivani su prema ljestvici boja CIEL*a*b* koristeći se bijelom podlogom. Mjerenja su ponovljena tri puta i zabilježene su srednje vrijednosti L*, a* i b*. Vertikalni parametar L* odnosi se na svjetlinu, a koordinate boja a* i b* kromatske su osi u crveno-zelenom i žuto-plavom smjeru. Na temelju spektrofotometrijskoga određivanja L*a*b* vrijednosti boja izračunata je ukupna razlika između dviju nijansi (ΔE). Pomak boje (ΔE*ab) izračunat je s pomoću jednadžbe $\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. Kada je ΔE bio veći od prag prihvatljivosti (ΔE* > 3.48), smatrao se klinički vidljivim, a vrijednost od 1.74 prihvaćena je kao prag perceptibilnosti (13). Rezultati su statistički analizirani u programskom paketu Statistical Package for the Social Sciences (SPSS) v.20. Vrijednosti promjena boje analizirane su mješovitim i faktorijalnim ANOVA testom (p ≤ 0.05). Nakon toga su za usporedbu (post-hoc analiza) korišteni Bonferronijevi ispravljeni t-testovi za nezavisne uzorke.

**Results**

The color of composite materials tested in this study changed in coffee and tea beyond the acceptability threshold (ΔE > 3.48) as early as seven days after immersion. After 30

**Rezultati**

Boja kompozitnih materijala testiranih u ovoj studiji promijenila se u kavi i čaju iznad praga prihvatljivosti (ΔE > 3.48) već sedam dana nakon uranjanja. Nakon 30-dnevno-
days of immersion, the smallest value of \( \Delta E_3 \) was detected for the Z250 composite, samples immersed in Coca-Cola, whereas the highest \( \Delta E_3 \) value was detected for nanocomposite samples immersed in coffee (\( \Delta E_3 = 13.23 \pm 2.11 \)). During water immersion (\( \Delta E_3 = 0.94 \pm 0.17 \)) and Coca-Cola immersion (\( \Delta E_3 = 0.71 \pm 0.61 \)), no significant changes were detected in \( \Delta E \) values of resin composites of both materials. The values of color difference (\( \Delta E \)) after immersion in different solutions during the time are shown in Table 3. To determine which of the materials had a higher sensitivity to pigmentation caused by tested solutions, the post-hoc test of \( \Delta E_3 \) value differences between two tested materials for each of the three solutions was performed by t-test for independent samples with Bonferroni corrected \( p \)-value (\( p = 0.05/3 = 0.017 \)). After 30 days of immersion, statistically significant differences in color alterations were caused only by coffee (\( p = 0.01 \)). Although a visible color change was found in samples of both materials immersed in tea, the change was not statistically significant (\( p = 0.19 \)).

The values of \( \Delta L^* \), \( \Delta a^* \), and \( \Delta b^* \) for tested materials immersed in tested solutions are given in Table 4. For each color dimension (\( L^* \), \( a^* \), and \( b^* \)) of both materials (microhybrid and nanocomposite), mixed ANOVA with Time (day one, day 30) as a repeated measure and Beverage (tea, coffee, Coca-Cola) between-groups was computed. Time x Beverage interaction in pigmentation was statistically significant (\( p = 0.01 \)).

### Table 3

| Material | Solution | \( \Delta L^* \) | \( \Delta a^* \) | \( \Delta b^* \) |
|----------|----------|-----------------|-----------------|-----------------|
| Z250     | Water    | 4.49 (±2.10)    | 4.55 (±2.46)    | 1.79 (±1.04)    |
| Z550     | Water    | 4.50 (±1.04)    | 7.61 (±1.64)    | 1.25 (±0.46)    |
|          | Tea      | 6.99 (±1.04)    | 6.20 (±1.42)    | 1.46 (±1.38)    |
|          | Coffee   | 5.65 (±1.60)    | 10.42 (±2.46)   | 1.22 (±0.83)    |
|          | Coca-Cola| 0.94 (±0.17)    | 10.23 (±2.23)   | 0.71 (±0.61)    |
|          | (1.-14. day) | 9.36 (±1.39) | 8.46 (±1.59) | 13.23 (±2.11) |
|          | (1.-30. day) | 2.37 (±0.39) | 1.59 (±0.45) | 2.48 (±0.34) |
|          | (after bleaching) | 2.73 (±0.23) | 1.92 (±0.55) | 3.12 (±0.90) |

### Table 4

| Material | Solution | \( \Delta L \) | \( \Delta a \) | \( \Delta b \) |
|----------|----------|---------------|---------------|---------------|
| Filtek Z250 | Tea | 7.73±1.56 | -2.09±0.45 | -6.35±1.65 |
|           | Coffee | 8.15±1.40 | -1.57±0.57 | -4.24±0.77 |
|           | Coca-Cola | -0.38±0.36 | 0.11±0.28 | 0.26±0.36 |
|           | Distilled water | -0.45±0.20 | 0.67±0.25 | 0.05±0.47 |
| Filtek Z550 | Tea | 5.93±1.27 | -1.71±0.37 | -5.87±1.06 |
|           | Coffee | 9.27±1.94 | 3.36±0.58 | 8.80±0.99 |
|           | Coca-Cola | -1.50±0.79 | -0.09±0.19 | -0.81±0.63 |
|           | Distilled water | -0.32±0.87 | -0.10±0.11 | 0.01±0.46 |
Age interaction was significant for all three color dimensions of both materials (all \( p < .001 \)). Post hoc comparisons were performed using t-tests with Bonferroni correction of p-value (\( p = 0.05/3 = 0.017 \)). On day 30, the color shifts at both tested materials were significant along all three \( L^* \), \( a^* \), and \( b^* \) axes in coffee and tea (\( p < 0.05 \)). A statistically significant decrease in \( L^* \) values (microhybrid: \( p < 0.001 \) for both tea and coffee; nanocomposite: \( p < 0.001 \) for both tea and coffee) pointed to a brightness shift along the white-black axis toward darker. A statistically significant increase in \( a^* \) values (microhybrid: \( p < 0.001 \) for tea, and \( p < 0.004 \) for coffee; nanocomposite: \( p < 0.001 \) for both tea and coffee) along the red-green axis indicates that samples immersed in coffee and tea became redder, whereas a significant increase in \( b^* \) values (microhybrid: \( p = 0.001 \) for tea, and \( p < 0.001 \) for coffee; nanocomposite: \( p < 0.001 \) for both tea and coffee) for tested materials along the yellow-blue axis indicated a shift towards yellow. An increase in \( L^* \), \( a^* \), and \( b^* \) for samples immersed in Coca-Cola has not pointed to any statistical differences in both tested materials (all \( p s > 0.05 \)).

The efficiency of bleaching in reducing external discoloration from the composite surface (\( \Delta E_4 \)), showed the difference between baseline \( \Delta E \) values (before discoloration by standing in beverages) and the values after application of 16% CP (Table 3.). After bleaching treatment, \( \Delta E \) values decreased within acceptable values (\( \Delta E < 3.48 \)) in both tested materials. Factorial ANOVA with Material (microhybrid and nanocomposite) and Beverage (tea, coffee, Coca-Cola) as between groups factors revealed significant differences in \( \Delta E \) values between materials (\( p = 0.03 \)), with bigger color changes with the nanomaterial Z550 than the microhybrid Z250 after application of 16% CP. A more considerable improvement in color change was observed in the nanocomposite.

Discussion

Aesthetic composite restorations are ordinarily exposed to food and drink effects in the oral environment, resulting in external discoloration. This research was conducted to investigate the selective effect of three heavily consumed beverages worldwide on the color of two different composite materials: coffee, tea, and carbonated drink (Coca-Cola).

Discoloration can be quantified subjectively by visual comparison of color differences or an objective measurement using an instrument. This study used a portable, wireless digital spectrophotometer, with the white-colored plate for the background to determine CIEL*a*b color coordinates. There are several color systems in use, however, the CIEL*a*b* color system has been extensively used in dental research (1, 11, 12). This color-difference formula provided data on overall color change, values of the change across the color coordinates, and also enabled comparisons with previous studies.

In this study, immersion in coffee and tea resulted in unacceptable color alteration of both composite materials. Tested composites showed clinically unacceptable color change after immersion in tea and coffee already after being immersed for seven days (Table 3.). Over time, discoloration progressively increased reaching the highest values at day 30, bila je značajna za sve tri dimenzije boja obaju materijala (svi \( p < .001 \)). Post hoc usporedbi provedene su 30. dana s po-moću t-testova s Bonferronijevom korekcijom p-vrijednosti (\( p = 0.05/3 = 0.017 \)) te su promjene boje na oba testirana ma terijala bile su značajne duž sve tri \( L^* \), \( a^* \) i \( b^* \) osi u kavi i čaju (\( p < 0.05 \)). Statistički značajno smanjenje vrijednosti \( L^* \) (mikrohibrid: \( p < 0.001 \) i za čaj i za kavu; nanokompozit: \( p = 0.001 \) za čaj i \( p < 0.001 \) za kavu) upućuje na pomak svjetline duž bijelo-crne osi prema širi. Statistički značajno povećanje vrijednosti \( a^* \) (mikrohibrid: \( p < 0.001 \) za čaj i \( p = 0.004 \) za kavu; nanokompozit: \( p < 0.001 \) i za čaj i za kavu) duž crveno-zelene osi pokazuje da su uzorci uronjeni u kavu i čaju postali crveniji, a značajno povećanje vrijednosti \( b^* \) (mikrohibrid: \( p = 0.001 \) za čaj i \( p < 0.001 \) za kavu; nanokompozit: \( p < 0.001 \) i za čaj i za kavu) za testirane materijale duž žuto-plave osi upućuje na pomak prema žutoj boji. Povećanje \( L^* \), \( a^* \) i \( b^* \) za uzorke uronjene u Coca-Colu nije pokazivalo nikakvu statističku razliku u oba testirana materijala (svi \( p s > 0.05 \)).

Učinkovitost izbjeljivanja u smanjenju vanjske promjene boje s površine kompozita (\( \Delta E_4 \)), pokazala je razliku između osnovnih vrijednosti \( \Delta E \) (prije promjene boje stajanjem u napitcima) i vrijednosti nakon primjene 16-postotnoga CP-a (tablica 3.). Posljje tretmana izbjeljivanja vrijednosti \( \Delta E_4 \) smanjile su na prihvatljivije vrijednosti (\( \Delta E < 3.48 \)) u oba ispitana materijala. Faktorijalna ANOVA s materijalom (mikrohibrid i nanokompozit) i pićem (čaj, kava, Coca-Cola) među skupinama otkrila je značajne razlike u vrijeditima \( \Delta E_4 \) između materijala (\( p = 0.03 \)), s većim promjenama boje kod nanomaterijala Z550 nego kod mikrohibrida Z250 nakon primjene 16-postotnoga CP-a. Značajnije poboljšanje promjene boje uočeno je u nanokompozitu.

Rasprava

Estetski kompozitni nadomjestci obično su u oralnom okružju izloženi djelovanju hrane i pića, što rezultira vanjskom diskoloracijom. Ovo istraživanje provedeno je da bi se istražio selektivni učinak triju napitaka koji se uvelike konzumiraju diljem svijeta na boju dvaju različitih kompozitnih materijala: kave, čaja i gaziranoga pića (Coca-Cola).

Promjena boje može se kvantificirati subjektivno vizualnom usporedbom razlika u boji ili objektivnim mjerenjem instrumentima. U ovoj studiji korišten je prijenosni, bežični digitalni spektrofotometar s bijelom pločom kao pozadinom za određivanje CIEL*a*b koordinata boje. U upotrebi je nekoliko sustava boje, no CIEL*a*b* sustav boja najčešće se koristi u stomatološkim istraživanjima (1, 11, 12). Ova formulacija za razliku u boji dala je podatke o ukupnoj promjeni boje i vrijednosti promjene u koordinatama boja, a također je omogućila usporedbu s već objavljenim studijama.

U ovoj je studiji uranjene u kavi i čaju rezultiralo neprihvatljivo promjenom boje obaju kompozitnih materijala. Uspitani kompoziti pokazali su klinički neprihvatljivu promjenu boje nakon uranja u čaj i kavu već poslije sedam dana (tablica 3.). Tijekom vremena se promjena boje progresivno povećavala te je postigla najviše vrijednosti tridesetoga.
as demonstrated previously (11, 14). Lower color stability in coffee and tea groups is consistent with previous studies (1, 15, 16, 17). Filtek Z250 showed a higher stainability in tea (ΔE<sub>3</sub> = 10.23) and coffee (ΔE<sub>3</sub> = 9.36), while the least color change (ΔE<sub>3</sub> = 0.71) was observed in Coca-Cola. After immersion, nanohybrid composite Z550 displayed color changes of ΔE<sub>3</sub> = 8.46 (tea), 13.23 (coffee) and 1.80 (Coca-Cola). Thus, the first part of the study hypothesis was partially confirmed as Coca-Cola color change values were found to be visually undetectable, while coffee and tea produced color changes beyond the acceptability threshold for both materials tested. Some previous studies have demonstrated greater composite discoloration in coffee compared to tea (16, 18), while others showed the opposite (1, 14). The difference in results can be attributed to different immersion protocols and materials tested.

Discoloration of samples immersed in coffee and tea is considered to be primarily superficial as a result of surface adsorption of colorants (14) or can be attributed to water absorption with pigments in the resin matrix (1) due to superficial degradation (8). According to Ferracane, the absorption of solvents begins immediately and peaks in one or two months when the polymer network is completely saturated (19). A rapid excretion of unreacted monomers from composite takes place in an aqueous environment. Water molecules enter the composite while unreacted matrix monomers and ions from the filler and activator emerge. Consequently, the superficial resin matrix is softened and discoloration resistance is ultimately reduced (9).

Discoloration assessment in this study was performed after seven, 14, and 30 days. This measurement schedule proved to be rational because the greatest color change occurred in the first seven days of immersion (Table 3.). Based on the assumption that a vast majority of unreacted monomers elute from composite during this period, a residual free space is occupied by water.

During this process of water sorption into the composite resin, the liquid is the carrier of the colorant through the diffusion process (20). Coffee has a strong discoloration effect on teeth and dental composites (17). Other colorants such as tannin or caffeine contribute to staining as they deeply penetrate the composite matrix (14, 21). Furthermore, tea contributes to composite discoloration due to the sorption of tannins (17).

Considering the type of composite material, a significantly higher nanocomposite discoloration was found only in samples immersed in coffee after 30 days (p < 0.05). Higher absorption of pigmented beverages in the nanocomposite is consistent with previous studies (9, 22). The difference in discoloration between two composites can be explained by the chemical composition of these materials. This refers to the composition of the organic part and amount of resin matrix since inorganic filler does not absorb water. According to manufacturer’s information, Z250 and Z550 have similar matrices in their composition, containing Bis-GMA, dana, kao što je već pokazano (11, 14). Niža stabilnost boje u skupinama kave i čaja u skladu je s dosadašnjim studijama (1, 15, 16, 17). Filtek Z250 pokazao je veću postojanost u čaju (ΔE<sub>3</sub> = 10.23) i kavi (ΔE<sub>3</sub> = 9.36), a najmanja promjena boje (ΔE<sub>3</sub> = 0.71) učena je u Coca-Cola. Nakon uranjanja je nohnobiirdin kompozit Z550 pokazao promjene boje ΔE<sub>3</sub> = 8.46 + (čaja), 13.23 + (kava) i 1.80 + (Coca-Cola). Dakle, prvi dio hipoteze djelomično je potvrđen jer je ustanovljeno da se vrijednosti u promjeni boje koka-kole vizualno ne mogu detektirati, a da su kava i čaj proizveli promjenu boje iznad praga prihvatljivosti za oba ispitanja materijalja. U prijašnjim istraživanjima zabilježena je veća kompozitna diskoloracija u kavi u usporedbi s čajem (16, 18), a druga su, pak, pokazala suprotno (1, 14). Razlika u rezultatima može se pripisati različitim protokolima uranjanja i testiranim materijalima. Promjene boje uzoraka uronjenih u kavu i čaj smatra se prvenstveno kao rezultat površinske adsorpcije bojila (14) ili se može pripisati apsorpciji vode s pigmentima u matričnoj smoli (1) zbog površinske degradacije (8). Prema Ferracanu, apsorpcija otapala počinje odmah i dostiže vrhunac za jedan ili dva mjeseca kada je polimerna mreža potpuno zasićena (19). Brzo izlučivanje nereagiranih monomera iz kompozita događa se u vodnom okružju. Molekule vode ulaze u kompozit dok iz punila i aktivatora izlaze nereagirani metinski monomeri i ioni. Posljedično, površinska smolna matica omekšana je i otpornost na promjenu boje u konačnici je smanjena (9).

Procjena promjene boje u ovoj studiji provedena je poslije 7, 14 i 30 dana. Takav raspored mjerenja pokazao se racionalnim jer se najveća promjena boje dogodila u prvih sedam dana poslije uranjanja (tablica 3.). Na temelju pretpostavke da velika većina nereagiranih monomera eluira iz kompozita tijekom toga razdoblja, preostali slobodni prostor zauzima voda.

Tijekom toga procesa sorpcije vode u kompozitnu smolu, tekućina je nositelj bojila u procesu difuzije (20). Kava snažno utječe na promjenu boje zuba i dentalnih kompozita (10, 14). Naime, tijekom njezina prženja nastaju smiješne obojeni visokomolekularni dušikovi spojevi pod nazivom melanoidini i oni su uglavnom odgovorni za tu promjenu boje (17). Druge boje, kao što su tanin ili kofein tomu pridonoše jer prodiru duboko u kompozitni matriks (14, 21). Nadalje, čaj pridonosi kompozitnoj diskoloraciji zbog sorpcije tannina (17).

S obzirom na vrstu kompozitnoga materijala, značajno veća promjena boje nanokompozita ustanovljena je nakon 30 dana samo u uzorcima uronjenima u kavu (p < 0.05). Veća apsorpcija pigmentiranih pića u nanokompozitu u skladu je s već objavljenim studijama (9, 22). Razlike u promjeni boje između dvaju kompozita može se objasniti kemijskim sastavom tih materijalja. To se odnosi na sastav organskoga dijela i količinu matriksa smole jer anorgansko punilo ne upija vodu. Prema podacima proizvođača, Z250 i Z550 imaju slične materije u svom sastavu koje sadržavaju monomere Bis-GMA, UDMA i Bis-EMA, uz dodatak nanokompozita PEGDMA i TEGDMA. Tektuča kromatografija visoke učinkovitosti (HPLC) potvrdila je da Z250 u svom sastavu ima veću hidrofobnoga monomera UDMA u usporedbi s Bis-GMA-
UDMA, and Bis-EMA monomers, with the addition of PEGDMA and TEGDMA to the nanocomposite. High-Performance Liquid Chromatography (HPLC) confirmed that Z250 contains a larger amount of hydrophobic monomer UDMA compared to Bis-GMA and Bis-EMA in its composition (23). Thus, Z250 may be less susceptible to discoloration by the percentage of hydrophobic monomer UDMA in the structure of material. UDMA increases the hydric stability of the composite (15) and demonstrates a lower water sorption and higher resistance to discoloration compared to hydrophilic Bis-GMA (21). Water sorption was attributed to monomers Bis-GMA (21) and TEGDMA in an organic matrix (21, 24). Small hydrophilic molecules of TEGDMA have higher mobility in an aqueous environment; wash out faster than larger, more massive molecules such as Bis-GMA (23). The emptied places of this molecule were occupied by small molecules of water, carrying a pigment. For this reason, any composite must always be adequately polymerized, since higher conversion means less unreacted mobile monomer, less water sorption, and greater color stability (1). Irrespective of the composite resin used, insufficient light-curing of the composite restoration, continued to be a challenge (25). For this reason, the samples in this study were polymerized with a lamp with optimal light intensity confirmed by a radiometer. Several reports have shown that small nanoparticles contribute to a smoother surface and lower discoloration over time due to minimal surface alteration (26). Previously, discoloration of nanomaterials was attributed to the porosity of the glass filler particles (9). The obtained results showed similar color susceptibility of nanocomposite after immersion in beverages compared to conventional microhybrid composite. These results corroborate the findings of a meta-analysis which did not confirm the advantage of nanocomposites in lower staining susceptibility (26).

Previous studies stated that the discoloration of composites might be a consequence of the low pH of beverage (22) causing surface erosion effect and roughening (10). The acidic environment may induce loss of structural ions, which then enable pigments from the solution to penetrate the softened surface. Composite materials tested in this study were immersed in acid solutions of pH values ranging from 2.26 in the structure of material. UDMA increases the hydric stability of the composite (15) and demonstrates a lower water sorption and higher resistance to discoloration compared to hydrophilic Bis-GMA (21). Water sorption was attributed to monomers Bis-GMA (21) and TEGDMA in an organic matrix (21, 24). Small hydrophilic molecules of TEGDMA have higher mobility in an aqueous environment; wash out faster than larger, more massive molecules such as Bis-GMA (23). The emptied places of this molecule were occupied by small molecules of water, carrying a pigment. For this reason, any composite must always be adequately polymerized, since higher conversion means less unreacted mobile monomer, less water sorption, and greater color stability (1). Irrespective of the composite resin used, insufficient light-curing of the composite restoration, continued to be a challenge (25). For this reason, the samples in this study were polymerized with a lamp with optimal light intensity confirmed by a radiometer. Several reports have shown that small nanoparticles contribute to a smoother surface and lower discoloration over time due to minimal surface alteration (26). Previously, discoloration of nanomaterials was attributed to the porosity of the glass filler particles (9). The obtained results showed similar color susceptibility of nanocomposite after immersion in beverages compared to conventional microhybrid composite. These results corroborate the findings of a meta-analysis which did not confirm the advantage of nanocomposites in lower staining susceptibility (26).

Previous studies stated that the discoloration of composites might be a consequence of the low pH of beverage (22) causing surface erosion effect and roughening (10). The acidic environment may induce loss of structural ions, which then enable pigments from the solution to penetrate the softened surface. Composite materials tested in this study were immersed in acid solutions of pH values ranging from 2.26 for Coca-Cola to 6.48 for tea (Table 2.). This study showed imperceptible staining for microhybrid composite in Coca-Cola, while nanocomposite in this beverage demonstrated color change beyond the perceptibility threshold (1.74). Manja promjena boje u Coca-Coli, u usporedbi s uzorcima uronjenima u kavu i čaju, u skladu je s rezultatima u dosadašnjim studijama (17, 21). Iako taj napitak ima visok kiseli pH prikladan za površinsko otapanje i omekšavanje polimera, manja sorpnciju vode i veću stabilnost boje (1). Bez obzira na korištenu kompozitnu smolu, nedovoljna polimerizacija u ovom istraživanju polimerizirani svjetiljkom optimalnog intenziteta potvrđuju u vode nom okružju i ispiru se brže od većih, masivnijih molekula kao što je Bis-GMA (23). Ispraznjena mjesta te molekule za uzele su male molekule vode koje su nosile pigment. Iz tog razloga svaki kompozit uvijek mora biti adekvatno polimeriziran jer veća konverzija znači manje nereagiranaobilna monomera, manja sorpnciju vode i veću stabilnost boje (1). Bez obzira na korištenu kompozitnu smolu, nedovoljna polimerizacija i dalje je izazov za kompozitne nadomjестке (25). Zbog toga su uzorci u ovom istraživanju polimerizirani svjetiljkom optimalnog intenziteta potvrđenog radiometrom. U nekoliko izvješća pokazano je da male nanočestice pridonose glatkijoj površini i nižoj diskoloraciji tijekom vremena zbog minimalne promjene površine (26). Prije su se promjene boje nanomaterijala pripisivala poroznosti čestica staklenog punila (9). Dobiveni rezultati pokazali su sličnu osjetljivost na boju nanokompozita nakon uranjanja u napitke u usporedbi s konvencionalnim mikrohibridnim kompozitima. Ti rezultati potvrđuju nalaze metaanalize u kojoj nije potvrđena prednost nanokompozita u nižoj osjetljivosti na bojenje (26).

U dosadašnjim studijama navedeno je da bi promjena boje kompozita mogla biti posljedica niskoga pH naptika (22), što uzrokuje efekt površinske erozije i hravost (10). Kisele okoline može izazvati gubitak strukturnih iona koji tada omogućuju pigmentima iz otopine da prodiru u omekšanu površinu. Kompozitni materijali ispitani u ovoj studiji bili su uronjeni u kisele otopine pH vrijednosti u rasponu od 2,26 za Coca-Colu do 6,48 za čaj (tablica 2.). Ova studija pokazala je neprimjetno bojenje mikrohibridnoga kompozita u koka-koli, dok je nanokompozit u ovom naptiku pokazao promjenu boje iznad praga perceptibilnosti (1,74). Manja promjena boje u Coca-Coli, u usporedbi s uzorcima uronjenima u kavu i čaju, u skladu je s rezultatima u dosadašnjim studijama (17, 21). Iako taj napitak ima visok kiseli pH prikladan za površinsko otapanje i omekšavanje polimera, niska promjena boje u toplini Coca-Cole pripisuje se sulfito-amoničkoj karameli (17). Ipak, manje opsežna promjena boje može biti i posljedica nedostatka žute boje u otopini (21). Promjena boje ispitanih kompozita nakon izlaganja deioniziranoj vodi bila je klinički neprimjetna (ΔE < 1), što je također istaknuto u već objavljenim studijama (9, 10). Minimalni pomak boje je (tablica 3.) može biti posljedica sorpnciju vode u organskom matriksu zato što je deionizirana voda bezbojna (21).

Značajna promjena boje kompozita uronjenih u kavu i čaju prikazana je u trima prostornim koordinatama – \( L^* \), \( a^* \), \( b^* \) (\( p < 0,05 \)). Za oba ispitana materijala glavni pomak prikazan je u vrijednostima \( \Delta L^* \) prema crnoj boji, a koordinate \( a^* \) i \( b^* \) pokazale su značajan otklon na pozitivniju vrijednost (tablica 4.). Posljedično, boja obaju ispitanih materijala u kavi i čaju postala je crvenija, žuća i tamnija. Pozitivne vrijednosti \( \Delta L^* \) nanokompozita u Coca-Coli upućuju na to da...
Significant discoloration of composites immersed in coffee and tea was demonstrated in three spatial coordinates, L*, a*, b* (p<0.05). For both tested materials, the main shift demonstrated in ΔL* values towards black, while a* and b* coordinates showed significant deflection to a more positive value (Table 4). Consequently, the color of both tested materials in coffee and tea became redder, more yellow, and dark. Positive ΔL* values of nanocomposites in Coca-Cola indicate that the samples became lighter, which is consistent with the previously reported results (14).

Tooth bleaching has gained popularity in recent years as a non-invasive and affordable method for smile attractiveness enhancement. Previous research reported that every fourth young adult used this method (5). In addition, this study evaluated the suitability of the at-home whitening method in removing discoloration from composite after exposure to stained beverages. Bleaching regained ΔE values within a clinically acceptable threshold (ΔE < 3.48), which is consistent with previous studies (9, 12). Removal of external discoloration from the composite surface using 16% CP proved to be effective on both tested composite materials. Therefore, the second part of the study hypothesis was accepted. Carbamide peroxide decomposes into oxidizing agent hydrogen peroxide that produces very reactive free radicals. These unstable radicals engage in chemical interactions with organic chromophores and oxidize stain molecules. Furthermore, these oxygen species convert the chains within stain into less complex molecules; modify their optical properties resulting in degradation products with lower molecular weights (27). The color has been achieved more efficiently on microhybrid material, likewise in the previous research papers (12). One explanation for this may be the composition, as Z250 contains less resin matrix than nanocomposite. Regarding nanocomposite, it contains a larger amount of resin on the surface; consequently, it is more difficult to remove discoloration by bleaching (12).

It is important to note that this study has certain limitations. Only one shade of composites was evaluated. Moreover, considering a clinical variable, dental restorations are subjected to the effect of the brushing and mastication, saliva components, thermal stress, fluid dynamics, and the adhesion of the biofilm that could also have a role in the process of discoloration. Since this was an in vitro study that is unable to simulate complex interactions in the oral cavity, future long-term in vivo studies are also needed to assess the color stability of the composites.

Conclusions

In conclusion, this in vitro study showed that coffee and green tea caused visually perceptible color changes on the composite resins that continue over time. The resulting color change of the composites presented is due to the chromaticity shift towards yellow, black, and red. Filtek Z250 showed less discoloration, dominantly for samples immersed in coffee. The patients should be informed about the effect of coffee and tea on composite discoloration, and about the cumulative effects on the change of the restoration color.

Zaključci

Zaključno, ova studija in vitro pokazala je da kava i zeleni čaj uzrokuju vizualno uočljive promjene boje na kompozitnim smolama koje se nastavljaju tijekom vremena. Promjena boje prikazanih kompozita poslije uživanja kave i čaja je u skladu s već objavljenim rezultatima (14).

Izbjeljivanje zuba posljednjih je godina postalo popula

no kao neinovazivna i pristupačna metoda za povećanje atrak

tivnosti osmijeha. Prethodno istraživanje pokazalo je da se

svaka četvrt vrla odrasla osoba koristila tom metodom (5).

Uz to, u ovoj studiji procjenjivala se i prikladnost metode

izbjeljivanja kod kuće za uklanjanje diskoloracije s kompozita

poslije izlaganja obojenim pićima. Izbjeljivanje je vrati

lo vrijednosti ΔE unutar klinički prihvatljivoga praga (ΔE <

3,48), što je u skladu s dosadašnjim studijama (9, 12). Uklana

nje vanjske promjene boje s kompozitne površine primjene

16-postotnoga CP-a pokazalo se učinkovitim pri upora

bi objašnjenja za to može biti sastav jer Z 250 sadržava manje matrice smole od nanokompozita. Kad je riječ o nanokompozitu, on sadržava veću količinu smole na površini, pa je posljedično teško ukloniti diskoloraciju izbjeljiv

janjem (12).

Važno je istaknuti da ova studija ima određena ograničen

ja. Ocjenjivana je samo jedna nijansa kompozita. Štoviše, s

obirom na kliničku varijablu, dentalne nadoknade podvrgnu

te su učinku četkanja i žvakanja, komponenti stres, toplinske stres, dinamici tekućine i adheziji biofilmova ko

ji bi također mogao utjecati na proces diskoloracije. Kako se radi o studiji in vitro koja ne može simulirati složene inte

rakcije u usnoj šupljini, u budućnosti su potrebne dugoročne studije in vivo za procjenu stabilnosti boje kompozita.
Kompozitna diskoloracija i izbjeljivanje

1. Gošić M, Stajić F, Pancerić D, Ljubić I, Medić M. Diskoloracija i izbjeljivanje korištenjem nanokompozita. Stomatol Prat 2012;51(1):107-111.

2. Schroeder T, da Silva PB, Basso GR, Franco MC, Maske TT, Centeno AL. Factors affecting the color stability and staining of aesthetic restorative materials. Acta Odontol Stand 2013;71(1):144-150.

3. M. A., A. K., L. H. B. – dizajnirali studiju; S. K., A. DŽ., I. T. – obavili pokus; A. K., L. H. B., A. G. G. – analizirali podatke; M. A., A. K., L. H. B. i A. G. G. – pretraživali literaturu; S. K., I. T., A. DŽ. – napisali rad, uz doprinos svih autora.

4. Doprinosi autora: S. K., M. A. – dizajnirali studiju; S. K., A. DŽ., I. T. – obavili pokus; A. K., L. H. B., A. G. G. – analizirali podatke; M. A., A. K., L. H. B. i A. G. G. – pretraživali literaturu; S. K., I. T., A. DŽ. – napisali rad, uz doprinos svih autora.

5. Diklić D, Sever EK, Galic N, Spajić I, Prskalo K. Attitudes of Students of Different Schools of University of Zagreb on Tooth Bleaching. Acta Stomatol Croat. 2016;50(4):301-309.

6. Ning K, Bronkhorst E, Bremers A, Bronkhorst H, van der Meer W, Yang F, Leeuwenburgh S, Loonmans W. Wear behavior of a micro-hybrid composite vs. a nanocomposite in the treatment of severe tooth wear patients: A 5-year clinical study. Dent Mater. 2021;37(12):1819-1827.

7. Omerović-Mikličanin E, Badnjević A, Kazlagić A, Hajić-Morac. Nanocomposites: a brief review. Health Technol. 2020;10(1):51–59.

8. Ert ağ E, Güler AU, Yücel AC, Gökşen A, Güler E. Color Stability of Resin Composites after Immersion in Different Drinks. Dent Mater J. 2006;25(2):371-376.

9. Villalta P, Lu H, Okte Z, García-Godoy F, Powers JM. Effects of staining and bleaching on color change of dental composite resins. J Prosthet Dent. 2006;95(2):137-142.

10. Ceci M, Viola M, Rattalino D, Beltrami R, Colombo M, Poggio C. Discoloration of different aesthetic restorative materials: A spectrophotometric evaluation. Eur J Dent. 2017;11(2):149-156.

References
11. Alkhadim YK, Hulbah MJ, Nassar HM. Color Shift, Color Stability, and Post-Polishing Surface Roughness of Esthetic Resin Composites. Materials (Basel). 2020;13(6):1376.
12. Al-Nahedh HN, Awliya WY. The effectiveness of four methods for stain removal from direct resin-based composite restorative materials. Saudi Dent J. 2013;25(2):61-67.
13. Ghinea R, Pérez MM, Herrera LJ, Rivas MJ, Yebra A, Paravina RD. Color difference thresholds in dental ceramics. J Dent. 2010;38 Suppl 2:e57-64.
14. S. Madhyastha P, G. Naik D, Kotian R, Srikant N, M. R. Bhat K. Effect of Staining Solutions on Color Stability of Silorane and Methacrylate Restorative Material. Int J Biomed Sci. 2015;11(1):29–34.
15. Ozera EH, Pascon FM, Correr AB, Puppin-Rontani RM, Castilho AR, Correr-Sobrinho L, Paula AB. Color Stability and Gloss of Esthetic Restorative Materials after Chemical Challenges. Braz Dent J. 2019;30(1):52-57.
16. Reddy PS, Tejaswi KL, Shetty S, Annapoorna BM, Pujari SC, Thipsawamy HM. Effects of commonly consumed beverages on surface roughness and color stability of the nano, microhybrid and hybrid composite resins: an in vitro study. J Contemp Dent Pract. 2013;14(6):718-723.
17. Manojlovic D, Lenhardt L, Milićević B, Antonov M, Miletic, V, Dramčić N. D. Evaluation of Staining-Dependent Colour Changes in Resin Composites Using Principal Component Analysis. Sci Rep. 2015;5:14638.
18. Duc O, Di Bella E, Krejci I, Betrisey E, Abdelaziz M, Ardu S. Staining susceptibility of resin composite materials. Am J Dent. 2019;32(1):39-42.
19. Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. Dental Materials. 2006;22(3):211-22.
20. Schulze KA, Marshall SJ, Gansky SA, Marshall GW. Color stability and hardness in dental composites after accelerated aging. Dent Mater. 2003;19(7):612-619.
21. Malekipour MR, Sharafi A, Kazemi S, Khazaei S, Shirani F. Comparison of color stability of a composite resin in different color media. Dent Res J (Isfahan). 2012;9(4):441-446.
22. Ardu S, Duc O, Di Bella E, Krejci I, Daher R. Color stability of different composite resins after polishing. Odontology. 2018;106(3):328-333.
23. Sideridou ID, Achillas SD. Elution Study of Unreacted Bis-GMA, TEGDMA, UDMA, and Bis-EMA from Light-Cured Dental Resins and Resin Composites Using HPLC. J Biomed Mater Res Part B: Appl Biomater. 2005;74(1):617–626.
24. Alberton Da Silva V, Alberton Da Silva S, Pecho OE, Bacchi A. Influence of composite type and light irradiance on color stability after immersion in different beverages. J Esthet Restor Dent. 2018;30(5):390-396.
25. Sartori N, Knezevic A, Peruchi LD, Phark JH, Duarte S Jr. Effects of Light Attenuation through Dental Tissues on Cure Depth of Composite Resins. Acta Stomatol Croat. 2019;53(2):95-105.
26. Maran BM, de Geus JL, Gutierrez MF, Heintze S, Tardem C, Barceleiro MO, Reis A, Loguerio AD. Nanofilled/nanohybrid and hybrid resin-based composite in patients with direct restorations in posterior teeth: A systematic review and meta-analysis. J Dent. 2020;99:103407.
27. Kwon SR, Wertz PW. Review of the Mechanism of Tooth Whitening. J Esthet Restor Dent. 2015;27(5):240-257.