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Influence of staining on the optical properties and surface topography of low-shrinkage and conventional dental composites

Uticaj bojenja na optička svojstva i topografiju površine kompozitnih materijala male kontrakcije i konvencionalnih stomatoloških kompozita

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Abstract

Background/Aim. Matching the optical properties of composite restorations and teeth is very important in esthetic dentistry. The challenge lies not only in the initial matching but also in the fact that these optical properties change significantly in the oral environment over time. The aim of the study was to examine the initial color, translucency, fluorescence, and surface topography of various composite materials, their changes after seven days of immersion in tea, as well as after repolishing. **Methods.** Two low-shrinkage nanohybrid composites (N'Durance® and Charisma® Diamond) and two conventional composites [Tetric EvoCeram® (nanohybrid) and Gradia® Direct (microhybrid)] in shade B1 were immersed in tea for seven days. Diffuse reflection, fluorescence, and surface roughness were measured before and after immersion in tea, as well as after repolishing. Color and translucency were calculated using the CIEDE2000 and CIEDTP2000 equations. **Results.** The highest initial lightness (L*) values were observed for Charisma® Diamond, while the highest red-green (a*) and yellow-blue (b*) coordinates were observed for Tetric EvoCeram®. The following trend in color change (ΔE_{00}) was observed: Tetric EvoCeram®>N'Durance®>Charisma® Diamond ≈ Gradia® Direct. The highest color change was recorded for Tetric EvoCeram® ($\Delta E_{00} = 6.0$). Additionally, the highest translucency parameter (TP_{00}) and surface roughness before and after immersion in tea were recorded for Tetric EvoCeram®, while the highest decrease in translucency intensity after staining was observed for Gradia® Direct (33%). After repolishing, color changes for Tetric EvoCeram® and N'Durance® remained higher than the clinically acceptable threshold, while the values for Charisma® Diamond and Gradia® Direct were clinically acceptable. Repolishing restored almost complete translucency, fluorescence, and surface roughness, bringing the spectral properties of the composites closer to their initial values. **Conclusion.** The initial optical characteristics and surface roughness of the composites, as well as their modifications after immersion and repolishing, depend on the type of composite material. The process of staining altered the brightness of the fluorescence, while leaving the spectral shape unaffected. The repolishing procedure almost completely restored the optical properties of all tested composite materials.

Key words:
color; composite resins; dental materials; fluorescence; materials testing; tea.

Apstrakt

Uvod/Cilj. Usklađivanje optičkih svojstava kompozita i zuba je veoma važno u estetskoj stomatologiji. Izazov ne leži samo u početnom podudaranju, već i u činjenici da se ova optička svojstva značajno menjaju u oralnoj sredini tokom vremena. Cilj rada bio je da se ispitaju početna boja, translucencija, fluorescencija i površinska topografija različitih kompozitnih materijala, njihova promena posle potapanja u čaj tokom sedam dana, kao i posle ponovnog poliranja. **Metode.** Dva nanohibridna kompozitna materijala male kontrakcije (N'Durance® i Charisma® Diamond) i dva konvencionalna kompozita [Tetric EvoCeram® (nanohibridni) i Gradia® Direct (mikrohibridni)] u nijansi B1 potopljeni su u rastvor čaja na sedam dana. Difuzna refleksija, fluorescencija i površinska hrapavost izmerene su pre i posle potapanja u čaj, kao i posle ponovnog poliranja. Boja i translucencija izračunate su prema CIEDE2000 i CIEDTP2000 formulama. **Rezultati.** Najveće inicijalne vrednosti svetloće (L*) uočene su kod kompozita Charisma® Diamond, dok su najveće vrednosti žutocrvene (a*) i žutoplave (b*) koordinate boje bile kod

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kompozita Tetric EvoCeram®. Primećen je sledeći trend promene boje (ΔE_{00}): Tetric EvoCeram®>N'Durance® >Charisma® Diamond ≈ Gradia® Direct. Najveća promena boje primećena je kod kompozita Tetric EvoCeram® ($\Delta E_{00} = 6{,}0$). Takođe, najveće vrednosti translucencija parametra (TP_{00}) i površinske hrapavosti pre i nakon potapanja u čaj zabeležene su kod kompozita Tetric EvoCeram®, dok je najveće smanjenje intenziteta translucencije nakon prebojavanja zabeleženo kod Gradia® Direct (33%). Nakon ponovnog poliranja, promene boje kod Tetric EvoCeram® i N'Durance® ostale su veće od klinički prihvatljivog praga, dok su zabeležene vrednosti za Charisma® Diamond i Gradia® Direct bile u granicama kliničke prihvatljivosti. Ponovno poliranje je skoro u potpunosti vratilo vrednosti translucencije, fluorescencije i površinske hrapavosti, dovodeći spektralna svojstva kompozita bliže početnim vrednostima. **Zaključak.** Početna optička svojstva, površinska hrapavost kao i njihove promene nakon potapanja i ponovnog poliranja zavise od tipa kompozitnog materijala. Prebojavanje je promenilo intenzitet fluorescencije, dok je oblik emisionog spektra ostao nepromenjen. Proces ponovnog poliranja skoro je u potpunosti vratio optička svojstva svih testiranih kompozitnih materijala.

Ključne reči:
boje; smole, kompozitne; stomatološki materijali; fluorescencija; materijali, testiranje; čaj.

Introduction

Ensuring that the optical properties of composite restorations match those of natural teeth is a crucial step in the field of esthetic dentistry. While color is commonly regarded as the primary esthetic characteristic, the significance of fluorescence should not be overlooked. Natural teeth exhibit fluorescence under ultraviolet (UV) radiation, which is particularly strong in intense daylight, especially during summer, and in certain artificial lighting environments, such as those in dance clubs and cinemas. Despite its relevance, the fluorescence of natural teeth and dental restorations remains underexplored in esthetic dentistry [1, 2].

Shade mismatching in esthetic restorations can be attributed to a variety of factors, the most significant of which is the use of inaccurate shade guides that fail to represent the true color and translucency of the restorative materials. Additional contributing factors include the surrounding environment, inadequate color rendering index of ambient lighting, physiological and psychological responses, metamerism, observation angle, the size of the visual field, mood, age, eye fatigue, and even gender. Furthermore, patients often have restorations from different brands and material types in the mouth [3, 4]. The challenge lies not only in achieving an initial match in color and fluorescence between natural teeth and restorations, but also in maintaining this match over a long time. The optical properties of restorative materials significantly change when a material is exposed to commonly consumed beverages and foods. These changes are a direct consequence of the adsorption and absorption of various colorants present in foods and beverages. Often, as time passes, these restorations become aesthetically unacceptable because of the intense change of color.

The initial color of the composite material depends on its structure, the monomer composition, filler content, and photoinitiator type [5]. One of the parameters that affects initial esthetic properties and color stability is the surface roughness of the restoration, which is related to the combination of factors, such as polishing and finishing procedures, but also to the composition of the monomer and the percentage, type, and size of filler particles [6, 7]. According to literature data, surface roughness has a direct influence on the susceptibility to extrinsic staining [8]. Different repolishing procedures can partially remove the stains and help restore the optical properties of the materials [9].

Low-shrinkage composites represent a new generation of composites used to reduce the shrinkage during polymerization and improve marginal adaptation. In addition, it would be expected that these composites have esthetic properties comparable to conventional composites. Only a few studies have been performed on the optical properties of low-shrinkage composites. Some of these composites showed similar or smaller color changes compared to the conventional ones [10, 11].

Using dental shade guides is the most common method for color communication in dentistry. Literature data indicate that restorative materials labeled with the same shade designation can vary significantly in color depending on the brand and type of material [12, 13]. Lee et al. [14] reported that color coordinates, translucency, changes in color, and translucency after curing, polishing, and thermal cycling varied among brands of the composite even though the shade designation was the same (A2).

Previous studies have revealed that exposure to various discolorations present in different foods and beverages affects the optical properties of dental composites and alters them to varying degrees [15–17]. Among the most frequently consumed beverages, tea has shown a high potential for discoloring teeth and restorations because it contains a significant amount of tannins. It can considerably change the color of composites over time.

The aim of this study was to examine the initial color, translucency, fluorescence, and surface topography of various commercial composites of the same shade designation and their changes after seven days of immersion in tea and after repolishing.

Methods

Forty samples of four commercial composites – two low-shrinkage nanohybrid (N'Durance® and Charisma® Diamond) and two conventional [Tetric EvoCeram® (nanohybrid) and Gradia® Direct (microhybrid)] (n = 10 *per* group) – were prepared according to the procedure described by Manojlovic et al. [15]. All composites were of B1 shade. The samples were first placed in distilled water at a temperature of 37 °C for 24 hrs. After that, half of the samples in each group were immersed in tea (specifically, black tea – English Breakfast, Sir Winston company LTD, London, UK) at the same temperature of 37 °C for seven days. The tea was prepared by immersing a pre-packaged tea bag in 150 mL of boiling water for 5 minutes, following the manufacturer's instructions. The staining solution was replaced regularly to prevent bacterial contamination. The other half of the samples were immersed in distilled water, which served as the control. Prior to taking measurements, the composite samples were rinsed under tap water for ten seconds and then dried by blotting them with paper towels. Subsequently, all specimens underwent repolishing, and additional measurements were conducted.

Diffuse reflection measurements

Reflection and translucency were calculated from diffuse reflection spectra obtained using a Shimadzu UV–Visible UV-2600 spectrophotometer (Shimadzu Corporation, Tokyo, Japan) equipped with an integrating sphere (ISR-2600), over the 360–830 nanometer (nm) range with a 1 nm step. Measurements were performed before and after immersion, as well as after polishing of the specimen. The sample color was calculated from the diffuse reflection spectrum using the CIELAB color system of the International Commission on Illumination (*Commission Internationale de l'Éclairage* – CIE), which includes the lightness (L*), the red-green coordinate (a*), the yellow-blue coordinate (b*), under standard illumination (D65) source against both white and black backgrounds [18].

The total color change (ΔE_{00}) was calculated according to the following CIEDE2000 equation [18, 19]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the adjusted values of the metric CIELAB differences in lightness, chroma, and hue, C'_s and C'_r are the adjusted chroma values for the sample and reference, calculated using the S_L, S_C, and S_H weighting functions, the k_L, k_C, and k_H parametric factors, and the chroma-hue interaction coefficient R_T [18]. The color changes (ΔE_{00}) smaller than 1.8 were considered clinically acceptable [19].

The translucency was determined from measurement results performed against a black (B) and white (W) background. The translucency parameter (TP_{00}) was evaluated from the following CIEDTP2000 equation:

$$TP_{00} = \sqrt{\left(\frac{L'_B - L'_W}{k_L S_L}\right)^2 + \left(\frac{C'_B - C'_W}{k_C S_C}\right)^2 + \left(\frac{H'_B - H'_W}{k_H S_H}\right)^2 + R_T\left(\frac{C'_B - C'_W}{k_C S_C}\right)\left(\frac{H'_B - H'_W}{k_H S_H}\right)}.$$

Fluorescence measurements

Excitation-emission matrices (EEM) were obtained from a Fluorolog®-3 Model FL3-221 spectrofluorometer (Horiba JobinYvon), which uses a 450-W xenon lamp excitation source and Hamamatsu R928 PMT detector. Measurements were performed in the front-face configuration on a 270 to 550 nm excitation range and 300 to 650 nm emission range, with 5 nm and 1 nm steps, respectively.

Total fluorescence (TF) emission is represented as a two-dimensional sum of emission intensities over the excitation-emission plane:

$$TF = \sum_{\lambda_{EX}=270nm}^{550nm} \sum_{\lambda_{EM}=300nm}^{650nm} I(\lambda_{EX}, \lambda_{EM}).$$

The TF change between sample and reference in percentage is taken as a measure of differences in fluorescence:

$$\Delta TF\ (\%) = \frac{TF_{sample}}{TF_{reference}} \cdot 100\%.$$

The contour plots were selected to represent the resulting surface in two dimensions.

Topography measurements

Surface characteristics of composite specimens were evaluated on Quesant® atomic force microscope (Agoura Hills, CA) operating in tapping mode in air with standard silicone tips (NanoAndMore Gmbh, Wetzlar, Germany), on the 15 × 15 micrometre (μm) sample area and with the persistent force of 40 Newton/meters (N/m).

Statistical analysis

The obtained data were analyzed and correlated using the statistical program SPSS, version 22 (SPSS Inc., Chicago, USA). Mean values and standard deviation were used to describe numerical data. Two-way and one-way analyses of variance (ANOVA) with Tukey's *post-hoc* test were conducted to assess significant differences in TP_{00}, ΔE_{00}, and surface roughness between the tested groups. All analyses were performed at a 95% significance level ($\alpha = 0.05$), with statistical significance set at $p < 0.05$. G*Power 3.1.9.4 software for Windows (Heinrich Heine University, Düsseldorf, Germany) was used to calculate sample sizes for the three outcomes. The difference between the two means was estimated using data from a pilot study for the discoloration test. The alpha error was set at 0.05, and the study had 80% beta power ($dz = 2.381$). Five samples *per* material group were required to observe significant differences.

Results

Despite all composites being assigned the same shade designation (B1), their CIE L*a*b* mean values (Table 1) and diffuse reflectance spectra (Figure 1 A–D) exhibited differences on both white and black backgrounds, both before and after immersion in tea. After repolishing, the spectra returned to the initial shape for all sample groups except for the Gradia® Direct on the white background.

The obtained mean values and standard deviations of ΔE_{00} after immersion in water and tea, as well as after

Table 1

Mean values of the International Commission on Illumination L*, a*, b* color system for the tested composite materials before immersion in tea

Composite brand	L*	a*	b*
N’Durance®	77.4	-0.7	4.7
Charisma® Diamond	78.5	-1.1	7.2
Tetric EvoCeram®	76.3	0.7	7.6
Gradia® Direct	77.5	-0.1	6.5

L* – lightness; a* – red-green coordinate; b* – yellow-blue coordinate.

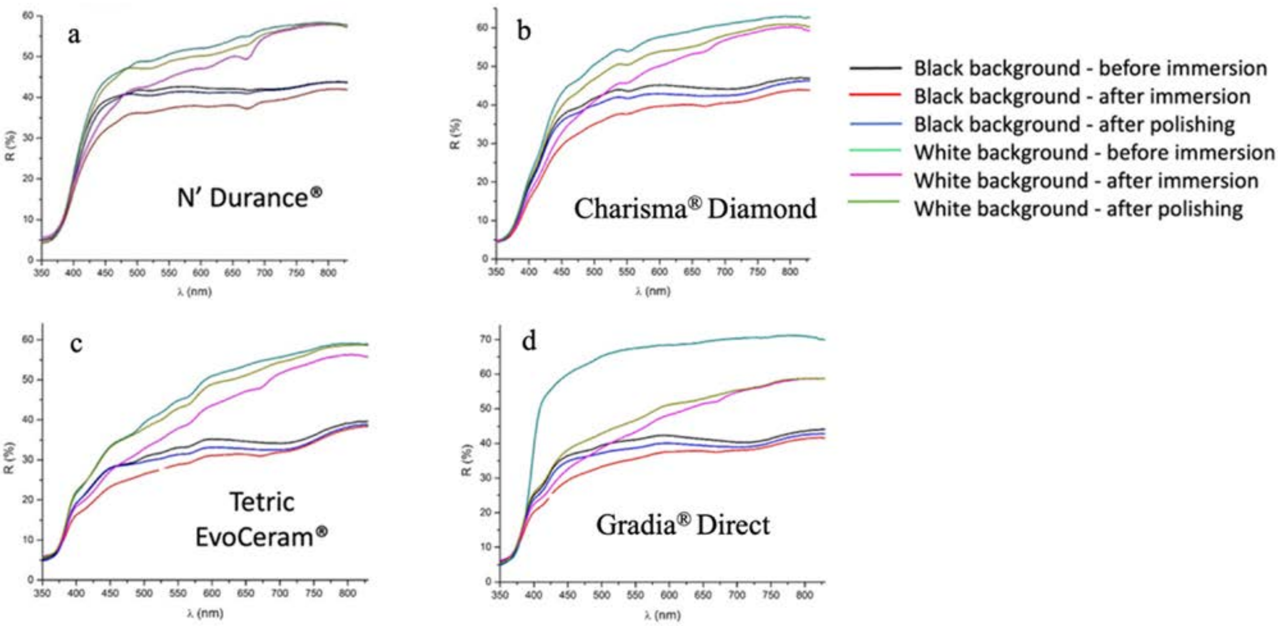

Fig. 1 – Diffuse reflectance spectra of composite samples before and after exposure to tea and after repolishing, on white and black backgrounds: a) N’Durance®; b) Charisma® Diamond; c) Tetric EvoCeram®; d) Gradia® Direct. R – reflectance.

***Note*: After repolishing, all spectra for all sample groups were returned to their initial shape, except for the Gradia® Direct group on a white background.**

subsequent repolishing, are presented in Figure 2. A statistically significant difference ($p < 0.05$) in color change was observed between samples immersed in water (control), tea, and repolished samples, and also between some of the materials, except between Gradia® Direct and Charisma® Diamond ($p > 0.05$). After repolishing, the color changes for Tetric EvoCeram® and N’Durance® remained above the clinically acceptable threshold ($\Delta E_{00} = 1.8$). The highest color change was recorded for Tetric EvoCeram® ($\Delta E_{00} = 6.0$), while ΔE_{00} values for Charisma® Diamond and Gradia® Direct were clinically acceptable.

Figure 3 presents TP_{00} values of the tested composites before and after immersion, as well as after repolishing. Initial translucency was significantly different ($p < 0.05$) for the tested composite brands, except between Gradia® Direct and Charisma® Diamond ($p > 0.05$). For all tested composites, TP_{00} values significantly increased ($p < 0.05$) after immersion in tea and were almost completely restored after repolishing, except for Tetric EvoCeram® ($p > 0.05$).

Figure 4 (a–d) shows EEM fluorescence 3D spectra of composites before and after immersion in tea, as well as after repolishing. In order to quantify the decrease, the volume under the fluorescent region was calculated. Tea staining caused different changes among the same shade-designated composites. Although the shape of the spectra remained the same, the intensity of their emission varied between groups. Gradia® Direct exhibited the highest initial fluorescence and the highest decrease in fluorescence intensity after staining (33%), while the lowest decrease (12%) was observed for the Charisma® Diamond composite. The reduction in fluorescence intensity occurred mainly in the 380–450 nm emission spectral region, where tea absorption is strongest. Repolishing reduced the staining effect on fluorescence, but not completely (Table 2).

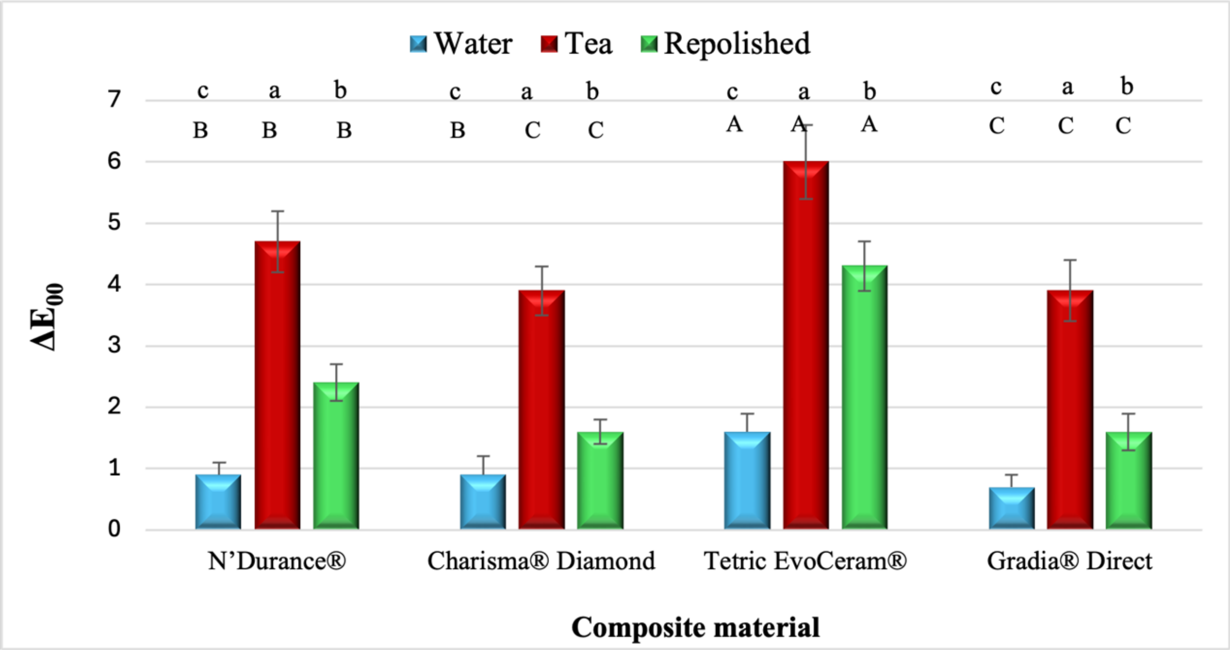

Fig. 2 – Color changes (ΔE_{00}) of composite materials after immersion in water and tea and subsequent repolishing. ΔE_{00} parameter values on the ordinate are given as numbers.

***Note*: Same letters indicate no significant differences ($p > 0.05$) between different materials (uppercase letters) and no significant differences for each material immersed in water, tea, or repolished (lowercase letters). The labels "A", "B", and "C" are assigned based on the values of the parameter. "A" is assigned to the material with the highest value. The next material is assigned label "B" if the difference is statistically significant; otherwise, it is labeled "A". The following material is compared with the previous one using the same principle. In-group assignments are presented with lowercase letters in the same way.**

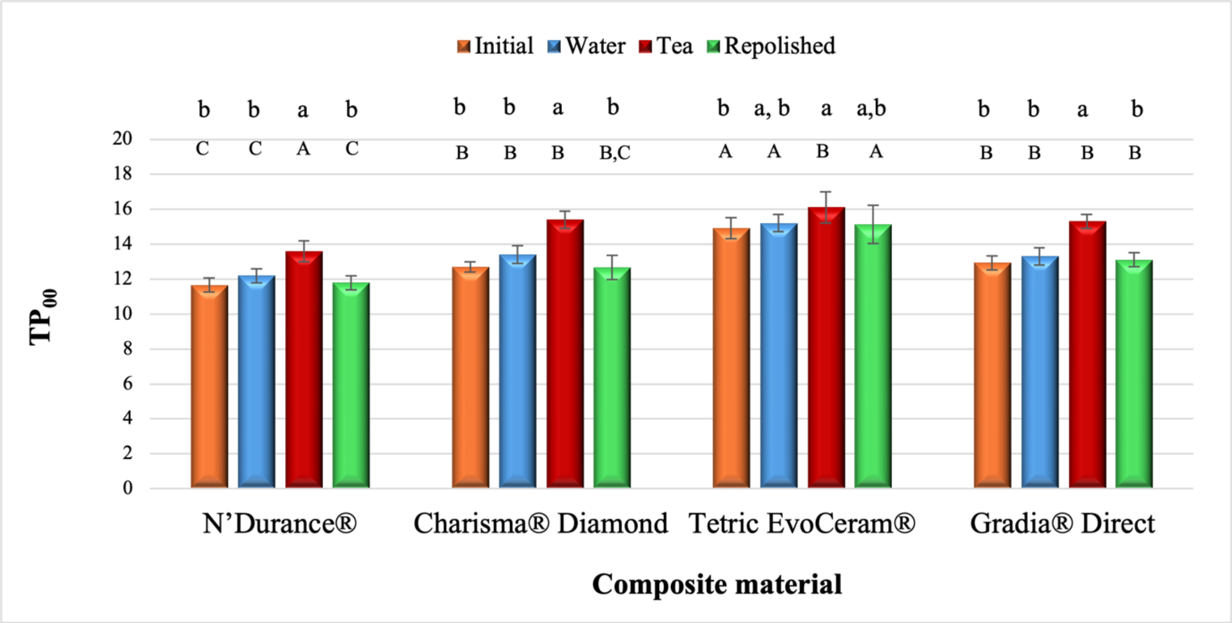

Fig. 3 – Translucency (TP_{00}) of the tested composite materials (initial, immersed in water and tea, and repolished). TP_{00} parameter values on the ordinate are given as numbers.

***Note*: Same letters indicate no significant differences ($p > 0.05$) between different materials (uppercase letters) and no significant differences for each material immersed in water, tea, or repolished (lowercase letters). The labels "A", "B", and "C" are assigned based on the values of the parameter. "A" is assigned to the material with the highest value. The next material is assigned label "B" if the difference is statistically significant; otherwise, it is labeled "A". The following material is compared with the previous one using the same principle. "B,C" mark indicates that the parameter value of the material shows no statistically significant difference from values "B" and "C", but these two show statistically different values. Other composite marks are assigned according to the same principles. In-group assignments are presented with lowercase letters in the same way.**

There was a statistically significant difference ($p < 0.05$) in the initial surface roughness between the materials, except between N’Durance® and Charisma® Diamond ($p = 0.139$). Tea staining significantly altered the surface of all tested samples ($p < 0.05$), except Tetric EvoCeram® ($p = 0.074$). No statistically significant difference was observed in the roughness of the initial and repolished samples ($p > 0.05$) for all tested composite materials except for Charisma® Diamond ($p < 0.05$) (Figure 5).

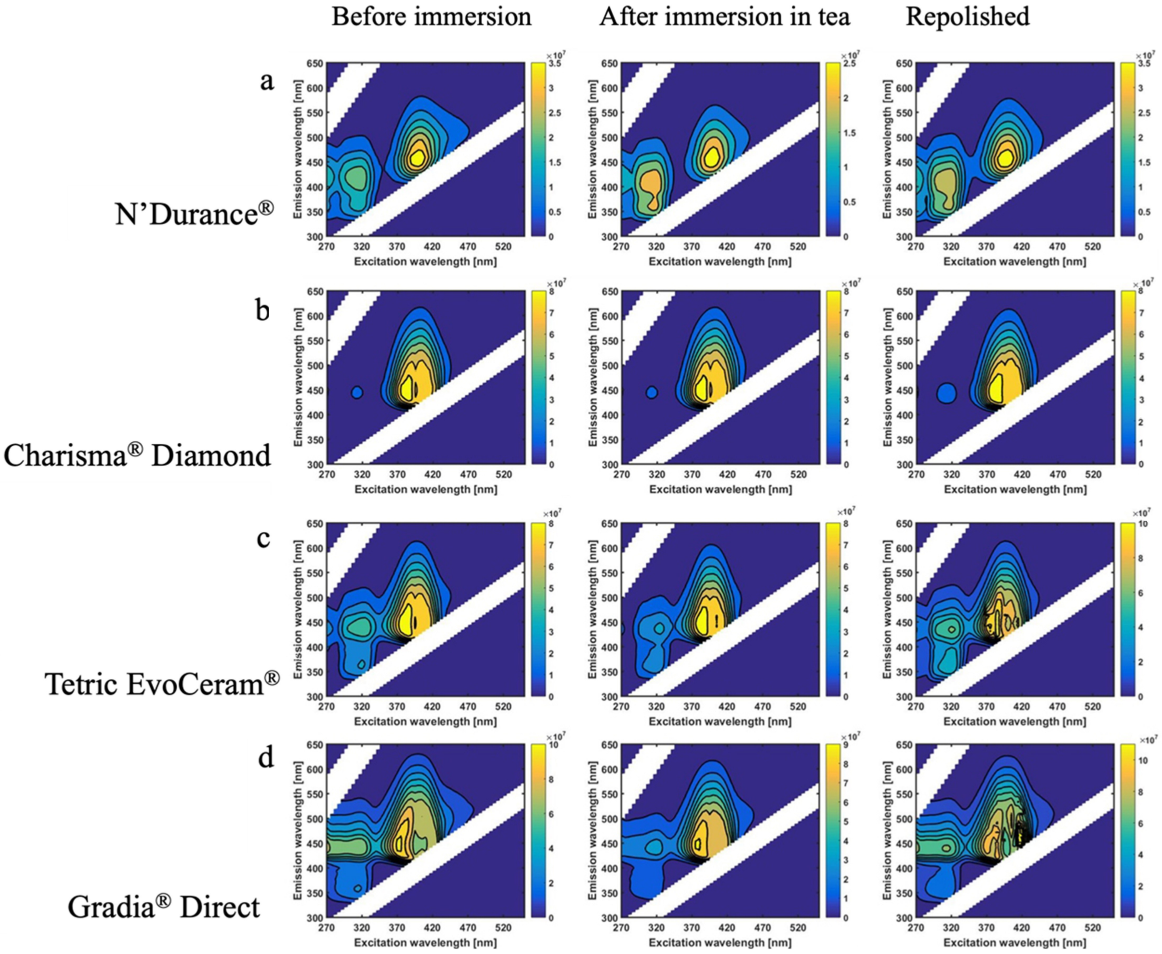

Fig. 4 – Fluorescence excitation-emission matrices (EEM) spectra of composite samples, before and after immersion in tea and after the subsequent repolishing: a) N’Durance® before immersion, after immersion and after polishing; b) Charisma® Diamond before immersion, after immersion, and after polishing; c) Tetric EvoCeram® before immersion, after immersion, and after polishing; d) Gradia® Direct before immersion, after immersion, and after polishing.

***Note*: Gradia® Direct showed the highest initial fluorescence and the highest decrease in fluorescence intensity after staining.**

Table 2

Changes in the total fluorescence after staining and after repolishing

Composite brand	after staining	after repolishing
N’Durance®	-20	2
Charisma® Diamond	-12	1
Tetric EvoCeram®	-18	3
Gradia® Direct	-33	-3

Values are given as percentages.

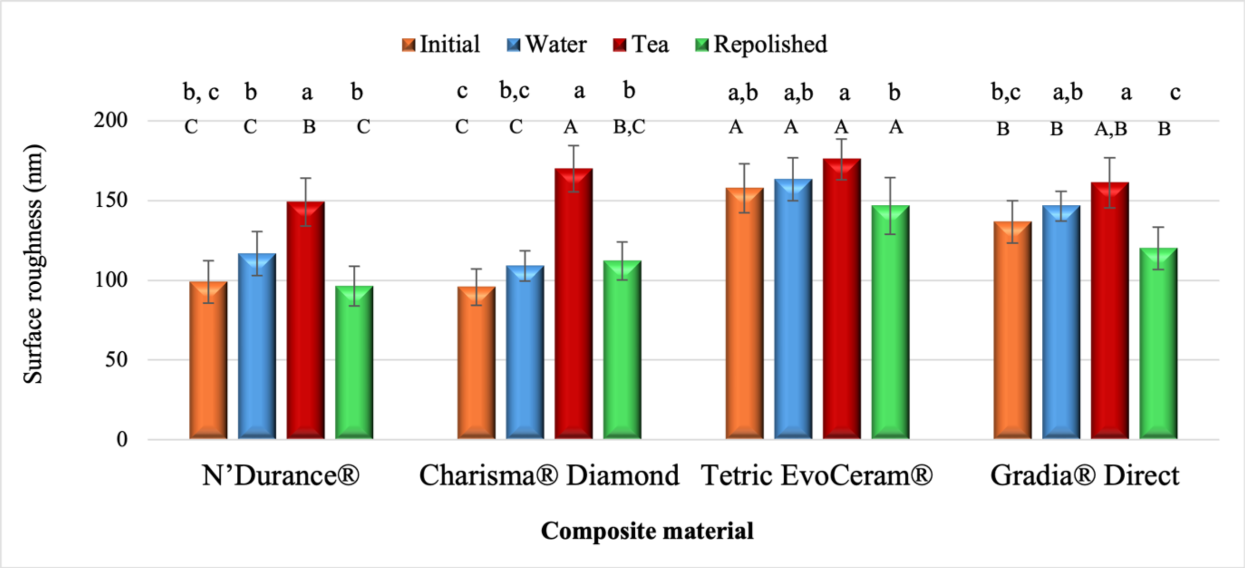

Fig. 5 – The surface roughness of composites before and after immersion in tea and after repolishing. nm – nanometer.

***Note*: Same letters indicate no significant differences ($p > 0.05$) between different materials (uppercase letters) and no significant differences for each material before immersion, immersed in water, tea, or repolished (lowercase letters). The labels "A", "B", and "C" are assigned based on the values of the parameter. "A" is assigned to the material with the highest value. The next material is assigned label "B" if the difference is statistically significant; otherwise, it is labeled "A". The following material is compared with the previous one using the same principle. "A,B" mark indicates that the parameter value of the material shows no statistically significant difference from values "A" and "B", but these two show statistically different values. Other composite marks are assigned according to the same principles. In-group assignments are presented with lowercase letters in the same way.**

Discussion

The initial optical properties of composites and their changes after staining depend on material characteristics such as filler type and concentration, particle size, type, and amount of organic matrix [20, 21], and surface quality. In this study, two low-shrinkage and two different conventional composites [based on bisphenol A-glycidyl methacrylate (BisGMA) and urethane dimethacrylate (UDMA)] were tested. The B1 shade of the composite was chosen as the lightest shade because of the assumption that lighter composites will change color more significantly under staining [22].

Despite having the same shade designation, composites from different manufacturers have different chemical constituents, and, therefore, their optical properties vary among them. Shade determination is typically conducted in clinical practice using the Vita shade guide. Nevertheless, prior research has demonstrated that the colors of composites do not align effectively with the Vita shade guide tabs, even when employing the layering technique [4, 23–26]. When comparing the shade tabs of the Vitapan classical shade guide with corresponding tabs composed of direct restorative composites, it was found that none of the materials or shade combinations achieved a satisfactory match [27]. Paravina et al. [28] discovered a lack of color compatibility among shade pairs that had the same shade identification. The A2 shade pairs have demonstrated the most optimal color matching, with C2 and B2 following closely behind.

In this study, the initial color parameters L*, a*, and b* differ among the tested B1 composite materials. Charisma® Diamond showed the highest lightness (L*) before immersion in tea, but the lowest a* value (indicating a shift toward green color). In contrast, Tetric EvoCeram® showed the lowest L* value and the highest a* and b* values (indicating a greater shift toward red and yellow).

The diffuse reflectance spectra (on both white and black backgrounds) of all examined B1 composites exhibited a consistent pattern: the reflectance of the specimens decreased after being immersed in tea, and then increased again following the repolishing process, returning to a level similar to the reflectance before immersion, except for the Gradia® Direct on the white background.

Numerous studies have shown color changes in composites after immersion in different staining solutions [15, 16, 29, 30]. According to Paravina et al. [19], ΔE_{00} larger than 1.8 is considered clinically unacceptable, and this threshold was used in this study to define clinical acceptability. The present results showed color changes higher than the clinically acceptable threshold for all tested materials. The highest total color change ($\Delta E_{00} = 6.0$) was observed for conventional, BisGMA-based nanohybrid (Tetric EvoCeram®) composites compared to the low-shrinkage nanohybrid (Charisma® Diamond and N'Durance®) and UDMA-based microhybrid (Gradia Direct®) composites. The present results indicate that the type of composite significantly affects the extent of optical changes. This result is in line with the previous report by Arocha et al. [11], who also found smaller color changes for the UDMA-based composite. They explained this by the fact that the hydrophilic hydroxyl group of BisGMA monomer induces more water sorption than the UDMA aliphatic chain. Contrary to this result, Manojlovic et al. [10] observed lower color changes for Tetric EvoCeram® than for the low-shrinkage, BisGMA-free composites, which were exposed to tea for two days. There is no apparent explanation for these differences, but this finding may indicate that BisGMA-based composite absorbs more water-soluble pigments during a longer exposure period. Observed differences between studies can also be explained by the fact that the color stability of the composite was affected by several factors, not only by the monomer type.

The translucency of all tested composites was significantly higher after immersion in tea, but was almost completely restored after repolishing. The highest initial TP_{00} value was recorded for BisGMA-based composite Tetric EvoCeram®, compared to low-shrinkage and conventional UDMA-based composites. This finding is consistent with other studies [31, 32] and may be associated with the refractive index of BisGMA monomer compared to urethane-based monomers.

Meller and Klein [33] found that all analyzed composite brands and shade types reached their maximum fluorescence at about the same excitation and emission wavelengths, but with distinctively varying fluorescence intensities. The results obtained in this study confirm these findings. Contour plots showed no variations in the shape, but their intensities decreased differently after staining. The highest decrease of 33% was observed for the Gradia® Direct composite, while the lowest decrease of 12% was found for the Charisma® Diamond composite. Differences in the extent of fluorescence reduction after staining can be attributed to different amounts of excited and emitted light reaching and escaping the samples. The intrinsic composite's fluorescent components keep their fluorescent potential, i.e., it is not affected by the adsorbed surface barrier. However, the surface barrier absorbs incident and emitted light and reduces fluorescence intensity. The effect vanishes when the surface barrier is removed by polishing the stained composite.

Repolishing and whitening are often performed in daily practice to restore the natural appearance of restorations. In this study, we used repolishing of composites to remove adsorbed layers on sample surfaces formed by staining. After repolishing, Gradia® Direct and Charisma® Diamond showed clinically acceptable ΔE_{00} values. The translucency of all composites regains values similar to those before staining. This indicates that the main process responsible for optical changes is the adsorption of staining pigments on the surface of composites and that these pigments can be removed by polishing. These results are consistent with the results previously reported by Türkün et al. [9]. In contrast, Tetric EvoCeram® and N'Durance® composites exhibited color changes higher than the clinically acceptable threshold even after repolishing, indicating that the deeper layers of these composites were affected by staining, which suggests that the discoloration in these composites may be irreversible.

A similar reasoning can be applied to discuss changes in composites' fluorescence. Fluorescence is also restored almost completely after repolishing stained composites, which indicates that the adsorbed surface layer affects the fluorescent properties to different extents, depending on the type of adsorbed pigments. Affected by the adsorbed pigments interface, the photons scatter inside the composites, and the fluorescent beam that tries to leave the matrix needs to penetrate this adsorbed pigment obstacle for the second time. By removing the obstacle, in this study, we showed the complete restoration of the initial fluorescence values. This might indicate that the interior of the composite's structure does not affect the fluorescence intensity of the manufactured composite and that the fluorophores inside the composite remain unaffected by staining. On the contrary, literature data show a different point of view. It is assumed that fluorescence is highly affected by the absorption coefficient of the composite itself, regarding the differences among the size of filler particles and their distribution among the tested composite groups [34]. Ameer and Mualla [35] have also found that composites with different filler particles show different changes in fluorescence intensity during the discoloration, even among different shades of the same manufacturer. In their investigation, fluorescence of composites with nanofillers decreased more than that of the microhybrids. This research suggests a possible connection between the composite's chemical composition and the stability of its fluorescence. Many authors explain this fluorescence intensity decrease as a result of the degradation of the organic composite matrix and the subsequent deactivation of fluorophores [36, 37].

It is known that surface polishing plays an important role in color determination. The unpolished material is more susceptible to staining from food and drinks [38]. The polishing degree depends on the material type and its chemical constituents. Although for Tetric EvoCeram® the difference is not significant, all materials showed a unique trend of higher roughness after immersion and lower after repolishing samples. In general, a higher roughness after immersion could be attributed to chemical erosion from tea due to its slightly acidic nature and adsorption of stains on the sample surfaces [39]. Initially, higher surface roughness was recorded for conventional compared to low-shrinkage composites. Following immersion in tea, comparable values were observed for all tested composites, and subsequent repolishing significantly restored the surface roughness values. Although Tetric EvoCeram® showed initially the highest roughness and also the highest values of ΔE_{00} after staining, the results of this study indicate that the susceptibility to staining did not necessarily influence the initial roughness. N'Durance showed significantly lower initial roughness but higher ΔE_{00} compared to Gradia® Direct. This finding is consistent with the research conducted by Reis et al. [8], which also concluded that the surfaces with the highest level of polish were not always the least prone to stains. The composition of the material, including the specific monomers and fillers used, influences its propensity to undergo color changes. Smaller filler particles do not consistently result in a superior polished surface and reduced susceptibility to discoloration.

The results indicate that external discoloration and the adsorption of pigments onto material surfaces are significant factors in the staining of composites. Repolishing materials after staining partially eliminates adsorbed stains and pigments from the composite surface, hence restoring the optical characteristics and roughness of the materials. Further studies on optical properties and surface topography are needed to clarify the correlation between the type of composite, surface roughness, time of exposure, and color changes.

Conclusion

According to the obtained results and considering restrictions of the study, one can conclude the following: even though the shades of all specimens were the same (B1), their initial color, translucency, fluorescence, and surface roughness varied among composites from different manufacturers. Immersion in tea significantly changed the optical properties of all tested materials. These changes were reliant upon the specific material used. The BisGMA-based composite exhibited a greater color change when immersed in tea compared to BisGMA-free composites. Staining changed the intensity of the composites' fluorescence but not the shape of the fluorescence spectra. Repolishing nearly restored translucency, fluorescence, and surface roughness, while partially eliminating discoloration and returning the spectral properties of composites to levels closer to their initial state.

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