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Original Article

# Effects of different toothpastes on the color and whiteness of stained anterior composite resin

Başak Yazkan, Ebru Yilmaz, Özge Gizem Yenidünya, and Nilgün Akgül

Department of Restorative Dentistry, Faculty of Dentistry, Pamukkale University, Denizli, Turkey

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## Abstract

**Purpose:** To evaluate changes in the color of an anterior nanohybrid composite resin and differences in its whitening index after 30 days of brushing with six brands of whitening toothpaste *in vitro* to simulate the situation in individuals with high coffee consumption.

**Methods:** Eighty-four disk-shaped resin specimens were prepared (shade A2). For initial staining, the samples were immersed in coffee solution for 14 days and then divided into eight groups for treatment with various toothpastes. Color was assessed at the baseline, after initial staining, and on days 7, 14, and 30 of the staining-and-brushing cycle. Color stability was evaluated based on the CIEDE2000 color difference ($\Delta E_{00}$), and differences in whiteness were determined using the whitening index for dentistry (WID).

**Results:** The highest $\Delta E_{00}$ and $\Delta$WID values were obtained with Colgate Herbal, followed by Opalescence Whitening and Crest Baking Soda and Peroxide, whereas the lowest values were obtained with distilled water, followed by Yotuel Pharma B5, on day 30 of the staining-and-brushing cycle.

**Conclusion:** In terms of improving the color and whiteness of coffee-stained anterior nanohybrid composite resin, Colgate Herbal, Opalescence Whitening, and Crest Baking Soda and Peroxide yielded promising results after 30 days of continuous use.

Keywords: toothpaste, whiteness index, whitening toothpaste

## Introduction

Improvements in composite resin materials have made it possible to achieve more esthetic restorations, with light refraction and transmission properties closer to those of tooth enamel, together with much better polishing properties and longer-term color stability [1]. Despite these improvements, however, restorations still show color changes over time depending on individual habits, such as smoking and frequent consumption of colored beverages such as tea, coffee, and red wine [2].

Tooth whitening is frequently performed for patients who visit dental clinics complaining of tooth discoloration [3], as tooth whiteness has considerable impact on smile attractiveness [4]. While whitening treatments can be applied in the office or at home under the guidance of a dentist, there are also products on the market that can be applied by individuals themselves [5]. Over-the-counter (OTC) tooth whiteners purchased and applied by consumers have an important area of use because they are cheap, easily accessible, and can be applied in a short time. Whitening systems applied with a ready-made spoon or brush (paint-on), tape- and pen-shaped systems, mouthwashes, chewing gums, and toothpastes are among such OTC products, although toothpastes are generally preferred [6].

Whitening toothpastes can exert their effects through mechanical (abrasives), chemical (surface-active agents and enzymes) and optic-modifying (blue covariate) actions, or can exploit the properties of activated charcoal/carbon [7]. Such toothpastes have been reported to affect the surfaces of not only teeth but also composite resin restorations [3].

It has been shown experimentally that the whitening effect of such toothpastes results from abrasion and chemical removal of stains on the surfaces of restorations, or by leaving a thin, translucent film containing blue covariant pigments [8,9]. Although many studies have investigated the effect of different whitening products on composite resin restorations, little attention has been paid to the effect of OTC whitening toothpastes on composite resins. Despite the recent development and launching of new whitening products, information on their effectiveness remains limited.

Coffee is a frequently consumed beverage worldwide, and excessive coffee consumption is well known to significantly discolor both teeth and tooth-colored restorations [6]. For this reason, dentists are often asked which whitening toothpaste to use, especially by individuals who consume coffee frequently. In this regard, recommendations as to the most effective toothpaste are obviously important and require evaluation.

Therefore, the aim of the present *in vitro* study was to compare the effects of different whitening toothpastes on the color of an anterior nanohybrid composite resin that had been stained with coffee. Changes in the whiteness index value after the staining-and-brushing cycle were also investigated. The null hypothesis was that the changes in the color and whiteness index would be clinically acceptable for all brands of toothpaste tested.

## Materials and Methods

The number of samples for the study was decided by considering a 90% statistical power and a 5% significance level ($\alpha$) in the G*Power 3.1 power analysis program (Erdfelder, Faul, & Buchner, Heinrich Heine University Düsseldorf, Düsseldorf, Germany). As a result of this analysis, a total of 96 samples were prepared, with 12 samples in each group.

### Specimen preparation

A nanohybrid anterior composite resin (Gradia Direct Anterior, GC Corp., Tokyo, Japan) was used in this study. A total of 96 composite samples were prepared using disk-shaped Teflon molds with a diameter of 8 mm and a height of 2 mm. A polyester matrix and a glass slab were placed on both sides of the mold to allow smoothing of the composite surface with a glass slab. The specimens were cured with a light-emitting diode light device (Valo Cordless, Ultradent, South Jordan, UT, USA) for 10 s at a power density of approximately 1,200 mW/cm$^2$, in accordance with the manufacturer's instructions.

A polishing system (Shofu-Super Snap Rainbow technique kit; Shofu Inc., Kyoto, Japan) with coarse, medium, fine, and superfine disks was applied to the upper surface of the samples in each group for 10 s. After polishing, the samples were kept in distilled water for 24 h and then randomly divided into 8 groups ($n$ = 12 in each group). They were then brushed daily for 30 consecutive days using different toothpastes (except for the controls) as follows:

1. No brushing and staining; kept in distilled water only (controls)
2. Brushing without toothpaste (controls)
3. Curaprox White is Black (Curaden AG, Kriens, Switzerland)
4. Colgate Herbal (Colgate-Palmolive Co., New York, NY, USA)
5. Meridol (CP-GABA GmbH, Hamburg, Germany)

Corresponding author: Başak Yazkan, Department of Restorative Dentistry, Faculty of Dentistry, Pamukkale University, Suleyman Demirel Street, Number:95, 20160 Pamukkale, Denizli, Turkey
Fax: +90-258-296-4223 E-mail: basakyazkan@hotmail.com

**Table 1** Ingredients, manufacturers and RDA information for the toothpastes used in the present study

| Toothpaste | Ingredients | Manufacturer | RDA value | Major whitening mechanism |
|---|---|---|---|---|
| Curaprox White is Black | Water, sorbitol, hydrated silica, glycerin, charcoal powder, aroma, decyl glucoside, cocamidopropyl betaine, sodium monofluorophosphate, tocopherol, xanthan gum, maltodextrin, mica, hydroxyapatite(nano), potassium acesulfame, titanium dioxide, microcrystalline cellulose, sodium chloride, citrus lemon peel oil, sodium hydroxide, maize starch, amyloglucosidase, glucose oxidase, urtica dioica leaf extract, potassium thiocyanate, cetearyl alcohol, hydrogenated lecithin, methyl lactate, methyl diisopropyl propionamide, ethyl menthane carboxamide, stearic acid, mannitol, sodium bisulfite, tin oxide, lactoperoxidase, limonene | Curaden, Kriens, Switzerland | 50 | active charcoal components |
| Colgate Herbal | calcium carbonate, water, sorbitol, sodium lauryl sulfate, hydrated silica, aroma, sodium monofluorophosphate, cellulose gum, magnesium aluminum silicate, sodium saccharin, sodium carbonate, benzyl alcohol, sodium bicarbonate, ananas sativus fruit juice, citrus aurantium dulcis juice, citrus lemon juice, fragaria ananassa fruit juice, mangifera indica juice, camellia sinensis leaf extract, anthemis nobilis flower oil, commiphora myrrha oil, eucalyptol, salvia officinalis oil, limonene, pigment green 7 (Cl 74260) | Colgate-Palmolive Co., New York, NY, USA | 110 | herbal ingredients, Abrasivity |
| Meridol | Water, hydrated silica, glycerin, hydroxyethylcellulose, aroma, cocamidopropyl betaine, sodium gluconate, polyoxyethylene tallow aminopropylamine (PEG-3), olaflur, stannous floride, sodium saccharin, potassium hydroxide, hydrochloric acid, limonene, pigment blue (Cl 74160), titanium dioxide (Cl 77891) | CP-GABA GmbH, Hamburg, Germany | 60-80 | blue covarin |
| Opalescence Whitening | glycerin, water, silica, sorbitol, xylitol, flavor (aroma), poloxamer 407, sodium lauryl sulfate, carbomer, sodium benzoate, sodium fluoride, sodium hydroxide, sucralose, xanthan gum, FD and C Blue No.1 (Cl 42090), FD and C Yellow No.5 (Cl 19140) | Ultradent Products, South Jordan, UT, USA | 90 | abrasivity |
| Yotuel Pharma B5 | sorbitol, water, hydrated silica, xylitol, glycerin, tetrapotassium pyrophosphate, panthenol (provitamin B5), papain, titanium dioxide, xanthan gum, potassium phosphate, aroma, sodium fluoride, sodium saccharin, diazolidinyl urea | Biocosmetics, Madrid, Spain | 36 | papain enzyme |
| Crest Baking Soda and Peroxide | glycerin, hydrated silica, water, propylene glycol, sodium bicarbonate, tetrasodium pyrophosphate, sorbitol, polyethylene glycol (PEG-12), flavor, sodium hydroxide, sodium lauryl sulfate, sodium saccharin, poloxamer 407, xanthan gum, cellulose gum, calcium peroxide, titanium dioxide, blue 1 | Procter & Gamble, Cincinnati, OH, USA | 107 | oxdant content (calcium peroxide) |

6. Opalescence Whitening Toothpaste (Ultradent Products, South Jordan, UT, USA)
7. Yotuel Pharma B5 (Biocosmetics, Madrid, Spain)
8. Crest Baking Soda and Peroxide (Procter & Gamble, Cincinnati, OH, USA)

The content, manufacturers, and relative dentin abrasion (RDA) values of the toothpastes used in the study are shown in Table 1 [10].

**Initial staining**

Before the staining-and-brushing cycle, all composite disk samples were immersed in 2 mL of coffee solution for 10 min daily at room temperature for 14 days. The coffee solution was prepared using 2 g of coffee powder and 200 mL of boiled distilled water, and applied after cooling to room temperature, in accordance with the manufacturer's instructions. The solution was refreshed every 24 h.

**Staining-and-brushing cycle**

The staining-and-brushing cycles were carried out as follows: The samples were immersed in coffee solution for 48 min per day [11], and brushed with an automatic toothbrush (Oral-B Genius 8,000 white electric (Oral-B Corp, Procter & Gamble, Cincinnati, OH, USA) for 5 s [12], and kept in distilled water until the next cycle over a 30-day period. The toothpaste slurry in each group was mixed with distilled water at a ratio of 3:1 and applied to the sample surfaces using a toothbrush with medium bristle hardness. The automatic toothbrush was standardized with a custom-made holder, and brushing was performed with a standard force of 2 N.

**Color and whiteness evaluation**

Color measurements were performed immediately after sample preparation, after initial staining, and on days 7, 14, and 30 of the staining-and-brushing cycle, using a dental spectrophotometer device (VITA Easyshade Advance 4.0; VITA Zahnfabrik, Bad Säckingen, Germany) calibrated and set to "tooth single" mode.

The 5-mm-diameter tip of the spectrophotometer was placed in the middle of each sample. L*, a*, and b* values were measured 3 times on both white (L* = 96.3, a* = 0.1, and b* = 1.9) and black backgrounds (L* = 8.9, a* = −0.7, and b* = 1.2). The spectrophotometer was recalibrated every 5 measurements. A customized mold compatible with the tip of the device was used to perform the measurements from the same point. Measurements were expressed using the CIELAB system. In this system, L* represents the lightness ranging from 0 (dark) to 100 (bright), a* represents the red-green chromaticity coordinate, and b* represents the yellow-blue chromaticity coordinate [13]. The chroma (C) and tone values (H) of the sample were also obtained numerically. The average L*, a*, and b* values were recorded respectively as LB*, aB*, and bB* on the white background and as LS*, aS*, and bS* on the black background. The CIEDE2000 color difference ($\Delta E_{00}$) was calculated using the formula: $\Delta E_{00}$ = (ΔL/KL. SL) + (ΔC/KC. SC)2 + (ΔH/KH. SH)2 + RT. (ΔC/KC. SC) × (ΔH/KH. SH) 0.5, where ΔL′, ΔC′, and ΔH′ are the differences in lightness, chroma, and hue between two specimens, respectively, and RT (rotation function) is a function that accounts for the interaction between the chroma and hue differences in the blue region.

In this study, the clinical thresholds for perceptibility and acceptability were 0.8 and 1.8, respectively [14]. Moreover, the degree of whiteness (WID) was quantified as follows [15]: WID = 0.55L* − 2.32a* − 1.100b*.

The difference in whiteness index between two time points (ΔWID) was calculated. The 50%:50% whiteness perceptibility (WPT) and whiteness acceptability (WAT) thresholds were 0.61 and 2.90, respectively [16].

**Statistical analysis**

Data were analyzed using IBM SPSS V23 (IBS Corp., Armonk, NY, USA). Conformance to a normal distribution was evaluated using the Shapiro-Wilk test. The Kruskal-Wallis test was used to compare the whiteness index values of the groups, and multiple comparisons were analyzed using the Dunn test. The Wilcoxon test was used to compare the whiteness index values within the groups. One-way analysis of variance was used to compare the delta whiteness index (ΔWID) values between the groups, and multiple comparisons were performed using Tamhane's $T^2$ test. The generalized linear model method was used for comparison of $\Delta E_{00}$ between the groups and time points, and multiple comparisons were performed using Tukey's honestly significant difference test. Analysis results are presented as mean ± standard deviation and median (range). The significance level was set at $P < 0.050$.

**Scanning electron microscopy analysis**

One sample from each experimental group was randomly selected for scanning electron microscopy (SEM) analysis and evaluated on day 30 of the staining-and-brushing cycle using a scanning electron microscope (Vega II, Tescan, Cambridge, England). The specimens were gold sputter-coated, and photographs of the representative areas were taken at magnifications of ×1,000, ×5,000, and ×10,000 (25 kV).

**Table 2** Descriptive statistics and multiple comparison of $\Delta E_{00}$ values by group and time

| Groups | Evaluation time | | | | Total |
|---|---|---|---|---|---|
| | $\Delta E_{00}1$ | $\Delta E_{00}2$ | $\Delta E_{00}3$ | $\Delta E_{00}4$ | |
| Curaprox White is Black | 4.64 ± 0.17A | 1.08 ± 0.13G | 1.12 ± 0.10G | 1.24 ± 0.09F | 2.02 ± 1.53d |
| Colgate Herbal | 4.65 ± 0.10A | 2.36 ± 0.08B | 2.38 ± 0.10B | 2.42 ± 0.09B | 2.95 ± 0.99a |
| Meridol | 4.64 ± 0.08A | 1.43 ± 0.16E | 1.49 ± 0.06E | 1.72 ± 0.08D | 2.32 ± 1.36c |
| Opalescence Whitening | 4.64 ± 0.02A | 2.03 ± 0.15C | 2.04 ± 0.06C | 2.08 ± 0.05C | 2.70 ± 1.14b |
| Yotuel Pharma B5 | 4.63 ± 0.11A | 0.99 ± 0.11G | 1.02 ± 0.03G | 1.06 ± 0.02G | 1.93 ± 1.58e |
| Crest Baking Soda and Peroxide | 4.65 ± 0.02A | 1.98 ± 0.13C | 2.00 ± 0.06C | 2.06 ± 0.13C | 2.67 ± 1.16b |
| Distilled water (paste-free brushing) | 4.65 ± 0.02A | 0.39 ± 0.07H | 0.41 ± 0.11H | 0.45 ± 0.05H | 1.48 ± 1.85f |
| Distilled water (no initial staining) | 0.14 ± 0.03I | 0.14 ± 0.01I | 0.14 ± 0.03I | 0.13 ± 0.03I | 0.14 ± 0.02g |

a-g: no difference between groups/times with the same letter; A-I: no difference between interactions with the same letter; mean ± *P* deflection. $\Delta E_{00}1$: ΔE staining-baseline; $\Delta E_{00}2$: ΔE 7th day of brushing-staining; $\Delta E_{00}3$: ΔE 14th day of brushing-staining; $\Delta E_{00}4$: ΔE 30th day of brushing-staining

**Table 3** Comparison of $\Delta E_{00}$ values by group and time

| Source | Fd | Sum of squares | Average of squares | *F* | *P* | Partial eta squared |
|---|---|---|---|---|---|---|
| Group | 7 | 273.305 | 39.044 | 4925.520 | <0.001 | 0.990 |
| Time | 3 | 541.016 | 180.339 | 22750.490 | <0.001 | 0.995 |
| Group*Time | 21 | 103.231 | 4.916 | 620.140 | <0.001 | 0.974 |

Fd, degrees of freedom; *F*, analysis of variance test statistic; R2 = 99.70%; adjusted R2 = 99.67%, *interaction

**Table 4** Comparison of W2 and W1 values between and within groups

| | Whiteness on day 30 of the staining and whitening cycle (W2) | | Whiteness index at baseline (W1) | | *P*** |
|---|---|---|---|---|---|
| | mean ± standard deviation | median (Q1- Q3) | mean ± standard deviation | median (Q1- Q3) | |
| Curaprox White is Black | 9.64 ± 0.09 | 9,63 (9,57-9,73)abc | 7.31 ± 0.21 | 7,29 (7,12-7,53)a | 0.002 |
| Colgate Herbal | 12.58 ± 0.29 | 12,55 (12,4-12,62)de | 7.31 ± 0.20 | 7,29 (7,15-7,48)a | 0.002 |
| Meridol | 10.74 ± 0.13 | 10,75 (10,64-10,86)abf | 7.30 ± 0.10 | 7,33 (7,22-7,37)a | 0.002 |
| Opalescence Whitening | 12.20 ± 0.08 | 12,18 (12,16-12,24)def | 7.32 ± 0.06 | 7,34 (7,28-7,38)a | 0.002 |
| Yotuel Pharma B5 | 9.33 ± 0.09 | 9,34 (9,26-9,39)ac | 7.32 ± 0.09 | 7,36 (7,27-7,38)a | 0.002 |
| Crest Baking Soda and Peroxide | 11.74 ± 0.07 | 11,77 (11,7-11,79)bdf | 7.32 ± 0.02 | 7,31 (7,31-7,33)a | 0.002 |
| Distilled water (paste-free brushing) | 8.64 ± 0.10 | 8,65 (8,58-8,7)c | 7.32 ± 0.03 | 7,31 (7,31-7,34)a | 0.002 |
| Distilled water (no initial staining) | 18.60 ± 0.15 | 18,65 (18,49-18,72)e | 18.38 ± 0.22 | 18,39 (18,22-18,55)b | 0.002 |
| *P** | | <0.001 | | <0.001 | |

*Kruskal Wallis test, **Wilcoxon test, a-f: no difference between groups with the same letter, median (Q1-Q3)

**Table 5** Comparison of ΔWID values between and within groups

| | ΔWID | | *P** |
|---|---|---|---|
| | mean ± standart deviation | median (Q1- Q3) | |
| Curaprox White is Black | 2.33 ± 0.16a | 2.24 (2.12-2.56) | |
| Colgate Herbal | 5.27 ± 0.31b | 5.28 (4.81-5.95) | |
| Meridol | 3.44 ± 0.12c | 3.46 (3.22-3.63) | |
| Opalescence Whitening | 4.87 ± 0.13d | 4.85 (4.72-5.11) | <0.001 |
| Yotuel Pharma B5 | 2.01 ± 0.13e | 2.00 (1.81-2.24) | |
| Crest Baking Soda and Peroxide | 4.42 ± 0.08f | 4.47 (4.24-4.51) | |
| Distilled water (paste-free brushing) | 1.31 ± 0.10g | 1.34 (1.09-1.45) | |
| Distilled water (no initial staining) | 0.22 ± 0.14h | 0.21 (0.02-0.52) | |

*One-way analysis of variance (Welch), a-h: no difference between groups with the same letter, median (Q1-Q3)

## Results

### Changes in color

The descriptive statistics and multiple comparisons of the $\Delta E_{00}1$ ($\Delta E_{Staining - Baseline}$), $\Delta E_{00}2$ ($\Delta E_{7th\ day\ of\ brushing\ -\ staining}$), $\Delta E_{00}3$ ($\Delta E_{14th\ day\ of\ brushing\ -\ staining}$), and $\Delta E_{00}4$ values ($\Delta E_{30th\ day\ of\ brushing\ -\ staining}$) between the groups are presented in Table 2. In addition, multiple comparisons according to group, time, and group × time interaction are shown in Table 3.

The interactions between "group," "time", and "group × time" had a significant effect on the $\Delta E_{00}$ value ($P < 0.05$; Table 3). The mean $\Delta E_{00}$ differed between the groups ($P < 0.001$). The highest $\Delta E_{00}$ value was obtained in the Colgate Herbal group, whereas the lowest value was recorded in the distilled water group. All groups except for the distilled water group showed a clinically perceptible color change ($\Delta E_{00} > 0.08$), but none of the groups except for the Colgate Herbal, Opalescence Whitening, and Crest Baking Soda and Peroxide groups had clinically unacceptable alterations ($\Delta E_{00} > 1.8$). No significant difference was evident between the Opalescence Whitening and Crest Baking Soda and Peroxide groups at any of the measurement time points ($P > 0.05$).

The mean $\Delta E_{00}$ values differed significantly between every different time points ($P < 0.001$). Although no significant difference was found between $\Delta E_{00}2$ and $\Delta E_{00}3$, a significant difference was found between $\Delta E_{00}1$ and $\Delta E_{00}4$ and the other time points. The highest color change value was obtained after initial staining, whereas the lowest mean value was obtained on day 7 of the staining-and-brushing cycle ($P < 0.05$; Table 3).

$\Delta E_{00}$ values differed significantly between the groups and time points ($P < 0.001$). The highest mean values were obtained in the Colgate Herbal, Crest Baking Soda and Peroxide, and distilled water (pasteless brushing) groups after initial staining, whereas the lowest mean values were obtained in the distilled water group on days 1, 7, and 14 of the staining-and-brushing cycle ($P < 0.05$; Table 3).

### Whiteness index

Table 4 compares the whiteness index values obtained at the baseline (W1) and on day 30 of the staining-and-whitening cycle (W2) between and within the groups, and Table 5 compares the delta whiteness index values (ΔWID) between the groups.

The baseline whiteness index values differed significantly between the groups ($P < 0.001$) owing to the higher values in the distilled water group than in the other groups. On day 30, the whiteness index values also dif-

fered significantly between the groups ($P < 0.001$). The highest median value was obtained in the distilled water only group, whereas the lowest average value was obtained in the distilled water (no paste) brushing group.

The mean ΔWID values differed significantly between the groups ($P < 0.001$) as follows: 5.27 in the Colgate Herbal group, 4.87 in the Opalescence Whitening group, 4.42 in the Crest Baking Soda and Peroxide group, 3.44 in the Meridol group, 2.33 in the Curaprox White Is Black group, 2.01 in the Yotuel Pharma B5 group, 1.31 in the distilled water (pasteless brushing) group, and 0.22 in the distilled water (without brushing and staining) group.

**Scanning electron microscopy**

Fig. 1(A–H) shows SEM photographs of the nanohybrid composite surfaces. The SEM photographs at ×2,000 and ×10,000 revealed that Colgate Herbal created the roughest surface appearance (Fig. 1A and B), whereas Yotuel Pharma B5 resulted in milder surface changes (Fig. 1C and D). Conversely, smoother surfaces were obtained in the control groups (Fig. 1E and F [pasteless brushing] and Fig. 1G and H [distilled water only]).

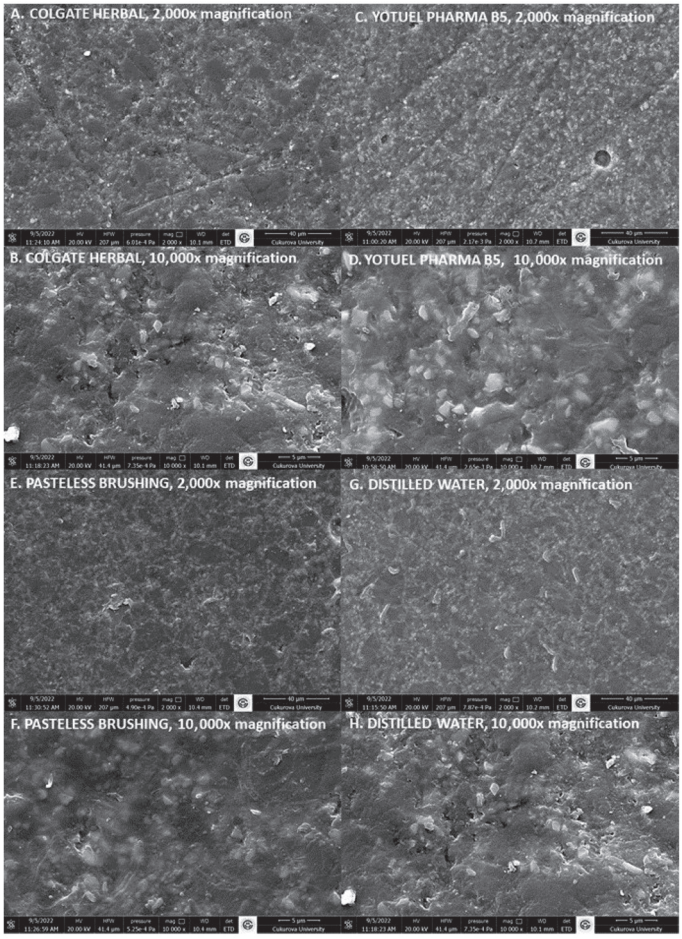


**Fig. 1** A: Colgate Herbal, ×2,000 magnification. B: Colgate Herbal, ×10,000 magnification. C: Yotuel Pharma B5, ×2,000 magnification. D: Yotuel Pharma B5, ×10,000 magnification. E: pasteless brushing, ×2,000 magnification. F: pasteless brushing, ×10,000 magnification. G: distilled water, ×2,000 magnification. H: distilled water, ×10,000 magnification

## Discussion

Today, a wide range of tooth-whitening products, including professional whitening systems and whitening toothpastes, are available to dentists and patients to meet the demand for stain removal from both teeth and composite resin restorations [17].

In this study, the effects of six whitening toothpaste brands on the color stability and whiteness of an esthetic resin composite material stained with coffee were investigated *in vitro*. During tooth brushing, toothpaste is diluted by saliva. To simulate this situation, toothpaste diluted with distilled water was used in this study [18,19].

Tooth brushing can be performed using a manual or an automatic toothbrush. Studies of brushing force applied by adults have found that the amount of force applied to toothbrush bristles ranges from 203 to 1533.3 g [20,21]. In addition, investigations of the wear of composite resins have indicated that a load ranging from 0.5 to 2.5 N should be applied in tests related to toothbrushing, in accordance with the International Organization for Standardization. Therefore, in this study, an Oral-B Genius 8000 white electric toothbrush was used by the same operator with a constant force pressure of 2 N.

Here, a coffee solution was used as the coloring agent. The low polarity yellow color pigments in coffee are absorbed by composite resins and penetrate the organic matrix, resulting in coloration [22]. It has been reported that the average time taken to consume a cup of coffee is 15 min, and that 3.2 cups are consumed per day on average [11]. For this reason, in the present study, samples were kept in 2 mL of coffee solution for 10 min to approximate this daily coffee consumption.

According to the latest guidance on color measurements published by the International Organization for Standardization, $\Delta E_{00}$ and ΔWID values should be interpreted with consideration for acceptability and perceptibility thresholds [4]. Perceptibility refers to detection of the minimum color difference by the human eye, whereas acceptability refers to the acceptance of any difference in color between a tooth and an adjacent restoration [23]. For CIEDE2000, the perceptibility threshold was set at $\Delta E_{00} > 0.8$, and the clinical acceptability threshold was set at $\Delta E_{00} \leq 1.8$ [24].

In terms of color differences and whiteness variations after the staining-and-brushing cycle in all experimental groups, Colgate Herbal yielded the most successful results, followed by Opalescence Whitening and Crest Baking and Soda Peroxide. Only in these three toothpaste groups did the observed color change exceed the clinically acceptable threshold ($\Delta E_{00} > 1.8$ and WID > 2.90) at all time points. Therefore, the study's null hypothesis was rejected.

The fact that these three toothpastes achieved a more significant color change on the composite resin may be primarily attributed to their higher RDA values in comparison with the other tested groups (Table 1). Second, the Colgate Herbal group yielded the highest color change value due to the greater cleaning effect of hydrated silica. A positive correlation has been reported between toothpaste abrasiveness and ability to reduce superficial stains [25]. Similarly to the present study, previous investigations have shown that abrasive whitening toothpastes can be effective for achieving color change after use for between 2 and 4 weeks [26,27]. However, abrasive toothpastes are known to cause dental wear. Abrasive cleaning may be further limited by the accessibility of the toothbrush to stained areas of the teeth or restorations [28].

Extrinsic staining on the surfaces of composite resin restorations can be removed using toothpastes containing certain abrasives, whereas intrinsic coloration can be removed using oxidants [29]. In the present study, the oxidant-containing Crest Baking and Soda Peroxide toothpaste was found to yield the best whitening effect. The whitening mechanism of calcium peroxide is thought to be attributable to an oxidation reaction in which colorant pigments break down. This whitening effect of peroxide is well documented [25].

In the present study, the toothpaste containing blue covarine pigment reduced color differences to below 50%:50% WAT ($\Delta E_{00}$:1.8). Blue covarine acts by changing the optical properties of the tooth through transition from the yellow to the blue axis. This overall color shift causes a difference in the perception of tooth whiteness. Blue covarine is a component of whitening toothpastes containing mechanical agents, of which hydrated silica is the abrasive most used [28]. Previous studies have shown that the blue covarine pigment is effective for whitening of teeth and composite resin restorations [30,31]. However, others have reported unsatisfactory results [29,32,33], consistent with those of the present study. Toothpastes containing blue covarine have been shown to be effective for whitening tooth surfaces [34,35]. However, this type of paste has been reported to have no significant whitening effect on composite resins [36,37].

The enzyme component of whitening toothpastes acts by breaking down organic molecules in the pellicle (biological film) layer, where external staining first begins, and removing the stained film layer [26]. A previous study has reported that toothpastes containing enzymes reduce external staining significantly more effectively than those without enzymes [38]. However, in the present study, the whitening effect of the papain-

containing toothpaste was not significantly better than those of the other whitening toothpastes. Similarly, toothpastes containing activated charcoal yielded poorer results than those containing abrasives and oxidants. This finding is consistent with a previous study [39], which showed that whitening toothpastes with hydrogen peroxide performed better with regular use than those containing activated charcoal. The whitening effect of activated charcoal is due to its mechanical abrasive activity and ability to absorb pigments and chromophores, thus removing stains from resin composite surfaces [39]. Few previous studies have investigated the color-changing effect of charcoal on resin composite surfaces with extrinsic stains.

An important limitation in this study is that evaluation parameters such as surface roughness and surface hardness were not considered in relation to the color results. Additionally, since the study was an *in vitro* study, irreproachable simulation of clinical conditions was not possible. Clinical studies are needed on this subject.

## Conflict of Interest

The authors have no conflicts of interest to declare in relation to this study.

## Authors' Contributions

Başak Yazkan conducted the primary literature search and wrote most of the manuscript. Ebru Yılmaz performed the experiment, wrote a part of the manuscript, and prepared Tables 1-5 and Fig. 1. Özge Gizem Yenidünya and Nilgün Akgül contributed to the proofreading of the manuscript. All authors reviewed the manuscript.

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