RDE Restorative Dentistry & Endodontics

Research Article

eISSN 2234-7666
Restor Dent Endod. 2025 Feb;50(1):e6
https://doi.org/10.5395/rde.2025.50.e6

Surface properties and susceptibility to staining of a resin composite after brushing with different whitening toothpastes

Aline da Silva Barros[1], **Carolina Meneghin Barbosa**[2,*], **Renata Siqueira Scatolin**[1], **Waldemir Francisco Vieira Junior**[2], **Laura Nobre Ferraz**[1]

[1]Hermínio Ometto Foundation, University of Araras, Brazil, Araras, Brazil
[2]Department of Restorative Dentistry, Piracicaba Dental School, University of Campina, Piracicaba, Brazil

ABSTRACT

Objectives: This study investigated the effects of different whitening toothpaste (WT) on the surface properties and staining susceptibility of a resin composite.
Methods: Cylindrical samples were prepared with a micro-hybrid resin composite and were randomized into groups according to the toothpaste ($n = 12$): distilled water (DW), regular toothpaste (RT), WT with silica + pyrophosphate (WT-S/P), WT with pentaphosphate and pyrophosphate (WT-P/P), WT with hydrogen peroxide and pyrophosphate (WT-HP/P) and WT with charcoal and pyrophosphate (WT-Ch/P). The samples were brushed for 825 cycles in an automatic brushing machine, simulating 30 days of brushing. After that, an immersion in coffee (10 mL/sample) was performed for 30 minutes for 30 days. The analyses of color, surface microhardness (SMH), and surface roughness (Ra) were performed at the initial time, after brushing with toothpaste and after immersion in coffee. The ΔL^*, Δa^*, Δb^*, ΔE_{ab}, $\Delta$and E_{00} values were calculated comparing after toothpaste with initial time and after coffee with after toothpaste. Data were analyzed using a mixed linear model for repeated measures (SMH), Kruskal-Wallis, Dunn, Friedman, and Nemenyi tests, with $\alpha = 0.05$.
Results: For ΔL^*, the WT-Ch/P group had the lowest values and differed from the other groups comparing the after toothpaste with the initial time interval ($p < 0.001$). The WT-Ch/P group had the lowest SMH values in after-toothpaste time ($p < 0.001$). In after-toothpaste time and after coffee time, the WT-S/P group had the highest Ra values and differed from the groups except the WT-Ch/P group ($p < 0.001$).
Conclusions: The toothpaste composition affects the surface characteristics and susceptibility to staining of the resin composite. The charcoal-based toothpaste had the worst performance for the color analyses and SMH.

Keywords: Composite resins; Staining; Surface properties; Toothpastes

Received: July 3, 2024 **Revised:** August 29, 2024 **Accepted:** November 18, 2024

Citation
Barros AS, Barbosa CM, Scatolin RS, Vieira-Junior WF, Ferraz LN. Surface properties and susceptibility to staining of a resin composite after brushing with different whitening toothpastes. Restor Dent Endod 2024;50(1):e6.

***Correspondence to**
Carolina Meneghin Barbosa, MSc
Department of Restorative Dentistry, Piracicaba Dental School, University of Campinas, Av. Limeira, 901 - Areião, Piracicaba 13414-903 SP, Brazil
Email: carolinameneghinbarbosa@gmail.com

INTRODUCTION

The desire for white teeth has led to a trend towards the increasing use of teeth whitening products [1–4]. Manufacturers of oral care products are constantly developing improvements and new approaches to tooth whitening [4]. Thus, at present, there are several types of products and technologies available, such as whitening toothpastes (WT), and these are used in an attempt to solve the problem of tooth discoloration [5,6].

WT is part of a category known as "over-the-counter" products (OTC). OTC products for teeth whitening are found on the shelves of pharmacies, supermarkets, or on the internet. These products promise tooth whitening and do not require a prescription or supervision of a dentist [7]. The majority of WT contains the same basic functional ingredients as conventional toothpaste [5,8]. The difference is the addition of a whitening agent, which can be of the abrasive, chemical, or optical type [5,8].

The abrasives added to WT act by means of mechanical removal of extrinsic pigmentations [5], and their effectiveness is related to the capacity for wear promoted by the abrasives [7]. Charcoal is considered an abrasive and may be found in WT. It has shown the ability to remove stains and deposits from teeth [9]. The most common chemical agents found in toothpastes include surfactants, enzymes, citrate, pyrophosphates, and hexametaphosphate. These components help to degrade stained biofilms, aiding their mechanical removal [5]. Furthermore, some WT contain hydrogen peroxide as the chemical agent; however, the presence of peroxides in toothpastes is less common and challenging, mainly due to aspects related to formulation [5]. Optical modifiers, such as blue covarine, mica, and titanium dioxide, act by modifying the interaction of light incident on the teeth, providing the sensation of whiter and brighter teeth [5,10,11].

WT is known to be capable of changing the surface properties of resin composite [12], such as reducing the surface microhardness (SMH) and increasing the surface roughness [13–15]. A resin composite with a rough surface is more susceptible to staining [16,17]. Moreover, the reduction in microhardness changes the properties of the resin composite making it more susceptible to degradation of its surface and resin matrix, leading to more extensive sorption and solubility, and resulting in surface staining [18,19]. Long-term color alterations in resin composite restorations occur due to superficial and marginal staining, microleakage, surface alterations, and internal deterioration of the material [20,21]. Thus, resin composite pigmentation may compromise the visual acceptability of these restorations and result in the need for their replacement [20,21].

Resin composites are highly esthetic materials, as they aim to imitate the natural characteristics of the tooth, such as color, translucency, and texture [22–24]. Thus, color stability has become one of the main requirements of restorative materials [19]. The objective of this study was not to claim that a specific type of toothpaste can prevent coffee stains, but rather to evaluate the surface properties and staining of a resin composite that had its surface altered by the use of different WT. The use of WT has increased every day and their effects on resin composite are well established in the literature. However, there is no investigation of how this altered surface behaves when exposed to coffee. Furthermore, although there are manuscripts that evaluate the impacts of brushing with toothpastes on resin materials, there is a lack of studies that evaluate the toothpaste of the same manufacturer with different active ingredients. The toothpastes evaluated in this study are available to patients as part of a single product line from a specific manufacturer. It is important to understand how these different types of products offered directly to patients may affect the resin composites.

Thus, the aim of this *in vitro* study was to investigate the effects of WT containing different whitening agents on susceptibility to staining and surface characteristics of a resin composite by means of color analysis, SMH, and roughness. The null hypotheses tested in this study were: (1) the use of WT with different whitening agents would not interfere with SMH, (2) surface roughness, and (3) color variables/susceptibility to staining of a micro-hybrid resin composite.

METHODS

Experimental design

This *in vitro* study had as experimental units resin com-

https://doi.org/10.5395/rde.2025.50.e6

posite specimens that were subjected to treatment with different toothpaste. Toothpaste varied their whitening agent (six levels): distilled water (DW), regular toothpaste (RT) (Colgate Total 12 Clean Mint; Colgate-Palmolive Company, São Bernardo do Campo, Brazil), WT with silica + pyrophosphate (WT-S/P) (Colgate Luminous White Brilliant; Colgate-Palmolive Company), WT with pentaphosphate and pyrophosphate (WT-P/P) (Colgate Luminous White Instant; Colgate-Palmolive Company), WT with hydrogen peroxide and pyrophosphate (WT-HP/P) (Colgate Luminous White Expert; Colgate-Palmolive Company), and WT with charcoal and pyrophosphate (WT-Ch/P) (Colgate Luminous White Carvão Ativado, Colgate-Palmolive Company). The detailed composition of the toothpaste is available in Table 1. The components of toothpastes and their derivatives are categorized in Table 1 according to the studies of Joiner [5] and Freitas *et al.* [25]. Time was the other factor under study for the analysis of surface roughness and SMH (initial, after brushing with toothpaste, and after immersion in coffee). The analyses performed were SMH, surface roughness (Ra), and color (ΔL^*, Δa^*, Δb^*, ΔE_{ab}, and ΔE_{00}).

Sample preparation

Cylindrical samples (*n* = 120) of Filtek Z250 micro-hybrid resin composite [12] (3M ESPE, St. Paul, MN, USA), color B1, were made. Of these 120 samples, 60 had 7.00 mm in diameter and 2.00 mm in thickness and were used to carry out the color and roughness analyses, and another 60 samples of 3.00 mm in diameter and 2.00 mm in height were used exclusively for SMH analyses. Twenty extra samples were prepared (10 with 7.00-mm diameter and 10 with 3.00-mm diameter), one of each diameter for each group as a precaution in case of accidental loss of a sample. At the end of the experiment, no samples were lost in any of the stages performed, so the data from the extra samples were disregarded. Samples were made by inserting an increment of resin composite into the polytetrafluoroethylene matrix. After inserting the resin composite, the increment was covered with a polyester strip and a glass slide under a weight of 500 g for 30 seconds. The samples were photoactivated for 20 seconds, as recommended by the manufacturer, with a diode emitting light (Valo Ultradent Products Inc., South Jordan, UT, USA) at standard power (1,000 mW/cm^2). After 24 hours the polishing process was carried out using a polishing machine (model APL 4; Arotec, Cotia, Brazil) for 1 minute with silicon carbide sanding discs (600, 1,200, and P4000 - Buehler Ltd., Lake Bluff, IL, USA). Felt disks (TCT, TWI; Arotec) associated with diamond pastes (3 1/2 µm and 1/4 µm) were used to finalize the polishing process. The surfaces of the samples were protected with colorless acid-resistant varnish so that only the surface that was polished was exposed for the treatments. In this way, the treatments were limited to only one surface of the resin composite, getting closer to the condition found in the oral environment. The samples were randomized into groups of 12 (*n* = 12). Sample size calculation, based on a previous study [12], indicated that six samples per group would yield an 80% power ($\beta = 0.8$), at $\alpha = 0.01$. To avoid possible losses and to follow previous studies in the field, the sample was doubled (*n* = 12 per group). After that, each sample group was randomized to the experimental groups. All randomizations performed in this study were performed by a person without any participation in the experiment.

Brushing with toothpaste

The samples were submitted to simulated brushing using toothbrush heads (Oral-B Indicator 40 Soft, Gillette do Brasil Ltda., Manaus, Brazil) coupled with an automatic brushing machine (Equilabor, Piracicaba, Brazil). The brush head was attached parallel to the sample surface. The samples were brushed with toothpaste slurry (proportion of 1 g:3 mL) according to the group, using a static axial load of 200 g and a speed of 5 movements/sec, at 37°C [26]. One month of brushing was simulated with 825 cycles [27]. After brushing, the samples were washed with DW for 10 seconds to remove toothpaste residues on the surface and stored in relative humidity.

Immersion in coffee

Coffee was prepared in the proportion of 50 mL of hot water and 7 g of soluble coffee (Nescafé Original; Nestlé, Araras, Brazil). The samples were immersed in 10 mL of coffee per sample for 30 minutes daily, simulating the contact of coffee with the tooth structure for one day of consumption [28,29]. After immersion, the samples

Table 1. Composition of toothpaste used in this study according to the manufacturers' information

Product	Manufacturer	Composition	Category
Colgate Total 12 Clean Mint	Colgate - Palmolive Industrial LTDA, São Bernardo do Campo, SP, Brazil	Active ingredients: sodium fluoride 0.32%, zinc citrate, zinc oxide Ingredients: glycerin, water, hydrated silica, sodium lauryl sulfate, arginine, aroma, cellulose gum, zinc oxide, poloxamer 407, tetrasodium pyrophosphate, zinc citrate, benzyl alcohol, xanthan gum, cocamidopropyl betaine, sodium fluoride, sodium saccharin, phosphoric acid, sucralose, Cl 77891 Contains sodium fluoride (1,450 ppm fluoride) Whitening agents: - Abrasives: hydrated silica - Chemical: tetrasodium pyrophosphate	Regular toothpaste (RT)
Colgate Luminous White Brilliant	Colgate - Palmolive Industrial LTDA, São Bernardo do Campo, SP, Brazil	Active ingredient: 0.32% sodium fluoride Ingredients: water, sorbitol, hydrated silica, PEG-12, sodium lauryl sulfate, aroma, cellulose gum, potassium hydroxide, tetrasodium pyrophosphate, phosphoric acid, cocamidopropyl betaine, sodium fluoride, benzyl alcohol, sodium saccharin, Cl 77891, limonene Contains sodium fluoride (1,450-ppm fluoride) Whitening agents: - Abrasives: hydrated silica - Chemical: tetrasodium pyrophosphate	Whitening toothpaste (WT-SP)
Colgate Luminous White Instant	Colgate - Palmolive Industrial LTDA, São Bernardo do Campo, SP, Brazil	Active ingredient: 0.243% sodium fluoride Ingredients: water, sorbitol, hydrated silica, sorbitol, glycerin, PEG-12, pentasodium triphosphate, tetrapotassium pyrophosphate, sodium lauryl sulfate, aroma, cellulose gum, cocamidopropyl betaine, sodium saccharin, xanthan gum, sodium fluoride, sodium hydroxide, hydroxypropyl methylcellulose, propylene glycol, polysorbate 80, mica, Cl 74160, Cl 77891, Cl 73360, Cl 17200, Cl 42051, eugenol Contains sodium fluoride (1,100 ppm fluoride). Whitening agents: - Abrasives: hydrated silica - Chemical: pentasodium triphosphate, tetrapotassium pyrophosphate - Others: mica	Whitening toothpaste (WT-PP)
Colgate Luminous White Expert	Colgate - Palmolive Industrial LTDA, São Bernardo do Campo, SP, Brazil	Active ingredients: hydrogen peroxide 2%, sodium monofluorophosphate 0.76% Ingredients: propylene glycol, calcium pyrophosphate, PVP-hydrogen peroxide, PEG/ PPG-116/ copolymer 66, PEG-12, glycerin, aroma, sodium lauryl sulfate, silica, PVP, tetrasodium pyrophosphate, sodium saccharin, sodium monofluorophosphate, disodium pyrophosphate, sucralose, BHT, eugenol Contains sodium monofluorophosphate (1,000-ppm fluoride). Whitening agents: - Abrasives: silica, calcium pyrophosphate - Bleaching: hydrogen peroxide - Chemical: tetrasodium pyrophosphate, disodium pyrophosphate	Whitening toothpaste (WT-HP/P)
Colgate Luminous White Carvão ativado	Colgate - Palmolive Industrial LTDA, São Bernardo do Campo, SP, Brazil	1,000-ppm sodium monofluorophosphate, water, sorbitol, hydrated silica, PEG-12, sodium lauryl sulfate, aroma, cellulose gum, potassium hydroxide, tetrasodium pyrophosphate, phosphoric acid, cocamidopropyl betaine, sodium fluoride, sodium saccharin, benzyl alcohol, charcoal powder, limonene Contains sodium fluoride (1,450-ppm fluoride). Whitening agents: - Abrasives: hydrated silica, calcium pyrophosphate - Chemical: pentasodium triphosphate, tetrapotassium pyrophosphate - Others: Cl 77266 (powdered charcoal)	Whitening toothpaste (WT-Ch/P)

These toothpastes were chosen based on the different whitening agents of the same commercial brand. The classification of whitening agents was made following the work of Joiner [5] and Feitas *et al*. [25]. An important observation is that mica and titanium dioxide can be considered whitening agents depending on the quantity. Thus, mica would be an abrasive agent and titanium dioxide would be an abrasive or optical agent. Despite this, mica and titanium dioxide are often just dyes and the quantity of these components in the toothpastes used in this study is unknown, thus making it difficult to classify these components (Vilhena *et al*. [11]).
BHT, butylated hydroxy toluene; PEG, polyethylene glycol; PPG, polypropylene glycol; PVP, polyvinylpyrrolidone.

https://doi.org/10.5395/rde.2025.50.e6

were washed in DW for 10 seconds. This protocol was repeated for 30 days.

Surface microhardness

SMH analysis was performed at the initial time, after toothpaste, and after coffee. A Knoop indenter was used with a load of 25 g and time of 5 seconds in a microdurometer (HMV-2000; Shimadzu, Tokyo, Japan). Five indentations were made in each sample, with a distance of 100 µm, and the average was calculated to determine the Knoop hardness number.

Surface roughness (Ra)

Ra analyses was performed at the initial time, after toothpaste, and after coffee. Roughness was measured using a profilometer (Surf-Corder 1700; Kosaka, Tokyo, Japan). Three different equidistant directions were measured on the surface of each sample, with a cutoff point of 0.25, a reading length of 1.25 mm, and a velocity of 0.1 mm/sec. The average of the values obtained was calculated and one Ra value per sample was considered.

Color analyses (ΔL^*, Δa^*, Δb^*, ΔE^*_{ab}, and ΔE_{00})

Color analyses was performed at the initial time, after toothpaste, and after coffee. The samples were placed on a white background (sample holder) inside a light booth (GTI mini matcher MM1e; GTI Graphic Technology, Newburgh, NY, USA) to standardize the ambient light during the measurement process. The samples were subjected to color reading using a spectrophotometer (Konica Minolta CM-700d spectrophotometer; Konica Minolta Investment, Shanghai, China) calibrated according to the manufacturer's instructions. The values obtained were quantified in L*, a*, and b* according to the CIE L*a*b* system. The calculation of ΔL^*, Δa^*, and Δb^* was performed. The overall color change was measured by calculating the ΔE_{ab} using the following formula: $\Delta E_{ab} = ([L_1 - L_0]^2 + [a_1 - a_0]^2 + [b_1 - b_0]^2)^{1/2}$. ΔE_{00} was calculated using the following formula:

$$\Delta E_{00} = \left[(\frac{\Delta L'}{K_L S_L})^2 + (\frac{\Delta C'}{K_C S_C})^2 + (\frac{\Delta H'}{K_H S_H})^2 + R_T(\frac{\Delta C'}{K_C S_C})(\frac{\Delta H'}{K_H S_H})\right]^{1/2}$$

All color analysis parameters were calculated by comparing after toothpaste with the initial time (impact of toothpaste) and after coffee after toothpaste (impact of staining on the brushed sample).

Statistical analyses

Descriptive and exploratory data analyses were performed. A mixed linear model for repeated measurements over time was then applied for SMH. The Ra and color data did not meet the assumptions of parametric analysis and so were analyzed by nonparametric tests. For comparisons between groups, the nonparametric tests of Kruskal-Wallis and Dunn were used, and for the comparisons of Ra between times, the nonparametric tests of Friedman and Nemenyi were used. Analyses were performed using the R program [30] with a significance level of 5%.

RESULTS

Surface microhardness

The results of the SMH analysis are shown in Table 2. When the time intervals for the same group were compared, the WT-S/P, WT-P/P, and WT-HP/P groups showed lower values after toothpaste use, compared with the initial time. For the other groups, no statistically significant differences were found when the time after toothpaste use was compared with the initial time. When the time after coffee use was compared with the time after toothpaste use, it was possible to observe that all groups showed statistically significant differences, with lower values in the time after coffee use compared with the time after toothpaste use.

When the groups were compared at the same time of analysis, no statistically significant differences were found between the groups at the initial time and after the coffee time. After the toothpaste time, the WT-Ch/P group had the lowest values and differed statistically from all other groups.

Surface roughness (Ra)

The results of the surface roughness tests are available in Table 3. When the times for the same group were compared, all groups showed statistically significant differences between these times. Lower values were observed in the time after toothpaste use compared with the initial time, irrespective of the toothpaste and lower

Table 2. Surface microhardness as a function of group and time

Group	Time		
	Initial	After toothpaste	After coffee
DW	90.37 ± 4.41 Aa	86.99 ± 5.21 Aa	75.41± 3.49 Ba
RT	91.13 ± 3.91 Aa	86.96 ± 5.04 Aa	72.95 ± 3.59 Ba
WT-S/P	91.34 ± 4.17 Aa	81.87 ± 3.26 Ba	75.27 ± 5.01 Ca
WT-P/P	90.53 ± 3.86 Aa	84.81 ± 4.80 Aa	76.58 ± 2.26 Ba
WT-HP/P	92.40 ± 4.30 Aa	81.83 ± 7.09 Ba	74.97 ± 2.81 Ca
WT-Ch/P	90.40 ± 2.94 Aa	70.92 ± 5.40 Bb	75.06 ± 2.12 Ba

Values are presented as mean ± standard deviation.
DW, distilled water; RT, regular toothpaste; WT-Ch/P, whitening toothpaste with charcoal and pyrophosphate; WT-HP/P, whitening toothpaste with hydrogen peroxide and pyrophosphate; WT-P/P, whitening toothpaste with pentaphosphate and pyrophosphate; WT-S/P, whitening toothpaste with silica and pyrophosphate.
Distinct letters (uppercase horizontally and lowercase vertically) indicate statistically significant differences ($p \leq 0.05$).
p (group) < 0.0001; p (time) < 0.0001; p (interaction) < 0.0001.

Table 3. Surface roughness (Ra) as a function of group and time

Group	Time			*p*-value
	Initial	After toothpaste	After coffee	
DW	0.23 ± 0.01 Ca	0.26 ± 0.00 Bd	0.30 ± 0.01 Ad	<0.0001
RT	0.23 ± 0.01 Ca	0.33 ± 0.01 Bdc	0.39 ± 0.01 Abc	<0.0001
WT-S/P	0.23 ± 0.01 Ca	0.50 ± 0.00 Ba	0.53 ± 0.01 Aa	<0.0001
WT-P/P	0.23 ± 0.01 Ca	0.29 ± 0.01 Bcd	0.34 ± 0.01 Acd	<0.0001
WT-HP/P	0.23 ± 0.01 Ca	0.35 ± 0.01 Bbc	0.40 ± 0.01 Abc	<0.0001
WT-Ch/P	0.23 ± 0.01 Ca	0.48 ± 0.01 Bab	0.53 ± 0.01 Aab	<0.0001

Values are presented as mean ± standard deviation.
DW, distilled water; RT, regular toothpaste; WT-Ch/P, whitening toothpaste with charcoal and pyrophosphate; WT-HP/P, whitening toothpaste with hydrogen peroxide and pyrophosphate; WT-P/P, whitening toothpaste with pentaphosphate and pyrophosphate; WT-S/P, whitening toothpaste with silica and pyrophosphate.
Distinct letters (uppercase horizontally and lowercase vertically) indicate statistically significant differences ($p \leq 0.05$).

values in the time after coffee compared with the after toothpaste time for all groups.

When the groups were compared at the same time, no statistically significant differences in the initial time were found. At the time after toothpaste use and after coffee time, the same results were observed between groups. The DW group had the lowest values and differed from all other groups brushed with toothpastes. The WT-S/P group had the highest roughness values and did not differ statistically from the WT-Ch/P group. The WT-HP/P group and the RT group showed intermediate roughness values and did not differ from each other and did not differ from the WT-Ch/P. The WT-P/P group had the lowest values among the toothpastes evaluated and did not differ from the RT group and from the WT-HP/P.

Color analyses (ΔL^*, Δa^*, Δb^*, ΔE^*_{ab}, and ΔE_{00})

The Δa and Δb analyses did not provide relevant results.

The ΔL^* results are shown in Table 4. The WT-Ch/P group had the lowest values and differed from all other groups in the time interval *after toothpaste–initial time*. In the time interval *after coffee–after toothpaste*, all groups that were brushed with toothpaste did not differ from the DW group, irrespective of the active principle.

For ΔE^*_{ab} (Table 5) in the time interval *after toothpaste–initial*, the WT-S/P group had the lowest values and differed from the DW group and the RT group but did not differ from the other groups brushed with WT. In the time interval *after coffee–after toothpaste*, the WT-Ch/P group had the highest values and differed from all other evaluated groups.

For ΔE_{00} (Table 6), the WT-S/P group presented the lowest values and differed from the DW group but did

https://doi.org/10.5395/rde.2025.50.e6

Table 4. of variation in color (ΔL*) according to time interval

Group	Time interval	
	After toothpaste–initial time	After coffee–after toothpaste
DW	0.24 (0.03 to 0.42) [ab]	–1.69 (–2.05 to –1.25) [ab]
RT	0.42 (–0.60 to 0.85) [a]	–1.48 (–2.07 to –0.19) [a]
WT-S/P	0.17 (–0.15 to 0.30) [abc]	–1.52 (–1.79 to –1.29) [a]
WT-P/P	0.10 (–0.41 to 0.35) [bc]	–1.51 (–3.77 to 0.62) [a]
WT-HP/P	0.01 (–0.63 to 0.26) [bc]	–1.71 (–2.33 to –1.26) [ab]
WT-Ch/P	0.02 (–0.38 to 0.15) [c]	–2.12 (–2.88 to –1.90) [b]
p-value	<0.0001	<0.0001

Values are presented as median (range).
DW, distilled water; RT, regular toothpaste; WT-Ch/P, whitening toothpaste with charcoal and pyrophosphate; WT-HP/P, whitening toothpaste with hydrogen peroxide and pyrophosphate; WT-P/P, whitening toothpaste with pentaphosphate and pyrophosphate; WT-S/P, whitening toothpaste with silica and pyrophosphate.
Different vertical letters indicate statistically significant differences ($p \leq 0.05$).

Table 5. Variation in color (ΔE_{ab}*) according to time interval

Group	Time interval	
	After toothpaste–initial time	After coffee–after toothpaste
DW	0.48 (0.38–0.76) [a]	2.03 (1.64–2.37) [b]
RT	0.67 (0.31–1.91) [a]	1.91 (1.36–2.46) [b]
WT-S/P	0.28 (0.17–0.60) [b]	1.95 (1.69–2.19) [b]
WT-P/P	0.41 (0.21–1.16) [ab]	1.83 (1.26–4.08) [b]
WT-HP/P	0.36 (0.22–1.14) [ab]	2.12 (1.59–3.07) [b]
WT-Ch/P	0.45 (0.29–0.60) [ab]	2.52 (2.27–3.28) [a]
p-value	0.0003	0.0003

Values are presented as median (range).
DW, distilled water; RT, regular toothpaste; WT-Ch/P, whitening toothpaste with charcoal and pyrophosphate; WT-HP/P, whitening toothpaste with hydrogen peroxide and pyrophosphate; WT-P/P, whitening toothpaste with pentaphosphate and pyrophosphate; WT-S/P, whitening toothpaste with silica and pyrophosphate.
Different vertical letters indicate statistically significant differences ($p \leq 0.05$).

not differ from the other groups brushed with WT in the time interval *after toothpaste–initial*. In addition, the WT-P/P group and the WT-HP/P group differed from the DW group but did not differ from the RT group or from the other groups of WT. In the time interval *after coffee–after toothpaste*, the WT-Ch/P group had the highest values and statistically differed from all other evaluated groups.

DISCUSSION

This study evaluated the action of WT containing different active agents on surface characteristics and susceptibility to staining of a micro-hybrid resin composite. The first and second null hypotheses tested in this study were rejected because the WT interfered with both the SMH and surface roughness of the micro-hybrid resin composite, promoting alterations in different intensities, which varied according to the active agent of the toothpaste used. The third null hypothesis tested in this study was also rejected because, depending on the toothpaste used and the time interval, the WT was able to interfere with the parameters evaluated in the color analysis. The use of WT was capable of promoting changes in surface characteristics and favored the staining of a micro-hybrid resin composite.

Table 6. Variation in color (ΔE_{00}) according to time interval

Group	Time interval	
	After toothpaste–initial time	After coffee–after toothpaste
DW	0.57 (0.46–0.83) [a]	1.84 (1.48–2.04) [b]
RT	0.51 (0.27–1.34) [ab]	1.80 (1.53–2.26) [b]
WT-S/P	0.25 (0.17–0.42) [c]	1.84 (1.61–2.03) [b]
WT-P/P	0.30 (0.15–0.94) [bc]	1.79 (1.49–3.02) [b]
WT-HP/P	0.37 (0.23–1.11) [bc]	1.90 (1.44–2.51) [b]
WT-Ch/P	0.37 (0.32–0.65) [abc]	2.23 (2.07–2.80) [a]
p-value	<0.0001	<0.0001

Values are presented as median (range).
DW, distilled water; RT, regular toothpaste; WT-Ch/P, whitening toothpaste with charcoal and pyrophosphate; WT-HP/P, whitening toothpaste with hydrogen peroxide and pyrophosphate; WT-P/P, whitening toothpaste with pentaphosphate and pyrophosphate; WT-S/P, whitening toothpaste with silica and pyrophosphate.
Different vertical letters indicate statistically significant differences ($p \leq 0.05$).

In the SMH analysis, the WT-Ch/P group not only showed statistically significant differences when the initial time and after toothpaste time were compared, but was also the only group in after toothpaste time that differed from the DW group and from all other groups evaluated, and showed the lowest values. This result may be associated with the action of charcoal. Charcoal is obtained as a residue when carbonaceous material is partially burned, or heated and is characterized by its high capacity for adsorption due to its high porosity [31]. Charcoal is used as an adsorbent in several areas such as medicine to aid in detoxification. In the industrial environment, it is used for the adsorption of gases and liquids and has been increasingly used, particularly in water treatment [31,32]. Charcoal is still present in some toothpaste and acts as an abrasive component, as it has a very high capacity for adsorbing pigments, chromophores, and extrinsic stains by means of dental abrasion [33]. Studies have shown that the action of charcoal on the resin composite surface is associated with the characteristics of its particles [34]. The shape, structure, and size of charcoal particles define its abrasiveness, ie, the larger the particle size, the more abrasive this component will be [34]. The study showed that toothpastes containing charcoal have irregular abrasive particles, which enhances their abrasive effect [34]. In this study, in addition to changing the SMH, the toothpaste containing charcoal also resulted in a statistically significant increase in surface roughness at the after toothpaste time, in agreement with several studies in the literature [15,35]. The literature reports that insufficient clinical and laboratory data to substantiate the safety and efficacy claims of charcoal and charcoal-based toothpastes [36].

In addition to the action of charcoal, the action of the brush bristles together with the brushing force is associated with increased roughness and decreased microhardness of the composite [37–39]. Since the resin composite is more conducive to mechanical fatigue, charcoal enhances the wear and weakening of the material, leading to cracks and ruptures [40]. This fact would also explain the increase in surface roughness after toothpaste time. This was observed in all groups evaluated irrespective of the toothpaste used, including the DW group. The abrasion caused by the toothbrush bristles is capable of wearing down the organic portion of the resin composite, forming spaces and consequently increasing the surface roughness [41]. This result is in agreement with other studies that also demonstrated an increase in surface roughness of the resin composite due to the action of the brush bristles [42,43]. When the roughness values between the groups at the after toothpaste time were compared, it was possible to observe that despite having increased roughness, the DW group was the one that showed the lowest values when compared with the groups that used toothpaste. Moreover, in these groups the increase in roughness in comparison with the initial values and those after brushing varied according to the active agent of the toothpaste used.

The brushing with WT with silica + pyrophosphate and WT with charcoal and pyrophosphate resulted in the highest increase in roughness values among the toothpaste evaluated. Studies have shown that hydrated silica was a highly effective abrasive and that it showed a higher increase in roughness values when associated with other abrasives [44–46], which was titanium dioxide, in the case of this group.

The WT-P/P group, despite showing an increase in surface roughness when the initial time and the after toothpaste time were compared, was the only type that did not differ from the DW group in the after toothpaste time. The mica and titanium dioxide can be considered whitening agents depending on the quantity [11]. Thus, mica would be an abrasive agent and titanium dioxide would be an abrasive or optical agent. Despite this, mica and titanium dioxide are often just dyes and the quantity of these components in the toothpastes used in this study is unknown, thus making it difficult to classify these components [11]. Based on the results found, it is assumed that the quantity of these components present in the toothpaste may have been sufficient to increase roughness but not for this increase to be of the same magnitude as that found in the other WT evaluated, thus justifying the results found.

The WT-HP/P group contains calcium pyrophosphate, silica, tetrasodium pyrophosphate, disodium pyrophosphate, and 2% hydrogen peroxide in their composition. According to a study, 2% hydrogen peroxide can cause an increase in the roughness of the resin composite, as it has the ability to release free radicals due to its high oxidation and reduction capacity [47]. This phenomenon acts by degrading the resin matrix and breaking the polymer chains of the resin composite [47], resulting in changes in their properties such as increased roughness and decreased microhardness [47–50]. Nevertheless, for the SMH analysis in this group, no statistically significant differences were found with the DW group. Furthermore, for the surface roughness analysis, this group did not show the highest values despite having differed from the DW and conventional toothpaste groups. This result may be associated with the fact that the toothpaste remained in contact with the resin composite surface for a short time, which reduced the adverse effects of the bleaching agent. Studies reported that the main factor related to the degradation of the resin composite

https://doi.org/10.5395/rde.2025.50.e6

surface is the time of exposure to the bleaching agent and not the concentration of this agent [51–53].

The RT group showed the least change in its properties. This is a common toothpaste without any addition of abrasive agents other than the abrasive common to non-WT [54]. In 2003, a study observed that non-WT showed a smaller increase in roughness compared with WT [52]. This can be explained by the size and shape of their abrasives, since the smaller the abrasive particles and the more regular their shape, the less wear of the resin composite structure [55].

After immersion in coffee, all groups were observed to have an increase in roughness and a decrease in SMH, irrespective of the values shown after brushing. This result may be associated with the pH of the coffee. Coffee has an acidic pH (pH 5.0) [38]. Acidity can have an effect on the resin matrix, thus promoting the displacement of filler particles, and generating alterations on the resin composite surface [38]. Furthermore, coffee is composed of water and coffee powder and the effect of water absorption can lead to degradation of polymeric materials [56]. The particles detach from the outer surface of the material, resulting in an increase in surface roughness [38,57]. These results were in agreement with other studies [56,58], which showed that coffee was able to alter the microhardness and surface roughness of the resin composite.

Relative to the resin composite susceptibility to staining, after the color analysis, statistically significant differences were found for the WT-Ch/P group in some of the parameters evaluated. When the initial time interval and that after toothpaste use were compared for ΔL^*, it was the only group that differed from the control group, showing a decrease in values, that is, its color was closer to black. This result may have been associated with the dark color of charcoal. Recent studies have concluded that charcoal-based toothpaste resulted in a more significant color change than that produced by conventional toothpaste. The organic matrix of resin composite restorative materials absorbs water, consequently, they are more prone to the penetration of coloring agents [59]. This result was in agreement with the studies [60] that proved that all charcoal-based toothpastes caused stains on resin composite restorations. Furthermore, in the composition of charcoal, there is pure, highly porous carbon, plus abrasives, detergents, therapeutic agents, and charcoal microparticles [34]. These components promote an increase in the porosity of the resin which becomes rough so that it can easily retain the charcoal pigments [9].

When the time interval after toothpaste use and time interval after coffee use were compared in the color analyses, the WT-Ch/P group showed higher ΔE_{00} and ΔE^*_{ab} values than the other groups; nevertheless, the values were statistically similar or lower than those for the control group and lower than that 4.2 units [61] or 3.3 units [62] that are the suggested default values for clinical acceptability of color differences. All other groups did not differ from the control group and also presented values lower than 4.2 and 3.3 units. Comparing the initial time and after toothpaste time interval, only the WT-S/P group differed from the DW group; however, it presented the lowest values than the other groups and lower than the clinical acceptability values.

This study was limited by the use of only one type of resin composite in the preparation of the samples. Furthermore, although the relationship between relative dentin abrasivity and the abrasive potential of toothpastes on restorative materials is controversial [63–65], it would be interesting to evaluate the abrasiveness of the tested toothpastes and see if it correlates with the results found in this study. In order to conduct new studies, it would be interesting to use different brands and types of resin composite, associating the carrying out of the staining protocol at other times, in addition to the use of other methodologies such as performing three-dimensional profilometry.

CONCLUSIONS

This study made it possible to conclude that the use of WT interferes with the SMH, surface roughness, and susceptibility to staining of the resin composite according to their composition. Furthermore, charcoal toothpaste was the WT that most reduced microhardness, influenced the increase in surface roughness, and interfered with the susceptibility to staining of a micro-hybrid resin composite. Clinically, the use of toothpaste impacts the properties of the resin composite and can even enhance or increase staining. These effects are greater in activated charcoal.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING/SUPPORT

This study was financed by the Foundation for Research Support of the State of São Paulo (FAPESP), process 2021/02969-5.

ACKNOWLEDGMENTS

We express our gratitude to Hermínio Ometto Foundation, University of Araras, Brazil and Piracicaba Dental School, University of Campinas, Brazil for all the support offered for this study.

AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Project administration: Barros AS, Barbosa CM, Ferraz LN. Formal analysis, Investigation, Methodology, Software, Validation, Visualization: all authors. Funding acquisition: Barros AS. Resources, Supervision: Barros AS, Barbosa CM. Writing - original draft: Barros AS, Barbosa CM, Ferraz LN. Writing - review & editing: all authors. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

REFERENCES

1. White DJ. Development of an improved whitening dentifrice based upon "stain-specific soft silica" technology. J Clin Dent 2001;12:25-29.
2. Pickles MJ, Evans M, Philpotts CJ, Joiner A, Lynch RJ, Noel N, *et al*. In vitro efficacy of a whitening toothpaste containing calcium carbonate and perlite. Int Dent J 2005;55(3 Suppl 1):197-202.
3. Dos Santos A, da Silva Miranda A, de Oliveira IL, da Silva Barbosa J, Leite JV, Lima RB, *et al*. Efetividade da ação clareadora dos dentifrícios no clareamento dental: uma revisão integrativa. Arquivos em Odontologia 2023;59:30-38.
4. Paixão AGP, Lucas RA, de Souza GC. Conceitos modernos para o clareamento dental: uma revisão narrativa da literatura. Braz J Dev 2023;9:2913-2929.
5. Joiner A. Whitening toothpastes: a review of the literature. J Dent 2010;38 Suppl 2:e17-e24.
6. Siqueira J, Galafassi D. Use of whitening dentifrices in dentistry: a literature review. Arch Health Invest 2022;11:373-378.
7. Karadas M, Duymus ZY. In vitro evaluation of the efficacy of different over-the-counter products on tooth whitening. Braz Dent J 2015;26:373-377.
8. Bispo LO, Neto FV, Lima PM, Carvalho ES, Vieira IM, Soares AF. Effectiveness of whitening toothpastes: a review of the literature. Res Soc Dev 2024;13:e4613345262.
9. Greenwall LH, Greenwall-Cohen J, Wilson NH. Charcoal-containing dentifrices. Br Dent J 2019;226:697-700.
10. Vaz VT, Jubilato DP, Oliveira MR, Bortolatto JF, Floros MC, Dantas AA, *et al*. Whitening toothpaste containing activated charcoal, blue covarine, hydrogen peroxide or microbeads: which one is the most effective? J Appl Oral Sci 2019;27:e20180051.
11. Vilhena FV, Frederico de Oliveira Graeff C, Svizero ND, D'Alpino PH. Effectiveness of experimental whitening toothpastes containing colorants on the optical properties of enamel. ScientificWorldJournal 2022;2022:4576912.
12. Barbosa CM, Scatolin RS, Vieira-Junior WF, Tanaka MH, Ferraz LN. Impact of combined at-home bleaching and whitening toothpaste use on the surface and color of a composite resin. Restor Dent Endod 2023;48:e26.
13. Khamverdi Z, Kasraie Sh, Rezaei-Soufi L, Jebeli S. Comparison of the effects of two whitening toothpastes on microhardness of the enamel and a microhybride composite resin: an in vitro study. J Dent (Tehran) 2010;7:139-145.
14. Nainan MT, Balan AK, Sharma R, Thomas SS, Deveerappa SB. The comparison of the effects of different whitening toothpastes on the micro hardness of a nano hybrid composite resin. J Conserv Dent 2014;17:550-554.
15. Dos Santos JH, Silva NL, Gomes MG, Paschoal MA, Gomes IA. Whitening toothpastes effect on nanoparticle resin composite roughness after a brushing challenge: an in vitro study. J Clin Exp Dent 2019;11:e334-e339.
16. Heintze SD, Forjanic M. Surface roughness of different dental materials before and after simulated toothbrushing in vitro. Oper Dent 2005;30:617-626.
17. Lorenz K, Noack B, Herrmann N, Hoffmann T. Tooth staining potential of experimental amine fluoride/stannous fluoride mouth rinse formulations: a randomized crossover forced staining study. Clin Oral Investig 2015;19:1039-1045.
18. Okte Z, Villalta P, García-Godoy F, Lu H, Powers JM. Surface hardness of resin composites after staining and bleaching. Oper Dent 2006;31:623-628.
19. Soares-Geraldo D, Scaramucci T, Steagall W, Braga SR, So-

https://doi.org/10.5395/rde.2025.50.e6

bral MA. Interaction between staining and degradation of a composite resin in contact with colored foods. Braz Oral Res 2011;25:369-375.
20. Buchalla W, Attin T, Hilgers RD, Hellwig E. The effect of water storage and light exposure on the color and translucency of a hybrid and a microfilled composite. J Prosthet Dent 2002;87:264-270.
21. Shah YR, Shiraguppi VL, Deosarkar BA, Shelke UR. Long-term survival and reasons for failure in direct anterior composite restorations: a systematic review. J Conserv Dent 2021;24:415-420.
22. Ferracane JL. Resin composite: state of the art. Dent Mater 2011;27:29-38.
23. Vargas MA, Margeas R. A systematic approach to contouring and polishing anterior resin composite restorations: a checklist manifesto. J Esthet Restor Dent 2021;33:20-26.
24. Rosin M, Froehlich L, Mazur N, Bervian RK, Santana SC, Piana EA, *et al*. Composite resins: a literature review. Res Soc Dev 2022;11:e257111335128.
25. de Freitas MR, de Carvalho MM, Liporoni PC, Fort AC, Moura RM, Zanatta RF. Effectiveness and adverse effects of over-the-counter whitening products on dental tissues. Front Dent Med 2021;2:687507.
26. Lima DA, Silva AL, Aguiar FH, Liporoni PC, Munin E, Ambrosano GM, *et al*. In vitro assessment of the effectiveness of whitening dentifrices for the removal of extrinsic tooth stains. Braz Oral Res 2008;22:106-111.
27. Vieira-Junior WF, Ferraz LN, Pini N, Ambrosano G, Aguiar F, Tabchoury C, *et al*. Effect of Toothpaste use against mineral loss promoted by dental bleaching. Oper Dent 2018;43:190-200.
28. Mori AA, Lima FF, Benetti AR, Terada RS, Fujimaki M, Pascotto RC. Susceptibility to coffee staining during enamel remineralization following the in-office bleaching technique: an in situ assessment. J Esthet Restor Dent 2016;28 Suppl 1:S23-S31.
29. Carlos NR, Pinto A, do Amaral F, França F, Turssi CP, Basting RT. Influence of staining solutions on color change and enamel surface properties during at-home and in-office dental bleaching: an in situ study. Oper Dent 2019;44:595-608.
30. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2021.
31. Fischer HC, de Lima LS, Felsner ML, Quináia SP. Study of adsorption capacity of commercial activated carbon versus storage time. Cienc Florest 2019;29:1090-1099.
32. Zellner T, Prasa D, Färber E, Hoffmann-Walbeck P, Genser D, Eyer F. The use of activated charcoal to treat intoxications. Dtsch Arztebl Int 2019;116:311-317.
33. Palandi SD, Kury M, Picolo MZ, Coelho CS, Cavalli V. Effects of activated charcoal powder combined with toothpastes on enamel color change and surface properties. J Esthet Restor Dent 2020;32:783-790.
34. Pertiwi UI, Eriwati YK, Irawan B. Surface changes of enamel after brushing with charcoal toothpaste. J Phys Conf Ser 2017;884:012002.
35. Koc Vural U, Bagdatli Z, Yilmaz AE, Yalçın Çakır F, Altundaşar E, Gurgan S. Effects of charcoal-based whitening toothpastes on human enamel in terms of color, surface roughness, and microhardness: an in vitro study. Clin Oral Investig 2021;25:5977-5985.
36. Brooks JK, Bashirelahi N, Reynolds MA. Charcoal and charcoal-based dentifrices: a literature review. J Am Dent Assoc 2017;148:661-670.
37. Correr Sobrinho L, Francisco MU, Consani S, Sinhoreti MA, Consani RL. Influência da escovação na rugosidade de superfície de materiais restauradores estéticos. Pós-Grad Rev Fac Odontol São José dos Campos 2001;4:47-55.
38. dos Santos PH, Consani S, Correr Sobrinho L, Coelho Sinhoreti MA. Effect of surface penetrating sealant on roughness of posterior composite resins. Am J Dent 2003;16:197-201.
39. McCabe JF, Molyvda S, Rolland SL, Rusby S, Carrick TE. Two- and three-body wear of dental restorative materials. Int Dent J 2002;52 Suppl 5:406-416.
40. Bianchi EC, de Aguiar PR, Poggi MR, Salgado MH, de Freitas CA, Bianchi AR. Estudo do desgaste abrasivo das resinas compostas disponíveis no mercado brasileiro. Mater Res 2003;6:255-264.
41. Garcia FC, Wang L, D'Alpino PH, Souza JB, Araújo PA, Mondelli RF. Evaluation of the roughness and mass loss of the flowable composites after simulated toothbrushing abrasion. Braz Oral Res 2004;18:156-161.
42. Trauth KG, Godoi AP, Colucci V, Corona SA, Catirse AB. The influence of mouthrinses and simulated toothbrushing on the surface roughness of a nanofilled composite resin. Braz Oral Res 2012;26:209-214.
43. Mondelli RF, Wang L, Garcia FC, Prakki A, Mondelli J, Franco EB, *et al*. Evaluation of weight loss and surface roughness of compomers after simulated toothbrushing abrasion test. J

Appl Oral Sci 2005;13:131-135.
44. Gusmão ES, de Melo JA, Ramos CG, dos Santos RL, da Silva Araújo AC, da Silva Feitosa D. Aplicabilidade clínica dos dentifrícios. Int J Dent 2003;2:231-235.
45. Cury JA, Rosing CK, Tenuta LM. Are all toothpastes the same? Int J Braz Dent 2010;6:254-256.
46. Monteiro B, Spohr AM. Surface roughness of composite resins after simulated toothbrushing with different dentifrices. J Int Oral Health 2015;7:1-5.
47. Hannig C, Duong S, Becker K, Brunner E, Kahler E, Attin T. Effect of bleaching on subsurface micro-hardness of composite and a polyacid modified composite. Dent Mater 2007;23:198-203.
48. de Abreu DR, Sasaki RT, Amaral FL, Flório FM, Basting RT. Effect of home-use and in-office bleaching agents containing hydrogen peroxide associated with amorphous calcium phosphate on enamel microhardness and surface roughness. J Esthet Restor Dent 2011;23:158-168.
49. Fernandes RA, Strazzi-Sahyon HB, Suzuki TY, Briso AL, Dos Santos PH. Effect of dental bleaching on the microhardness and surface roughness of sealed composite resins. Restor Dent Endod 2020;45:e12.
50. Wang L, Francisconi LF, Atta MT, Dos Santos JR, Del Padre NC, Gonini A, *et al*. Effect of bleaching gels on surface roughness of nanofilled composite resins. Eur J Dent 2011;5:173-179.
51. Attin T, Hannig C, Wiegand A, Attin R. Effect of bleaching on restorative materials and restorations: a systematic review. Dent Mater 2004;20:852-861.
52. Worschech CC, Rodrigues JA, Martins LR, Ambrosano GM. In vitro evaluation of human dental enamel surface roughness bleached with 35% carbamide peroxide and submitted to abrasive dentifrice brushing. Pesqui Odontol Bras 2003;17:342-348.
53. Pozzobon RT, Cândido MS, Rodrigues Júnior AL. Análise da rugosidade superficial de materiais restauradores estéticos: efeito de agentes clareadores e tempo. Rev Odonto Ciênc 2005;20:204-209.
54. Hilgenberg SP, Pinto SC, Farago PV, Santos FA, Wambier DS. Physical-chemical characteristics of whitening toothpaste and evaluation of its effects on enamel roughness. Braz Oral Res 2011;25:288-294.
55. Singh RP, Sharma S, Logani A, Shah N, Singh S. Comparative evaluation of tooth substance loss and its correlation with the abrasivity and chemical composition of different dentifrices. Indian J Dent Res 2016;27:630-636.
56. Reddy PS, Tejaswi KL, Shetty S, Annapoorna BM, Pujari SC, Thippeswamy 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;14:718-723.
57. Chowdhury D, Mazumdar P, Desai P, Datta P. Comparative evaluation of surface roughness and color stability of nanohybrid composite resin after periodic exposure to tea, coffee, and Coca-cola: an in vitro profilometric and image analysis study. J Conserv Dent 2020;23:395-401.
58. Badra VV, Faraoni JJ, Ramos RP, Palma-Dibb RG. Influence of different beverages on the microhardness and surface roughness of resin composites. Oper Dent 2005;30:213-219.
59. Torso VH, Fraga MA, Lopes RM, Aranha AC, Correr-Sobrinho L, Correr AB. Charcoal-based dentifrices: effect on color stability and surface wear of resin composites. J Esthet Restor Dent 2021;33:815-823.
60. Bragança GF, Soares PF, Simeão Borges J, Fernandes Vilela AB, Santos Filho PC, Soares CJ. Effects of charcoal toothpaste on the surface roughness, color stability, and marginal staining of resin composites. Oper Dent 2022;47:214-224.
61. Alghazali N, Burnside G, Moallem M, Smith P, Preston A, Jarad FD. Assessment of perceptibility and acceptability of color difference of denture teeth. J Dent 2012;40 Suppl 1:e10-e17.
62. Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. Quintessence Int 1991;22:377-386.
63. Liljeborg A, Tellefsen G, Johannsen G. The use of a profilometer for both quantitative and qualitative measurements of toothpaste abrasivity. Int J Dent Hyg 2010;8:237-243.
64. Roselino Lde M, Chinelatti MA, Alandia-Román CC, Pires-de-Souza Fde C. Effect of brushing time and dentifrice abrasiveness on color change and surface roughness of resin composites. Braz Dent J 2015;26:507-513.
65. Carvalho LF, Alves LM, Bergamo ET, Benalcazar Jalkh EB, Campos TM, Zahoui A, *et al*. Influence of abrasive dentifrices on polymeric reconstructive material properties after simulated toothbrushing. Biomater Investig Dent 2023;10:2268670.

https://doi.org/10.5395/rde.2025.50.e6