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Color and surface roughness alterations of bulk-fill resin composites submitted to simulated toothbrushing with whitening dentifrices

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Aim: To evaluate the surface roughness and color stability of bulk-fill resin composites after simulated toothbrushing with whitening dentifrices. The radioactive/relative dentin abrasion (RDA) and radioactive/relative enamel abrasion (REA) of dentifrices were also assessed. **Methods:** Specimens (n=10) of Tetric N Ceram Bulk Fill (TNCB), Filtek One Bulk Fill (FOB) resin composites, and Z100 (Control) were prepared using a cylindrical Teflon matrix. Surface roughness (Ra, µm) was assessed by a roughness meter and the color evaluations (ΔE_{ab}, ΔE_{00}, WI_D) were performed using a digital spectrophotometer based on the CIELAB system. Three measurements were performed per sample, before and after simulated toothbrushing with 3D Oral-B White Perfection (3DW) and Black is White (BW) dentifrices. The abrasivity (REA and RDA values) of the used dentifrices was also determined by the Hefferren abrasivity test. **Results:** The Ra values increased significantly in all resin composites after 3DW and BW toothbrushing. The acceptable threshold color varied among resin composites, and TNCB and Z100 presented the highest ΔE_{ab} and ΔE_{00} for BW dentifrice. The 3DW dentifrice was significantly more abrasive than BW dentifrice on enamel and dentin. **Conclusions:** simulated toothbrushing with tested whitening dentifrices increased the surface roughness at acceptable levels. The Tetric N Ceram Bulk-fill and Z100 composite showed the highest color alteration in BW. 3D White Perfection dentifrice was more abrasive on dentin and enamel than Black is White.

Keywords: Composite resins. Dentifrices. Bleaching agents.

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Introduction

Conventional composites restore tooth cavities in increments of 2 mm, reducing tension during polymerization contraction and improving light absorption[1,2]. However, the conventional technique is time-consuming and increases operative error, leading to gaps, decreased bond strength, and early restoration fracture[3]. These limitations allowed the emergence of bulk-fill restorative composites, which can be inserted in increments of 4 to 5 mm, decreasing the sensitivity of the technique[4-6]. They are also clinically comparable to conventional restorative composites regarding anatomical shape, color, marginal changes, secondary caries, postoperative sensitivity, and retention[7].

Some Bulk-fill composites may have a better adaptation to cavity walls[8], although there are not enough data to explore the relationship between the use of this material and microleakage, they are innovative materials for conservative dentistry that can reduce treatment steps and duration of operative times[9]. Laboratory studies indicate similar or better performance of these materials compared to conventional ones in terms of polymerization stress, degree of conversion, and resistance to bending and fracture[10]. Current studies demonstrate that the clinical performance of conventional resins and bulk-fill resins for carious lesion restorations is similar[11], including longevity in posterior permanent teeth[12].

Toothbrushing exposes restorative materials in the oral cavity to changes in surface properties[13]. Currently, new whitening techniques, including "over-the-counter" whitening agents (e.g., dentifrices and mouthwashes)[14], have arisen, exempting professional supervision. Whitening dentifrices with abrasive and chemical agents, such as chalk, silicate, bentonite, or peroxide, may promote adverse effects on soft and hard tissues. Meanwhile, whitening-abrasive dentifrices compromise teeth' mineral structure, mischaracterizing enamel prisms[15].

3D White perfection (Oral B) is one of the tooth whitening dentifrices found on the market responsible for tooth wear[16]. Its whitening process occurs due to hydrated silica and mica (crystallized minerals used as micro polishing system) and hexametaphosphate, capable of adsorption on the dental surface[16]. An activated carbon dentifrice (Black is White, Curaprox) was also manufactured to minimize the abrasive and chemical effects of most whitening dentifrices[17]. Although activated carbon-based dentifrices are legally marketed to whiten teeth, scientific evidence proving the real whitening effect is limited and still insufficient to prove the cosmetic benefit of these products. 'Black is White Curaprox® dentifrice was less effective than other whitening dentifrices in reducing extrinsic stains[18].

Laboratory studies on abrasion are important to the development of new dentifrice formulations, evaluation the quality control, and estimate of clinical abrasivity. Individual behavioral differences in toothbrushing affect the abrasivity of dentifrices[19,20]. Abrasion values of dentifrices can be measured using radioactive/relative dentin abrasion (RDA) and radioactive/relative enamel abrasion (REA), and practitioners should consider both values when recommending dentifrices to prevent tooth wear[21].

Although there is evidence of acceptable results for wear and surface roughness of bulk-fill composites, comparable to conventional composites, when brushed with a non-whitening dentifrice, the brushing time and composition of the dentifrices used must be considered, since attrition and abfraction can affect the service life of restorations[22]. After toothbrushing, changes in surface color and roughness of composite resins are related to the interaction between the composition of bulk-fill resins and characteristics of the whitening dentifrice[23]. Furthermore, the increased surface roughness may contribute to bacterial adhesion and dental biofilm maturation[24].

The evaluation of the performance of different dentifrices has already demonstrated greater abrasiveness of whitening dentifrices compared to the conventional one[25]. Increased roughness has already been observed in both whitening and conventional dentifrices, and both had similar effects on tooth enamel color[26].

Therefore, this study aimed to evaluate the surface roughness and color stability of bulk-fill composites after simulated toothbrushing with whitening dentifrices. REA and RDA of dentifrices 3D White Perfection (containing polishing microparticles) and Black is White (containing activated carbon) were also assessed. The following null hypotheses were tested: 1) surface roughness of restorative composites is not different after simulated toothbrushing; 2) surface color is not different between composites after simulated toothbrushing.

Material and Methods

Study design

Sixty specimens were randomized into three groups according to the resin composite materials: Z100/positive control (3M ESPE, St. Paul, MN, EUA), Tetric N Ceram Bulk-Fill (TNCB) (Ivoclar ivadent, Schaan, Liechtenstein), and Filtek One Bulk-Fill (FOB) (3M ESPE, St. Paul, MN, EUA). Each group underwent simulated toothbrushing with two types of whitening dentifrices (n=10): 3D Oral-B White Perfection (3DW) (Procter & Gamble Manufactura, Manaus, AM, Brazil) and Black is White (BW) (Curaprox, Curaden International AG, Kriens, Switzerland). Surface roughness and color stability were measured at baseline and after 10,000 toothbrushing cycles. In the study's second phase, dentifrices were tested for REA and RDA (n=8) using the Hefferren abrasivity test[27].

Specimen preparation

Twenty specimens of each composite were prepared using a cylindrical Teflon matrix (2mm thick and 6 mm in diameter) (Table 1). Single increments of restorative material filled the matrix, and then a polyester strip with a glass plate flattened the surface to avoid bubble formation. Specimens were polymerized using Emitter C equipment (SCHUSTER, Santa Maria, RS, Brazil), with light intensity above 800 mW/cm² according to an RD-7 radiometer reading (ECEL, Ribeirão Preto, SP, Brazil). Light-curing time was 20 seconds, according to the recommendations of the manufacturer. Subsequently, specimens were immersed for 24 hours in distilled water.

Table 1. Manufacturer, trade name, and composition of restorative composites and whitening dentifrices used in the study.

Manufacturer	Composite	Composition
3M ESPE/ St. Paul, MN, EUA	Z100 Color A3	Treated silanized ceramic (80-90% by weight), TEGDMA, BisGMA, 2-Benzotriazolyl-4-methylphenol (0.1416-0.145% by weight). Average particle size: 0.6 μm.
Ivoclar-Vivadent, Bendererstrasse Schaan, Germany	Tetric N Ceram Bulk-fill Color A3	Bis-GMA, Bis-EMA e UDMA (19-21% by weight) and 75-77% by weight (53-55% by volume) inorganic particles (average: 0.6 μm). Filler consists of barium glass, prepolymer, ytterbium trifluoride, and mixed oxides. Inorganic fillers particles sized 0.04 to 3 μm.
3M ESPE/ St. Paul, MN, EUA	Filtek One Bulk-fill Color A3	AUDMA, UDMA, and 1,12-dodecane-DMA. Zirconia (4-11 nm) and silica (20 nm) may be aggregated and agglomerated. Ytterbium trifluoride from agglomerated particles (100 nm); 76.5% by weight (58.4% by volume)
(CURAPROX) Amlehnstrasse, Kriens, Switzerland	Black is White	Water, sorbitol, hydrated silica, glycerin, charcoal powder, flavor, decyl glucoside, cocamidopropyl betaine, sodium monofluorophosphate (950 ppm), tocopherol, xanthan gum, maltodextrin, mica, hydroxyapatite (nano), acesulfame potassium, titanium dioxide, microcrystalline cellulose, sodium chloride, potassium chloride, citrus lemon peel oil, sodium hydroxide, zea mays starch, amyloglucosidase, glucose oxidase, urtica dioica leaf extract, potassium thiocyanate, cetearyl alcohol, hydrogenated lecithin, mentyl lactate, methyl diisopropyl propionamide, ethyl menthane carboxamide, stearic acid, mannitol, sodium bisulfite, tin oxide, lactoperoxidase, and limonen.
(P&G) Cincinnati, Ohio, EUA	3D White Perfection Oral-B	Sodium fluoride (1100 ppm fluoride), glycerin, hydrated silica, sodium hexametaphosphate, water, PEG-6, flavor, trisodium phosphate, sodium lauryl sulfate, carrageenan, cocamidopropyl betaine, mica (CI 77019), sodium saccharin, PEG-20M, xanthan gum, titanium dioxide (CI 77891), sucralose, limonen, pigment blue 15 (CI 74160).

TEGDMA: triethylene glycol dimethacrylate; Bis-GMA: bisphenol A glycidyl methacrylate; UDMA: urethane dimethacrylate; Bis-EMA: bisphenol A polyethylene glycol dimethacrylate; AUDMA: aromatic urethane dimethacrylate.

Surface roughness

Surface roughness (Ra, μm) was assessed using a roughness meter (Surftest SJ-301, Mitutoyo, Japan). Specimens were individually fixed on a glass plate with utility wax, and three random roughness readings were taken per sample, before and after the simulated toothbrushing. Mean roughness values were calculated and included in the data analysis.

For surface roughness readings, Ra was adjusted to translate the absolute distances of the roughness profile from the centerline, within the Lm measurement (measurement limit). Equipment parameters were standardized using the following test conditions: Lc (cut-off/filtering, minimizing the interference of surface ripple) - 0.25 mm and speed of 0.5 mm/s. Readings considered the mean between peaks and valleys (Ra), covered in a trajectory performed by the mechanical probe (4.0 mm)[28].

Color Evaluations

Color evaluations were performed using a digital spectrophotometer (Vita Easyshade, Vita Zahnfabrik, Bad Säckingen, Germany). Colors measurements were performed by positioning specimens on a white background to prevent potential absorption effects on color parameters. Three measurements were performed per sample so that the active tip of the spectrophotometer reached the center of each specimen before (baseline) and after the simulated toothbrushing (10,000 cycles). Mean color values were calculated and included in data analysis[28].

The first color evaluation was based on the CIELAB system. For this, a color space system determines color in a three-dimensional space, where L* represents the lightness, a* measures red (positive) or green (negative) colors, and b* measures yellow (positive) or blue (negative) colors. Color differences (ΔE_{ab}) between coordinates were calculated by $\Delta E_{ab} = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$ to compare values before and after treatment[29].

To analyze the color differences perceived by the human eye, the ΔE_{00} (CIEDE2000) calculation was performed according to the equation: $[(\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + R_T (\Delta C'/K_C S_C)(\Delta H'/K_H S_H)]^{½}$. Where ΔL', ΔC', and ΔH' are the differences in Lightness, Chroma, and Hue for a pair of specimens, and R_T is a function that accounts for the interaction between Chroma and Hue differences in the blue region. Weighting functions S_L, S_C, and S_H adjust the total color difference for variation in the location of the color difference pair, and K_L, K_C, and K_H are empirical terms used for correcting (weighting) the metric differences to the CIEDE2000 differences for each coordinate[30,31].

The interpretation of color differences among tooth-colored materials through 50:50% perceptibility (PT) and 50:50% acceptability threshold (AT) was based on the results reported in References[32,33] (Table 2).

Table 2. 50:50% perceptibility (PT) and 50:50% acceptability threshold.

Threshold	Rating and interpretation	ΔE00	ΔEab
≤PT	(5) Excellent match	≤0.8	≤1.2
>PT, ≤AT	(4) Acceptable match	>0.8, ≤1.8	>1.2, ≤2.7
>AT, ≤AT × 2	(3) Mismatch type [a]	>1.8, ≤3.6	>2.7, ≤5.4
>AT × 2, ≤AT × 3	(2) Mismatch type [b]	>3.6, ≤5.4	>5.4, ≤8.1
>AT × 3	(1) Mismatch type [c]	>5.4	>8.1

Mismatch types: [a] = moderately unacceptable; [b] = clearly unacceptable; and [c] = extremely unacceptable.

The whitening index for dentistry (WI_D) was also calculated, with the parameters L*, a*, and b* being used in the equation[30] $WI_D = 0.511L^* - 2.324a^* - 1.100b^*$. The differences in WI_D between the initial and final measurements were analyzed to obtain the ΔWI_D, considering the perceptibility threshold and acceptability 0.72 and 2.60, respectively[34].

Simulated toothbrushing

A toothbrushing machine (Biopdi, São Carlos, Brazil) composed of ten arms articulated by pulleys and with back-and-forth movements performed the simulated toothbrushing. Sixty toothbrushes with straight soft bristles (Oral-B Indicator Plus 35 P&G Cincinnati, Ohio, USA; one/sample) were adapted to the equipment by sectioning handles at intermediary height, leaving the long axis of bristles perpendicular and in contact with specimens embedded in acrylic resin. For the abrasivity test, 30 toothbrushes were combined with each dentifrice (BW or 3DW).

Dentifrices (Table 1) were suspended and diluted in distilled water (3:1 ratio) using a mechanical stirrer. Samples were subjected to 10,000 cycles at 4 Hz frequency (240 toothbrushing per minute) and an axial load of 200 g. After toothbrushing, specimens were removed, rinsed under running water, and immersed in distilled water.

Abrasivity testing of dentifrices

The abrasivity of dentifrices was verified using the Hefferren abrasivity test, recommended by the American Dental Association (ADA) and Organization for Standardization (ISO) 11609. ISO specifies a limited abrasivity from the standard reference material ($Ca_2P_2O_7$) of 2.5x for dentin and 4x for enamel. Therefore, arbitrary values of 100 (limit of 250) and 10 (limit of 40) were assigned for dentin and enamel, respectively. The ratio between standard and tested materials was calculated.

Samples of dentin and enamel from human teeth were subjected to neutron bombardment, resulting in radioactive phosphorus (^{32}P) formation under controlled conditions described by ADA. Subsequently, samples were assembled in methyl methacrylate and coupled to a V-8 cross-brushing machine. After exposition to solutions of standard reference material (10g) and 0.5% carboxymethyl cellulose (CMC) glycerin (50 mL), dentin samples were subjected to 1,500 toothbrushing cycles and enamel samples to 5,000 toothbrushing cycles, following a "sandwich design". Bristles followed ADA specifications, with a load of 150 g.

Each set of teeth was brushed with the standard reference material (10 g $Ca_2P_2O_7$/ 50 mL at 0.5% CMC) before and after toothbrushing with the product under test (25 g product/40 mL water). This procedure was repeated to test products on all teeth, with modified Latin squares design to avoid interaction of factors.

A scintillation cocktail of "Ultima Gold" (5 mL) was added to the weighted sample (1 mL). The sample was mixed and immediately placed in a liquid scintillation counter for radiation detection. After counting, liquid values per minute (CPM) were divided by sample weight to calculate liquid CPM/gram of dentifrice (CPM/g). Net CPM/g of anterior and posterior standard reference material for each dentifrice was calculated, and the mean value was used to calculate RDA and REA.

Statistical Analysis

Color evaluation and surface roughness values were compared using Kruskal-Wallis test pairwise comparison and the Wilcoxon test. Relative abrasion data were analyzed using one-way ANOVA (IBM statistics software SPSS, USA), and additional pairwise comparisons were performed using the Student-Newman-Keuls posthoc test. The significance level was set at 0.05 (2-sided).

Results

Surface roughness increased significantly in all composites after 3DW toothbrushing, but with no differences between composites. Regarding BW, all composites also increased surface roughness after toothbrushing. However, surface roughness was significantly higher in FOB after toothbrushing (Table 3).

Table 3. Mean and standard deviation of roughness (µm) before and after toothbrushing with 3DW (Oral B) and BW (Curaprox) dentifrices.

3DW	Z100	TNCB	FOB
BEFORE	0.10 (0.01)Aa	0.10 (0.01)Aa	0.11 (0.01)Aa
AFTER	0.19 (0.01)Ba	0.22 (0.04)Ba	0.20 (0.02)Ba
BW	**Z100**	**TNCB**	**FOB**
BEFORE	0.10 (0.02)Aa	0.10 (0.01)Aa	0.11 (0.01)Aa
AFTER	0.19 (0.02)Ba	0.15 (0.01)Ba	0.24 (0.03)Bb

Different uppercase letters in the same column indicate statistically significant differences before and after within the same group. Different lowercase letters in the same row indicate statistically significant differences between groups.

Table 4 and Table 5 show the color parameters of composites brushed with 3DW and BW respectively. The L* color parameters decreased in almost all groups, except in FOB (3DW). The b* color parameters decreased or remained stable in 2 dentifrices. The color varied among composites, TNCB presented the highest ΔE_{ab} and ΔE_{00} (Figure 1) for both dentifrices, although no difference from Z100 (BW).

Table 4. Mean ±standard deviation L*, a*, and b* values of specimens before and after toothbrushing with Oral B (3DW) and Curaprox (BW) dentifrices.

Color dimension	Oral B dentifrice (3DW)		
	Resin composite	**BEFORE**	**AFTER**
L*	Z100	82.11 (1.32)Aa	80.64 (1.16)Ab
	TNCB	87.72 (1.42)Ba	87.47 (1.38)Bb
	FOB	85.48 (1.62)Ba	87.16 (1.40)Bb
a*	Z100	2.95 (0.19)Aa	2.89 (0.11)Aa
	TNCB	-0.77 (0.21)Ba	-0.57 (0.18)Bb
	FOB	1.80 (0.13)Ca	1.65 (0.12)Cb
b*	Z100	26.33 (0.68)Aa	25.71 (0.62)Ab
	TNCB	17.81 (0.73)Ba	14.82 (0.57)Bb
	FOB	25.81 (0.51)Aa	25.75 (0.40)Aa
Color dimension	**Curaprox dentifrice (BW)**		
	Resin composite	**BEFORE**	**AFTER**
L*	Z100	81.69 (0.86)Aa	76.78 (1.14)Ab
	TNCB	86.52 (1.46)Ba	81.08 (1.71)Bb
	FOB	84.39 (1.44)Ba	83.69(1.37)Bb

Continue

Continuation

a*	Z100	2.84 (0.10)Aa	2.79 (0.10)Aa
	TNCB	-0.75 (0.30)Ba	-0.19 (0.32)Bb
	FOB	2.03 (0.13)Ca	1.94 (0.12)Ca
b*	Z100	25.83 (0.47)Aa	25.66 (0.53)Aa
	TNCB	18.15 (0.81)Ba	14.93 (0.32)Bb
	FOB	26.77 (0.52)Aa	25.12 (0.49)Ab

Different uppercase letters in the same column indicate statistically significant differences between groups. Different lowercase letters in the same row indicate statistically significant differences before and after within the same group.

Table 5. Mean ± standard deviation color variation (ΔE_{ab}, ΔE_{00}, WI_D).

Color variation	Oral B dentifrice (3DW)		
	Z100	**TNCB**	**FOB**
ΔE_{ab}	1.66 (0.66)a	3.02 (0.36)b	1.76 (0.31)a
ΔE_{00}	1.07 (0.42)a	1.76 (0.19)b	1.12 (0.24)a
ΔWI_D	0.05 (0.79)a	2.68 (0.65)b	1.26 (0.56)a
Color variation	**Curaprox dentifrice (BW)**		
	Z100	**TNCB**	**FOB**
ΔE_{ab}	4.91 (0.82)a	6.37 (0.57)a	1.82 (0.29)b
ΔE_{00}	3.42 (0.59)a	4.12 (0.40)a	0.91 (0.16)b
ΔWI_D	-2.17 (0.62)a	-0.55 (0.59)b	1.66 (0.38)c

Different lowercase letters in the same row indicate statistically significant differences between groups.

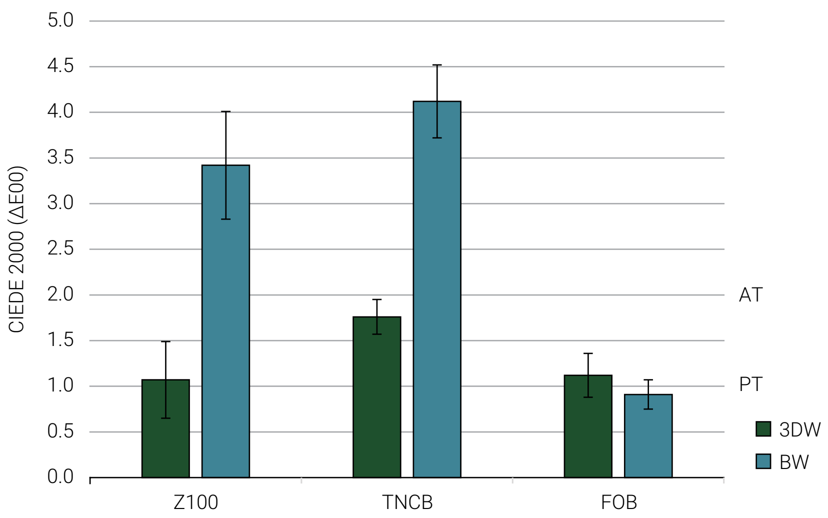

Figure 1. Mean and standard deviation values of Δ*E*00 between different groups.

The interpretation of color differences among tooth-colored materials through 50:50% perceptibility (PT) and 50:50% acceptability threshold (AT) for the Oral B (3DW) dentifrice was: ΔE_{ab}: Z100 and FOB was classified as an acceptable match; for TNCB was mismatch type (moderately unacceptable); ΔE_{00}: was classified acceptable match for three materials. For Curaprox (BW) dentifrice was ΔE_{ab}: Z100 was mismatch type (moderately unacceptable); FOB was classified as an acceptable match; TNCB was mismatch type (clearly unacceptable); ΔE_{00}: Z100 was mismatch type (moderately unacceptable); FOB was classified acceptable match; TNCB was mismatch type (clearly unacceptable).

As for the whiteness index, considering the classification of 50:50% whiteness perceptibility threshold (W_{PT}), TNCB and FOB showed a noticeable color change with Oral B dentifrice (3DW), and Z100 and FOB showed a noticeable color change with Curaprox (BW). Still, considering the classification of 50:50% whiteness acceptability threshold (W_{AT}), with Oral B dentifrice (3DW), the TNCB result was clinically unacceptable and with Curaprox (BW), Z100 and TNCB showed a tendency to darken (ΔWI_D negative).

Table 6 shows RDA and REA values, where mean values (± standard deviation) are listed in descending order (high mean values of RDA and REA represent high abrasivity). The 3DW dentifrice was significantly more abrasive than BW dentifrice on enamel and dentin.

Table 6. Mean and standard deviation of abrasivity on dentin and enamel.

Dentifrices	Sample size (n=8)	RDA	REA
Oral-B 3D White Perfection	8	189.82 (3.66)A	9.68 (0.69)A
CURAPROX Black is White Frest Lime-mint	8	116.30 (2.39)B	3.14 (0.34)B

Different uppercase letters in the same column indicate statistically significant differences (p<0.05) between dentifrices.

Discussion

This study evaluated the surface roughness and color stability of bulk-fill composites after simulated toothbrushing with whitening dentifrices (3D Oral-B White Perfection and CURAPROX Black is White). Our hypotheses were rejected once surface roughness and color changed after abrasion.

Evaluated composites showed an increase in surface roughness after simulated brushing, thus rejecting the first null hypothesis. This effect was already expected for both conventional and bulk-fill composites[13,35-37] due to toothbrushing movements, which compromise the finishing and polishing of surface layers by wearing and altering surface topography[38]. The Ra values after brushing with 3DW were not different between composites. However, FOB presented the most pronounceable increase in surface roughness after brushing with BW, differing from Z100 (conventional composite). This may be related to the fact that the FOB resin is nanohybrid, and contains a mixture of nanoparticles and larger irregular particles, a fact that can cause greater irregularity before wear[35]. Nevertheless, surface roughness was not clinically relevant in the present study, since alterations ranged between 0.10 and 0.24 μm. Roughness values higher than 0.2 μm would increase biofilm accumulation, secondary caries, and periodontal inflammation[38]. Some authors also consider changes in roughness from 0.22 to 0.24 μm as clinically irrelevant[39].

The use of CIEDE2000 for the study of color stability is recommended due to its greater agreement (95%) with visual findings, that is, it can better represent the human perception of color change[33]. Regarding color parameters, L* indicates the luminosity of an object (zero being total black or 100 total white), a* indicates the red (+a) and green (-a) axis, and b* indicates the yellow (+b) and blue (-b) axis[37]. Values of a* and b* close to zero represent white or gray colors, while the opposite occurs with saturated colors, in which values are high[40]. When color is evaluated after whitening, L* values are expected to increase and b* values decrease[41]. The latter parameter is probably more affected by whitening effects than L* values[41]. Our findings revealed that b* values decreased or remained stable

It was observed that the L* values decreased more when BW than 3DW dentifrice was used. This may be justified by the fact that the 3DW toothpaste proved to be more abrasive than BW, according to the RDA and REA values found in this study. The literature shows a relationship between the degree of abrasiveness of whitening dentifrices and the ability to polish the surface and improve brightness (>*L)[42]. Another hypothesis is that the dark color of the BW toothpaste may have stained the restorative materials tested. Torso et al.[43] (2021), concluded that color change and surface wear shown by charcoal dentifrices may compromise the longevity of restorations. This study showed that charcoal-based dentifrices resulted in greater color change than conventional dentifrices. The charcoal made the composite resin darker in color.

The perceptibility threshold (PT) is related to the smallest color difference that can be detected by an observer. The 50:50% perceptibility threshold is equivalent to a situation in which 50% of the evaluators notice a difference in color between the two evaluated objects (eg dental restorations) while the other 50% do not notice a difference. Thus, the color difference that is acceptable for 50% of the observers corresponds to the 50:50% acceptability threshold (AT)[33]. According to Paravina et al.[32] (2015), it is possible to correlate the visual thresholds with the findings of laboratory and clinical studies, as shown in Table 2.

The present study revealed that the ΔE_{ab} value of the TNCB resin brushed with the 3DW dentifrice corresponded to a moderately acceptable classification, while the ΔE_{00} was considered an acceptable correspondence. When brushed with the BW dentifrice, the TNCB resin, both $\Delta E_{ab,}$ and ΔE_{00} were classified as clearly unacceptable. The ΔE_{ab} and ΔE_{00} values of the Z100 resin brushed with the BW dentifrice were moderately unacceptable. Torso et al.[43] (2021) reported that BW dentifrice caused a noticeable change in the color of the Z350 resin after 417 brushing cycles and a change outside the acceptable range after 5004 brushing cycles.

The organic phase and low amount of filler particles of TNCB may increase pigment incorporation (evidenced by worst ΔE_{ab})[44]. According to Trevisan et al.[44], the TNCB resin showed the worst color stability probably because of the volumetric distribution between the organic and inorganic phases; however, it is unknown whether this pigmentation occurs clinically due to limitations of *in vitro* studies.

Color stability is related to the hydrophilic capacity of the resin matrix. When evaluating the composition of the tested resins, it is possible to observe that the TNCB resin has in its formulation the Bis-GMA known to have a greater affinity for water than the AUDMA[45] present in the FOB composite resin. This fact may explain the lower color stability of this composite resin in the present study after brushing with 3DW and BW dentifrices. It was reported that the Bis-GMA-based resin matrix has higher water sorption due to its hydrophilicity which is leading to less stain resistance compared to other methacrylate monomers[46,47]. However, the Z100 resin after brushing with the BW dentifrice showed a moderate incompatibility, these differences are probably related to the organic matrix composition since TEGDMA and Bis-GMA are hydrophilic monomers, which are more susceptible to pigment incorporation[48].

Furthermore, increasing the amount of TEGDMA in the resin matrix from 0 to 1% resulted in the increased water uptake of Bis-GMA-based resins[46]. Barutcugil et al.[49] reported that bulk-fill resin composite containing Bis-GMA and TEGDMA monomers, presented the highest color change after immersion in beverages when compared to nanohybrid resin composites[49].

Mada and other authors[50] (2018), reported that color alterations in hybrids resins composites can be measured by evaluating the whiteness index. Considering the values obtained by applying the index, the FOB composite presented a perceptible color change after treatment with the two dentifrices (Oral B 3DW and Curaprox BW). In the study by Backes et al.[48] (2020), when evaluating the performance of conventional Filtek and bulk-fill resins in terms of color stability, it was concluded that the conventional composite showed greater color alterations when a darkening test was used. In the present study, Z100 (conventional) and TNCB were the only composites that showed negative ΔWI_D values after brushing with Curaprox BW, indicating a lower bleaching index in the post-treatment evaluation, representing the darkening of the sample[51].

High dentin abrasivity in whitening dentifrices was already expected[21].

The 3DW dentifrice showed higher RDA and REA values than BW; according to RDA values, high abrasivity values range from 151 to 250, 3DW showed approximately 189 RDA value, and medium abrasivity from 70 to 150, 3DW showed approximately 116 RDA value[21], respectively. Machla et al.[52] also classified the charcoal-based dentifrice as medium abrasive and Koc et al.[26] found no change in the surface roughness after brushing with BW dentifrice. Hamza et al.[53] observed the same cleaning efficacy between BW and conventional abrasive dentifrices, but less dentin wear. Therefore, the need for a higher level of abrasivity is questioned since low and high abrasivity presented similar cleaning efficacy. Highly abrasive dentifrice can lead to wear in regions affected by incipient caries, especially when brushing frequency is increased[54]

Philpotts et al.[55] investigated the *in vitro* enamel and dentin wear by dentifrices with different levels of abrasivity. The relationship between REA and enamel wear was not determined due to the limited abrasiveness of the products tested, but a good correlation between dentin wear and RDA was found. Although *in vitro* studies control exposure time, temperature and acidity of the environment, and type of agent and substrate, only trends and indications on wear extension are obtained once biological variations of the oral environment cannot be fully replicated[56].

Few studies regarding the color stability and surface roughness of bulk-fill composites evaluated whitening dentifrices with activated carbon. The present *in vitro* study provides new knowledge regarding the abrasivity potential of whitening dentifrices and their effects on the optical and surface properties of bulk-fill composites. However, further *in vitro* and *in vivo* studies are advised to consolidate our results, confirm changes, and evaluate the longevity and efficacy of bulk-fill composites against toothbrushing with whitening dentifrices. Also, the comparison of whitening and no-whitening dentifrices is advised.

Conclusion

The roughness of all composites increased to acceptable levels after brushing with 3DW and BW dentifrices.

The Tetric N Ceram Bulk-fill resin showed greater color change after simulated toothbrushing, with a classification of clearly unacceptable when BW dentifrice was used; the Z100 resin composite associated with the BW dentifrice resulted in moderately unacceptable changes. Both showed a tendency to darken.

The 3D White Perfection dentifrice was more abrasive on dentin and enamel than Black is White.

Conflict of interests

None.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

Authors Contribution

Caroline de Farias Charamba: Substantial contributions to the conception and design of the work; Acquisition, analysis and interpretation of data for the work; Drafting the work and revising it critically for important intellectual content; Final approval of the version to be published; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Mariana Melani Alexandrino Costa: Acquisition of data for the work; Drafting the work; Final approval of the version to be published; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Renally Bezerra Wanderley e Lima: Analysis and interpretation of data for the work; Drafting the work and revising it critically for important intellectual content; Final approval of the version to be published; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Rosângela Marques Duarte: Substantial contributions to the conception and design of the work; Analysis and interpretation of data for the work; Revising the work critically for important intellectual content; Final approval of the version to be published; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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