Original Research
Dentistry

Effect of whitening toothpastes and activated charcoal powder on enamel wear and surface roughness

Bruna Tavares CARNEIRO[a]
Matheus KURY[b]
Jovana Cacique LOPES[a]
Rafael Silva GONÇALVES[c]
Thais Yumi Umeda SUZUKI[a]
Mayara Zaghi dal PICOLO[b]
Marcelo GIANNINI[b]
Carolina Bosso ANDRÉ[a]

[a]Universidade Federal de Minas Gerais – UFMG, School of Dentistry, Department of Restorative Dentistry, Belo Horizonte, MG, Brazil.

[b]Universidade Estadual de Campinas – Unicamp, Piracicaba Dental School, Department of Restorative Dentistry, Piracicaba, SP, Brazil.

[c]Universidade Federal de Minas Gerais – UFMG, Department of Physics, Laboratory of Characterization and Processing of Nanomaterials, Belo Horizonte, MG, Brazil.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Carolina Bosso André, PhD.
E-mail: carolina.bosso@gmail.com

https://doi.org/10.1590/1807-3107bor-2023.vol37.0092

Submitted: November 19, 2022
Accepted for publication: April 24, 2023
Last revision: June 21, 2023

Abstract: This study aimed to evaluate surface roughness (Sa), roughness profile (Rv), and enamel wear after brushing with different whitening toothpastes and charcoal powders. Sixty (n = 10) bovine enamel blocks (6 × 6 × 3 mm) were randomly distributed into six groups according to toothpaste type: regular toothpaste (CONT), toothpaste containing 2% hydrogen peroxide (HP), toothpaste containing titanium dioxide (TiO_2), toothpaste containing charcoal (COAL), toothpaste containing charcoal and TiO_2 (COAL+TiO_2), and activated charcoal powder (COAL_PWD). Each block was subjected to 30,000 reciprocal cycles at a 1:3 proportion slurry. After brushing, the blocks were analyzed using an optical profilometer to determine Sa, Rv, and enamel wear. In addition, representative 3D images of each group and wear profiles were obtained. Sa was analyzed using generalized linear models followed by Bonferroni correction, whereas Rv was analyzed using one-way analysis of variance. After brushing, COAL and COAL+TiO_2 showed higher Sa values than COAL_PWD. However, no significant difference was observed in Sa between whitening toothpaste and COAL_PWD, and CONT ($p > 0.05$). In addition, no differences were observed among the groups in Rv ($p > 0.05$). Conversely, enamel wear was higher for TiO_2, COAL, COAL+TiO_2, and COAL_PWD than for CONT. CONT showed the least enamel wear, whereas HP showed intermediate values. Representative 3D images and line profiles showed lower step-height and lower mean surface losses for the CONT and HP groups than for the other groups. Whitening toothpastes and COAL_PWD did not increase Sa or Rv compared with CONT, while CONT demonstrated lower enamel wear.

Keywords: Charcoal; Hydrogen Peroxide; Toothbrushing; Toothpastes.

Introduction

Tooth discoloration can affect self-esteem and quality of life.[1] Some lifestyle factors such as smoking, drinking colored beverages such as tea, coffee, and red wine, and insufficient dental hygiene may cause tooth discoloration.[2] Tooth bleaching with hydrogen peroxide-based agents is a conservative and effective approach to resolve tooth discoloration and render optimal esthetic outcomes.[1] Nevertheless, alternative oral care products with claims of a dental whitening effect have gained attention in recent years due to their convenient over-the-counter access and lower costs.[1] Toothpastes with a whitening effect usually contain abrasive substances and/or chemical or optical agents. Regular toothpastes have highly complex formulations that include humectants as solvent, abrasives, surfactants, thickening agents, fluorides, opacifying agents, sweeteners, colorants, flavorings, and buffering agents.[3] The most common strategies for the whitening effect of toothpastes include increase in the concentration of abrasives or incorporation of harder abrasives, such as calcium pyrophosphate, hydrated silica, hydroxyapatite, or more recently, activated charcoal.[3-5] Furthermore, pigments such as blue covarine or titanium dioxide (TiO_2), or even hydrogen peroxide have been added to whitening toothpastes.[4,5]

As abrasives are harder than the stain, removal of extrinsic stains adherent to the enamel surface is successful during tooth brushing without affecting the underlying intrinsic discoloration or natural shade of the tooth.[6] Blue covarine may cause an optical illusion after its deposition on the tooth surface, which can shift the color perception from yellow to blue.[7] A similar optical effect may be obtained with TiO_2 based on its intense white aspect.[8,9]

Hydrogen peroxide is another agent used to achieve the so-called whitening effect. The mechanism of action is similar to in-office or at-home bleaching procedure: oxidation of organic chromophores to non-colored organic compounds.[4] These modifications would turn stains into imperceptible compounds by the human eye.[10] Since a very low concentration of hydrogen peroxide (0.1–2%) is added into toothpastes allied to the inherent instability of peroxide, it may directly compromise the whitening action.[10] The abrasive property and chemical composition of toothpastes may cause wear and lead to tooth sensitivity.[11]

As for charcoal, its abrasive potential varies depending on the source and methods of preparing and milling the charcoal.[12] It can be extracted from different natural sources such as nutshells, coconut husks, bamboo and peat, and even wood or coal.[12] Lately, charcoal products used as whitening agents are available in powder forms, incorporated into several toothpastes, and diluted into mouthrinses.[13,14] It is important to note that using the powder adds an additional step in the toothbrushing habit since the powder cannot replace the use of fluoride-containing toothpastes.[8] The fine powder used alone or incorporated into toothpastes is activated charcoal, which has been oxidized by controlled reheating or chemical means.[15] Activated charcoal has a high surface area, thereby absorbing pigments and chromophores and removing stains.[16] However, the whitening effect of activated charcoal products and their impact on the enamel surface remains questionable.[8,13] For instance, charcoal powder alone was found to increase enamel surface roughness and not whiten teeth *in vitro*,[8] while a charcoal-containing toothpaste powder did not promote greater surface loss compared with brushing with no toothpaste.[17]

Therefore, this study aimed to evaluate the effects of five different toothpastes and charcoal powder on enamel surface roughness and enamel wear of bovine teeth after simulated tooth brushing. The five products included regular toothpaste (CONT), toothpaste containing 2% hydrogen peroxide (HP), toothpaste containing titanium dioxide (TiO_2), toothpaste containing charcoal (COAL), toothpaste containing charcoal and TiO_2 (COAL+TiO_2),and activated charcoal powder (COAL_PWD). The null hypotheses were as follows: a) whitening toothpastes and charcoal powder do not increase enamel surface roughness compared with regular toothpaste after brushing cycles and b) whitening toothpastes and charcoal powder do not cause more enamel wear compared with regular toothpaste after brushing cycles.

Methodology

Experimental design

Bovine enamel blocks (n =1 0/group) were subjected to brushing with six different toothpaste types: regular toothpaste (control), hydrogen peroxide-containing toothpaste, TiO_2-containing toothpaste, two activated charcoal-containing toothpaste, and activated charcoal powder. Surface roughness (Sa), roughness profile (Rv), and enamel wear were measured after simulated tooth brushing.

Specimen preparation

Bovine enamel blocks were obtained to measure the effects of different whitening toothpastes on Sa, Rv, and enamel wear. Bovine incisors were cleaned and stored in 0.1% thymol solution at 4°C for no longer than 60 days. Teeth without cracks and defects in the enamel and with at least 3.5-mm thickness of the buccal hard tissue were selected (60 incisors). Roots were removed 2 mm below the cementoenamel junction using a low-speed precision cutting machine (Isomet, Buehler, Lake Bluff, USA) under water refrigeration. One block (6 × 6 × 3 mm) of each tooth was obtained from the central region of the crown. The enamel surface of each block was flattened, finished with silicon carbide sandpaper (#600, #1200, and #2000 grit), and polished using a diamond aqueous suspension (1/4 mm) with polishing cloths and a polishing machine (Arotec Ind. Com., São Paulo, Brazil). Dentin was flattened using a polishing machine equipped with #600 silicon carbide sandpaper. After finishing and polishing, the blocks were cleaned in an ultrasonic bath for 10 min and stored in distilled water at 4°C until use.

Group division

The blocks were randomly divided into six groups (n = 10) according to the brushing agent used: a) Colgate Triple Action (CONT): a regular toothpaste, b) Colgate Luminous Advanced Expert (HP): 2% hydrogen peroxide-containing toothpaste, c) Colgate Optic White Stain Fighter (TiO_2): TiO_2-containing toothpaste, d) Colgate Optic White with Charcoal Teeth Whitening (COAL): activated charcoal-containing toothpaste, e) Crest 3D White Whitening Therapy Charcoal Deep Clean (COAL+TiO_2): activated charcoal- and TiO_2-containing toothpaste, and f) activated charcoal powder (COAL_PWD). The sample size was calculated with a desired power of 95% and $\alpha = 0.05$, and at least eight samples were obtained for each group. The brushing agents used in this study are listed in Table 1.

Brushing protocol

Adhesive tape (Floor and Safety Marking Tape, Scotch® 3M, Austin, USA) was applied to only half of the enamel surface of each block to protect this region from brushing and to serve as a control area for enamel wear and Rv. The blocks were then attached to a mechanical brushing machine (MEV 4-10XY – Odeme Dental research, Luzerna, Brazil) with the enamel surface positioned upward. The uncovered area was subjected to 30,000 reciprocal strokes (150 cycles/min) with a load of 200 g, simulating approximately 2 years of toothbrushing.[18] The same soft toothbrushes (Colgate Classic Clean Toothbrush, Colgate-Palmolive Company) were used for all groups. The blocks were then immersed in a 1:3 slurry prepared using toothpaste or charcoal powder in distilled water. The pH of the slurry was measured using a pH meter (Ms Tecnoponon Instrumentação, Piracicaba, SP, Brazil). After brushing, the samples were washed in running water and stored in distilled water at 37°C.

3D Optical profilometer analysis

A non-contact 3D optical profilometer (Zygo New ViewÔ 7300, Zygo Corp., Middlefield, USA) with 0.1-nm height resolution was used to scan the enamel surface and determine Sa, Rv, and wear resistance. Three 1-mm 3D images of the center of each block were obtained, with one half of the blocks being the control area and the other half the brushed area. The 3D images were analyzed using ProfilmOnline (Filmetrics Inc., San Diego, USA). For Sa, which describes the mean arithmetic height in three dimensions, two 300 mm × 300 mm measurements for each area (control and brushed) were performed for each 3D image. Rv (2D), which corresponds to the maximum valley depth deviation from the mean line, was calculated using the mean of three measurements for each image (1 mm length). The depth of the brushed surface (surface wear) was assessed using the two-point height tool (step-height measurement in line) of the ProfilmOnline. The mean step-heights of the control and brushed areas were calculated to determine the surface loss for each image. Representative images based on the average values were obtained for each group. Data were exported to software (Origin-Pro 2022, OriginLab, Northampton, USA), and representative line profile graphs were obtained for each group. Enamel wear

Table 1. Commercial name, manufacturer, composition, and fluoride concentration of each toothpaste tested.

Abbreviation: commercial name in USA (Brazilian commercial name- Manufacturer)	Composition*	Fluoride concentration**	Slurry pH
CONT: Colgate Triple Action (Colgate Tripla Ação – Colgate-Palmolive Industrial Ltda., São Bernardo do Campo, Brazil).	Water, calcium carbonate, sorbitol, sodium lauryl sulfate, sodium monofluorophosphate, flavor, cellulose gum, tetrasodium pyrophosphate, sodium bicarbonate, benzyl alcohol, sodium saccharin, xanthan gum, sodium hydroxide, CI 74160 (pigment blue), and limonene.	1,450 ppm	10.0
HP: Colgate Optic White Advanced (Colgate Luminous White Advanced Expert – Colgate-Palmolive, S.A. de C.V., San Jose Iturbide Guanajuato, Mexico).	Hydrogen peroxide (2%), sodium monofluorophosphate, propylene glycol, calcium pyrophosphate, PVP (polyvinylpyrrolidone), PEG/PPG-116/66 copolymer, PEG-12, glycerin, flavor, sodium lauryl sulfate, silica, tetrasodium pyrophosphate, sucralose, BHT (*butylated hydroxytoluene*), and eugenol.	1,000 ppm	6.5
TiO_2: Colgate Optic White Stain Fighter (Colgate Luminous White Brilliant – Colgate-Palmolive Industrial Ltda.).	Water, sodium fluoride, sorbitol, hydrated silica, PEG-12, sodium lauryl sulfate, flavor, cellulose gum, potassium hydroxide, tetrasodium pyrophosphate, phosphoric acid, cocamidopropyl betaine, benzyl alcohol, sodium saccharin, CI 77891 (titanium dioxide), limonene.	1,450 ppm	7.7
COAL: Colgate Optic White with Charcoal Teeth Whitening (Colagate Luminous White Carvão Ativado – Colgate-Palmolive, S.A. de C.V.).	Water, hydrated sílica, sorbitol, calcium pyrophosphate, glycerin, PEG-12, pentasodium triphosphate, tetrapotassium pyrophosphate, flavor, sodium lauryl sulfate, sodium monofluorophosphate, cellulose gum, sodium saccharin, xanthan gumcocamidopropyl betaine, CI 77266 (charcoal powder), CI 16035 (red pigment), CI 42090 (brilliant blue pigment), CI 19140 (yellow pigement), and limonene.	1,000 ppm	7.7
COAL+TiO_2: Crest 3D White Whitening Therapy Charcoal Deep Clean (Oral-B 3D White/White Therapy Purification Charcoal – Procter & Gamble Company, Greensboro, USA).	Sodium fluoride, water, sorbitol, hydrated silica, disodium pyrophosphate, sodium lauryl sulfate, cellulose gum, flavor, sodium hydroxide, sodium saccharin, carbomer, titanium dioxide, charcoal powder, mica, limonene, sucralose, and polysorbate 80.	1,100 ppm	7.6
COAL_PWD: Activated Charcoal (Carvvo – L'aromatic Indústria e Comércio Ltda.-ME, Lauro de Freitas, Brazil)	Carbon, kaolin, citrus aurantium dulcis oil (orange oil), and flavor.	None	10.0

*According to the manufacturer.** The composition is described as per the Brazilian version of toothpastes. The composition may vary by country.

and Sa (within-subject factor: brushing; between-subject factor: group) data were analyzed using generalized linear models corrected for multiple testing by the Bonferroni correction, whereas Rv was analyzed using one-way analysis of variance ($p < 0.05$).

Results

pH, Sa, and Rv

The pH of the slurry varied from 6.5 (HP) to 10 (COAL_PWD) and is presented in Table 1. Table 2 lists the Sa values of the control and brushed areas. Generalized linear models indicated that the "group" factor significantly influenced Sa ($p = 0.018$), while brushing and the interaction group*brushing did not ($p = 0.912$ and $p = 0.255$, respectively). No significant differences were observed among the groups when only the control areas were compared, indicating a homogeneous distribution of the samples among the groups before brushing. After brushing, TiO_2 ($p = 0.006$) and COAL+TiO_2 ($p = 0.005$) toothpastes demonstrated higher Sa values than COAL_PWD. The other toothpastes presented intermediate Sa values, with no significant differences among them. When comparing Sa of the brushed side with that of the corresponding unbrushed side, no significant differences were observed for any of the brushing

Table 2. Mean (95% CI) surface roughness (Sa in μm) before and after brushing.

Toothpaste	Control	Brushed	Percentage of increase () or decrease (-)*
CONT	1.70 (1.42–2.04) a A	1.65 (1.38–1.97) ab A	- 2.9%
HP	1.62 (1.36–1.94) a A	1.70 (1.42–2.03) ab A	4.7%
TiO_2	1.69 (1.41–2.02) a A	1.96 (1.63–2.34) a A	13.8%
COAL	1.66 (1.39–1.99) a A	1.54 (1.28–1.84) ab A	- 12.8%
COAL+TiO_2	1.71 (1.43–2.05) a A	1.96 (1.64–2.35) a A	7.2%
COAL_PWD	1.55 (1.29–1.85) a A	1.21 (1.01–1.45) b A	- 21.9%

*Percentages were calculated using the mean Sa for each side.
Different letters indicate significant differences between the groups. Lower-case letters compare different toothpaste types within the same brushing condition (control x brushed). Upper-case letters compare different brushing condition within the same toothpaste type.

Table 3. Mean (SD) roughness profile (Rv in μm).

Toothpaste	Rv
CONT	0.39 (0.07) a
HP	0.41 (0.08) a
TiO_2	0.40 (0.09) a
COAL	0.44 (0.13) a
COAL+TiO_2	0.47 (0.11) a
COAL_PWD	0.35 (0.12) a

Same letters indicate no significant difference ($p>0.05$).

agents ($p > 0.05$). Numerically, half of the groups presented a decrease in Sa values (from 2.9% to 21.9% among the brushing agents), while the other half presented an increase (from 4.7% to 13.8%). In addition, no significant difference was observed in Rv among the groups (Table 3).

Enamel wear

Figure 1 shows the enamel wear values for each tested group. Unlike Sa and Rv, enamel wear was higher for TiO_2, COAL, COAL+TiO_2, and COAL_PWD than for regular toothpaste (CONT; $p < 0.001$) and HP ($p < 0.001$). In addition, HP presented a higher enamel wear than CONT ($p = 0.038$). Representative surface 3D images are shown in Figure 2, and Figure 3 shows representative graphs of the line profiles for each brushing agent tested. Figure 2A (CONT) and Figure 2B (HP) show a lower and subtle step-height of the brushed surface than the other groups. Similarly, Figures 3A (CONT) and 3B (HP) show a line profile with a lower mean surface loss than the other groups.

Discussion

The first null hypothesis was accepted because all whitening toothpastes and charcoal powder presented similar Sa and Rv compared with regular toothpaste after brushing. However, COAL_PWD presented lower Sa than the TiO_2 and COAL+TiO_2 toothpastes, indicating that charcoal powder can promote more homogenous surface wear, acting similarly to polishing materials. Although no statistically significant difference was detected, COAL_PWD reduced Sa after brushing (21.9% reduction), corroborating the expected polishing effect. In contrast to other toothpastes, TiO_2 and COAL+TiO_2 toothpastes also contain hydrated silica. Both these toothpastes showed a slight increase in Sa (13.8% and 7.2%, respectively), with no significant difference. Hydrated silica is a medium-hard abrasive added to toothpastes to remove stains.[4] However, its abrasiveness depends on the amount, size, shape, and percentage of the silica added,[4,19] which is not disclosed by the manufacturer.

It is unclear whether Sa plays an important role in bacterial adhesion. Some studies have shown that roughened surfaces can significantly enhance bacterial attachment,[20,21] while others have failed to report roughness as a determining factor for bacterial adhesion[22] and biofilm formation.[23]

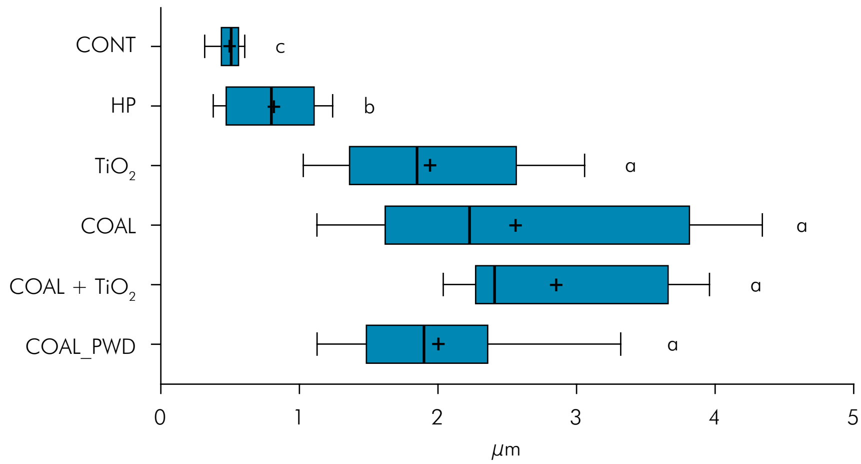

Figure 1. Box-plot graph of enamel wear of each toothpaste and charcoal powder. Different lower-case letters indicate significant differences between groups. CONT presented the lowest wear values, followed by HP. COAL, COAL+TiO_2, and COAL_PWD presented the highest wear values, with no difference between them.

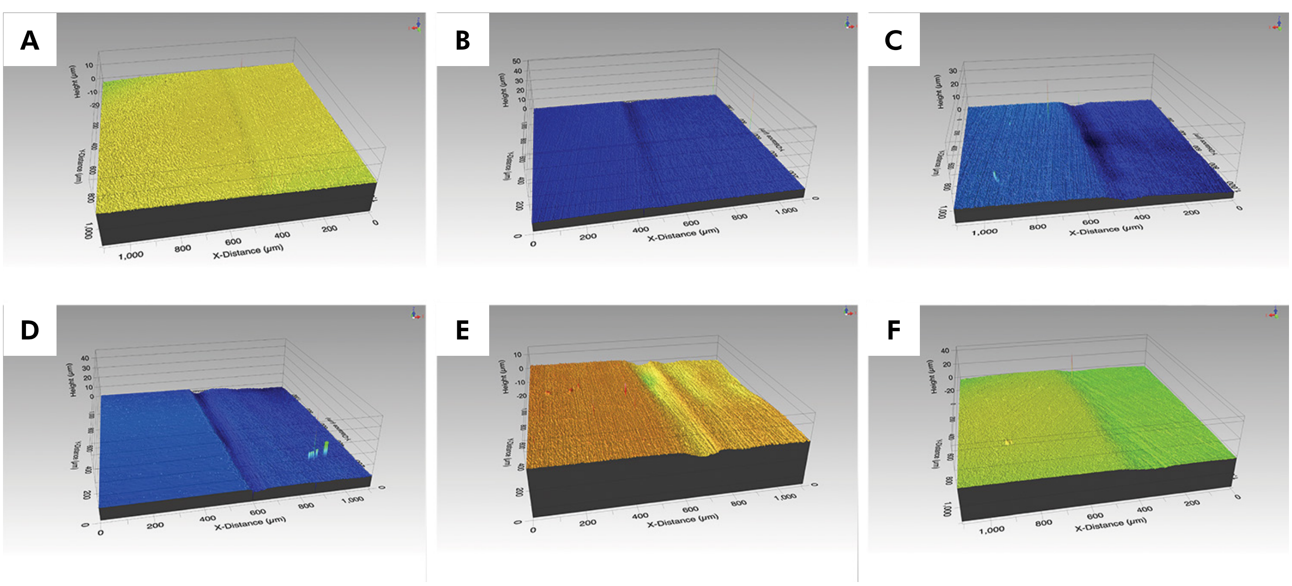

Figure 2. Representative 3D surface images of unbrushed (left side) and brushed (right side) areas of each group tested. (A) CONT. (B) HP. (C) TiO_2. (D) COAL. (E) COAL+TiO_2. (F) COAL_PWD. Height axes indicate that COAL, COAL+TiO_2, and COAL_PWD presented a more evident and deeper step on the brushed side compared with CONT and HP.

Regarding microbiological aspects, Rv seems to be more relevant to the growth and development of *Streptococcus mutans* than Sa. The morphology of the depressed areas helped to avoid the displacement of *S. mutans* colonies, improving consolidation of the acquired pellicle.[24] Although no significant differences were observed for Rv among the groups in this study, deeper valleys were observed for all whitening toothpastes and charcoal powder than for CONT (Figure 3).

In contrast, in a recent systematic review and meta-analysis, the majority of studies (five of seven) revealed an increase in Sa, which could be attributed to the use of whitening toothpastes. Consequently, the meta-analysis showed a positive correlation between Sa and the intervention group (whitening

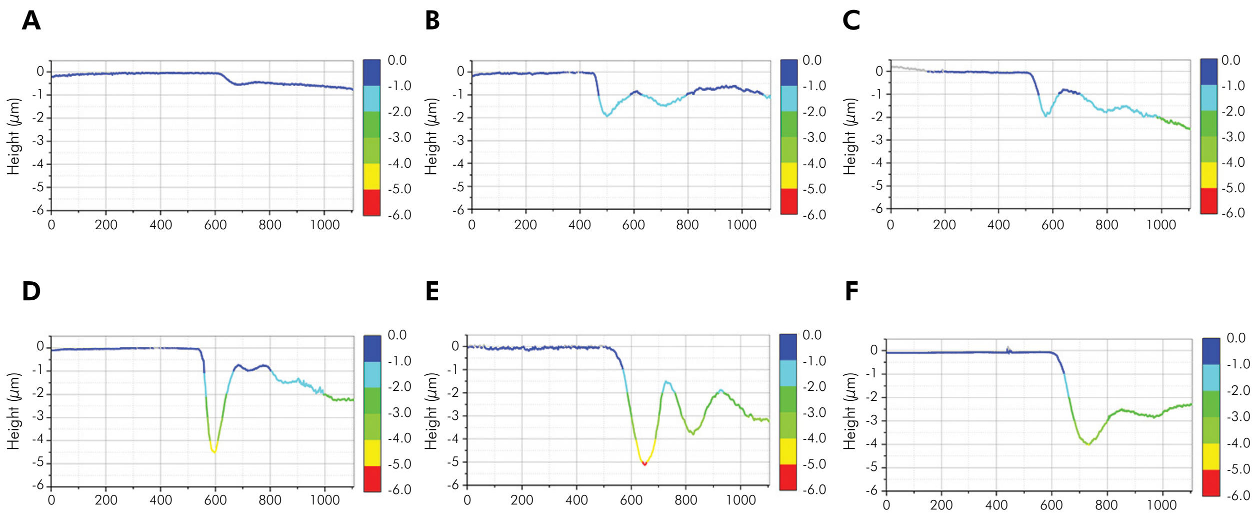

Figure 3. Representative profile line of each group tested. (A) CONT. (B) HP. (C) TiO_2. (D) COAL. (E) COAL+TiO_2. (F) COAL_PWD. Green, light green, yellow, and red indicate areas with wear over 2, 3, 4, and 5 mm, respectively. COAL, COAL+TiO_2, and COAL_PWD presented an increased wear and deeper valleys compared with CONT and HP.

toothpastes).[25] Additionally, an *in vitro* study observed surface morphology changes when a whitening toothpaste containing charcoal was tested. The whitening toothpaste groups presented large and deep craters in conjunction with other flaws on the surface, despite the initial smooth aspect.[14] Even with the benefit of stain removal, abrasives might increase the risk of superficial damage to dental tissues and restorative materials.[26]

Although no difference in surface roughness was observed between the unbrushed and brushed sides for the same toothpaste, differences in enamel wear were observed, and thus, the second null hypothesis had to be rejected. The main finding of this study was the lowest wear after 30,000 brushing cycles for the CONT group. This toothpaste contains sodium bicarbonate as an abrasive, which is reported to have a low hardness.[4] We suggest that this softer abrasive prevents the increase in enamel wear following brushing cycles compared with the other toothpastes. HP exhibited an intermediate wear value. It contained silica as an abrasive and had the lowest slurry pH of 6.5. Although an increase in enamel wear was observed for HP compared with the CONT group, TiO_2, COAL, COAL+TiO_2, and COAL_PWD presented the highest wear values. The last four groups also presented a high variation of values within the same group (from 1–2 to 3.5–4 mm of enamel wear) and had abrasives with medium hardness.[4] We hypothesize that the slurry was not always homogenous for these groups, which affected the maintenance of abrasives between toothbrush bristles. However, these groups exhibited surface wear that was always greater than 1 mm, which was twice that observed for CONT. The COAL_PWD group presented further surface loss when sequential brushing was performed with any of the whitening toothpastes. As the manufacturer indicates powder use prior to regular brushing and the patients decide which product to purchase, surface loss might be exacerbated in a clinical setting depending on the powder and toothpaste combination.

One reason for concern is that most of these toothpastes do not include the abrasiveness index (RDA) on the label. According to the American Dental Association (ADA), the maximum RDA value to avoid structural damage to dental tissues is 250.[4] Further, ADA-approved toothpastes should also contain fluoride.[27] However, these so-called natural, ecofriendly, and organic toothpastes have gained visibility, as shown in a recent study that evaluated the labels of 50 dental products containing activated charcoal.[13] Another main concern is the absence of fluoride (in powder or toothpaste) and charcoal's potential to inactivate fluoride due to it absorptive capability.[13,28]

All tested toothpastes contained fluoride, except for COAL_PWD, which is a powder containing carbon, kaolin, Citrus Aurantium Dulcis oil (orange oil), and flavor, according to the manufacturer. Fluoride can be found in different formulations such as NaF, Na_2FPO_3, $C_27H_{60}F_2N_2O_3$, SnF_2, or a combination of these.[29] Since no erosive challenge was performed with low-pH substances in this study, we could not evaluate the protective effect of fluoride. However, the beneficial effects of fluoride are well described in the literature. It acts as a catalyst in the de-remineralization process, accelerating remineralization by around five times. This is possible because of reservoir formation in saliva, which remains for a few hours, and aggregation in the dental biofilm, which lasts for an extend period.[30] For this reason, toothpastes (or any product designed to substitute toothpastes) without fluoride should be discouraged. However, it should be kept in mind that a pH higher than 5.5 along with the presence of fluoride in all toothpastes do not rule out the possibility of decrease in enamel mineral content. An *in situ* study indicated that toothbrushing with fluoride-containing toothpaste was not capable of maintaining the enamel surface microhardness.[31] Therefore, abrasion may play a fundamental role in the regulation of enamel mineral loss.

Phosphoric acid can also be found in toothpaste and claims to control pH in TiO_2 toothpastes. However, it is unclear whether the presence of phosphoric acid has a microabrasion effect (similar to products designed for microabrasion). The microabrasion uses phosphoric acid to change the optical characteristics of the enamel and increase the polishing aspect, resulting in different light refractions and the ability to camouflage stains.[32] Moreover, restorations might also be affected, losing the polish, brightness, and volume, as well as increasing Sa. Recently, charcoal-based toothpaste and powder were shown to significantly increase surface loss with a conventional composite by means of a profilometry method.[33] Thus, the use of whitening toothpastes and powders requires caution, especially in patients with risk factors for gingival recession, non-carious lesions, and hypersensitivity [3,34] and should not be used for a prolonged time.

Based on this, it is important to highlight that even though systematic reviews and meta-analyses have concluded that whitening toothpastes indeed promote a higher color change than regular toothpastes,[35,36] clinical evidence indicates that the whitening effect of these toothpastes is not long-lasting.[37] In other words, patients would have to prolong their use, thereby increasing the risk of enamel surface loss, as shown in this study. Instead, patients could seek professionally supervised bleaching with long-term efficacy and safety, which are well-established in the literature.[38,39] In addition, even though these systematic reviews were conducted prior to the massive launch of activated charcoal products, *in vitro* studies have already reported their inefficacy in promoting color change.[8,40] Therefore, it becomes even clearer that the use of such products should be discouraged by dentists.

It is worth mentioning that this study presents the inherent limitation of an *in vitro* design, not ruling out the action of human saliva on upholding or recovering Sa, Rv, and enamel wear. Additionally, no temporal evaluation of the variables was conducted. In other words, analyses could be performed at different time points to determine whether a certain brushing time was detrimental to the enamel surface. Finally, the lack of colorimetric evaluation could be questioned, but previous studies have shown that charcoal-based products are not as effective as peroxide-based agents in resolving tooth discolation.[8,15]

Conclusion

Within the limitations of this *in vitro* study, it can be concluded that

a. Different agents added to the toothpastes tested did not affect the enamel Sa.
b. Rv was similar for all the toothpastes tested.
c. Brushing with the regular toothpaste resulted in the lowest enamel wear after 30,000 cycles.

References

1. Pavicic DK, Kolceg M, Lajnert V, Pavlic A, Brumini M, Spalj S. Changes in quality of life induced by tooth whitening are moderated by perfectionism: a randomized, double-blind, placebo-controlled trial. Int J Prosthodont. 2018;31(4):394-6. https://doi.org/10.11607/ijp.5499
2. Hattab FN, Qudeimat MA, al-Rimawi HS. Dental discoloration: an overview. J Esthet Dent. 1999;11(6):291-310. https://doi.org/10.1111/j.1708-8240.1999.tb00413.x
3. Joiner A. Whitening toothpastes: a review of the literature. J Dent. 2010;38 Suppl 2:e17-24. https://doi.org/10.1016/j.jdent.2010.05.017
4. Epple M, Meyer F, Enax J. A critical review of modern concepts for teeth whitening. Dent J. 2019 Aug;7(3):79. https://doi.org/10.3390/dj7030079
5. Maldupa I, Brinkmane A, Rendeniece I, Mihailova A. Evidence based toothpaste classification, according to certain characteristics of their chemical composition. Stomatologija. 2012;14(1):12-22.
6. White DJ. Development of an improved whitening dentifrice based upon "stain-specific soft silica" technology. J Clin Dent. 2001;12(2):25-9.
7. Tao D, Smith RN, Zhang Q, Sun JN, Philpotts CJ, Ricketts SR, et al. Tooth whitening evaluation of blue covarine containing toothpastes. J Dent. 2017 Dec;67S:S20-4. https://doi.org/10.1016/j.jdent.2017.10.014
8. 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 Dec;32(8):783-90. https://doi.org/10.1111/jerd.12646
9. Vieira-Junior WF, Lima DA, Tabchoury CP, Ambrosano GM, Aguiar FH, Lovadino JR. Effect of toothpaste application prior to dental bleaching on whitening effectiveness and enamel properties. Oper Dent. 2016;41(1):E29-38. https://doi.org/10.2341/15-042-L
10. Lippert F. An introduction to toothpaste: its purpose, history and ingredients. Monogr Oral Sci. 2013;23:1-14. https://doi.org/10.1159/000350456
11. Addy M, Hunter ML. Can tooth brushing damage your health? Effects on oral and dental tissues. Int Dent J. 2003;53 Suppl 3:177-86. https://doi.org/10.1111/j.1875-595X.2003.tb00768.x
12. Greenwall LH, Greenwall-Cohen J, Wilson NH. Charcoal-containing dentifrices. Br Dent J. 2019 May;226(9):697-700. https://doi.org/10.1038/s41415-019-0232-8
13. Brooks JK, Bashirelahi N, Reynolds MA. Charcoal and charcoal-based dentifrices: a literature review. J Am Dent Assoc. 2017 Sep;148(9):661-70. https://doi.org/10.1016/j.adaj.2017.05.001
14. Dionysopoulos D, Papageorgiou S, Malletzidou L, Gerasimidou O, Tolidis K. Effect of novel charcoal-containing whitening toothpaste and mouthwash on color change and surface morphology of enamel. J Conserv Dent. 2020;23(6):624-31. https://doi.org/10.4103/JCD.JCD_570_20
15. 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 Oct;25(10):5977-85. https://doi.org/10.1007/s00784-021-03903-x
16. Vaz VT, Jubilato DP. Oliveira MRMd, Bortolatto JF, Floros MC, Dantas AAR, et al. Whitening toothpaste containing activated charcoal, blue covarine, hydrogen peroxide or microbeads: which one is the most effective? J Appl Oral Sc. 2019; 27. https://doi.org/10.1590/1678-7757-2018-0051
17. Viana ÍE, Weiss GS, Sakae LO, Niemeyer SH, Borges AB, Scaramucci T. Activated charcoal toothpastes do not increase erosive tooth wear. J Dent. 2021 Jun;109:103677. https://doi.org/10.1016/j.jdent.2021.103677
18. Sahadi BO, Nima G, Andre CB, Sebold M, Palma-Dibb RG, Faraoni JJ, et al. Microhardness homogeneity of RBCs light-cured with a multiple-peak LED and surface characterization after wear. Braz Dent J. 2021;32(3):92-104. https://doi.org/10.1590/0103-6440202104044
19. Hamza B, Tanner M, Attin T, Wegehaupt FJ. Dentin abrasivity and cleaning efficacy of novel/alternative toothpastes. Oral Health Prev Dent. 2020 Sep;18(1):713-8. https://doi.org/10.3290/j.ohpd.a45074
20. Reyes CD, García AJ. A centrifugation cell adhesion assay for high-throughput screening of biomaterial surfaces. J Biomed Mater Res A. 2003 Oct;67(1):328-33. https://doi.org/10.1002/jbm.a.10122
21. Hahnel S, Rosentritt M, Bürgers R, Handel G. Surface properties and in vitro Streptococcus mutans adhesion to dental resin polymers. J Mater Sci Mater Med. 2008 Jul;19(7):2619-27. https://doi.org/10.1007/s10856-007-3352-7
22. Teutle-Coyotecatl B, Contreras-Bulnes R, Rodríguez-Vilchis LE, Scougall-Vilchis RJ, Velazquez-Enriquez U, Almaguer-Flores A, et al. Effect of surface roughness of deciduous and permanent tooth enamel on bacterial adhesion. Microorganisms. 2022 Aug;10(9):1701. https://doi.org/10.3390/microorganisms10091701
23. Cazzaniga G, Ottobelli M, Ionescu AC, Paolone G, Gherlone E, Ferracane JL, et al. In vitro biofilm formation on resin-based composites after different finishing and polishing procedures. J Dent. 2017 Dec;67:43-52. https://doi.org/10.1016/j.jdent.2017.07.012

24. Park JW, Song CW, Jung JH, Ahn SJ, Ferracane JL. The effects of surface roughness of composite resin on biofilm formation of Streptococcus mutans in the presence of saliva. Oper Dent. 2012;37(5):532-9. https://doi.org/10.2341/11-371-L
25. Jamwal N, Rao A, Shenoy R, Pai M, Aparna K, Avinash B. Effect of whitening toothpaste on surface roughness and microhardness of human teeth: a systematic review and meta-analysis. F1000Res. 2022;11 :22. https://doi.org/10.12688/f1000research.76180.3
26. Bauler LD, Santos CS, Lima GS, Moraes RR. Charcoal-based dentifrices and powders: analyses of product labels, Instagram engagement, and altmetrics. Braz Dent J. 2021;32(2):80-9. https://doi.org/10.1590/0103-6440202104233
27. Hunter M, Addy M, Pickles M, Joiner A. The role of toothpastes and toothbrushes in the aetiology of tooth wear. Inter Dent J. 2002; 52:399-405. https://doi.org/10.1590/0103-6440202104233
28. Mondal NK, Bhaumik R, Roy P, Das B, Datta JK. Investigation on fixed bed column performance of fluoride adsorption by sugarcane charcoal. J Environ Biol. 2013 Nov;34(6):1059-64.
29. Amaechi BT, van Loveren C. Fluorides and non-fluoride remineralization systems. Monogr Oral Sci. 2013;23:15-26. https://doi.org/10.1159/000350458
30. Cury JA, Amaral RC, Tenuta LM, Del Bel Cury AA, Tabchoury CP. Low-fluoride toothpaste and deciduous enamel demineralization under biofilm accumulation and sucrose exposure. Eur J Oral Sci. 2010 Aug;118(4):370-5. https://doi.org/10.1111/j.1600-0722.2010.00745.x
31. Silva-Junior MF, Cruz PS, Bozzi AC, Daroz LG, Santos-Daroz CB. Effect of bleaching agents and toothpastes on the enamel: an in situ study. Am J Dent. 2019 Dec;32(6):288-92.
32. Killian CM, Croll TP. Enamel microabrasion to improve enamel surface texture. J Esthet Dent. 1990;2(5):125-8. https://doi.org/10.1111/j.1708-8240.1990.tb00627.x
33. 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 Jul;33(5):815-23. https://doi.org/10.1111/jerd.12741
34. 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(4):288-94. https://doi.org/10.1590/S1806-83242011005000012
35. Devila A, Lasta R, Zanella L, Agnol MD, Rodrigues-Junior SA. Efficacy and adverse effects of whitening dentifrices compared with other products: a systematic review and meta-analysis. Oper Dent. 2020;45(2):E77-90. https://doi.org/10.2341/18-298-L
36. Soeteman GD, Valkenburg C, Van der Weijden GA, Van Loveren C, Bakker E, Slot DE. Whitening dentifrice and tooth surface discoloration-a systematic review and meta-analysis. Int J Dent Hyg. 2018 Feb;16(1):24-35. https://doi.org/10.1111/idh.12289
37. Vladislavic NZ, Tadin A, Gavic L, Jerkovic D, Franic I, Verzak Z. In vivo evaluation of whitening toothpaste efficiency and patient treatment satisfaction: a randomized controlled trial. Clin Oral Investig. 2022 Jan;26(1):739-50. https://doi.org/10.1007/s00784-021-04052-x
38. Kury M, Wada EE. Silva DPd, Tabchoury CPM, Giannini M, Cavalli V. Effect of violet LED light on in-office bleaching protocols: a randomized controlled clinical trial. J Appl Oral Sci. 2020; 28. https://doi.org/10.1590/1678-7757-2019-0720
39. Ferraz NK, Nogueira LC, Neiva IM, Ferreira RC, Moreira AN, Magalhães CS. Longevity, effectiveness, safety, and impact on quality of life of low-concentration hydrogen peroxides in-office bleaching: a randomized clinical trial. Clin Oral Investig. 2019 May;23(5):2061-70. https://doi.org/10.1007/s00784-018-2607-7
40. Rashid S, Hendren J, Elgendy H, Oak E, Shahinian C, Gabriel A, et al. Impact of brushing with charcoal on tooth color and enamel loss: an in vitro study. Am J Dent. 2022 Jun;35(2):133-6.