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The in vitro Effect of Dentifrices With Activated Charcoal on Eroded Teeth

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ABSTRACT

Aim: The objective of this research was to compare the abrasive potential of dentifrices containing activated charcoal with those of a conventional dentifrice on the development of erosive tooth wear (ETW) in vitro.
Methods: Enamel and dentin samples were divided into toothpastes (n = 12): group (G)1–Colgate Triple Action (1450 ppm F) (positive control); G2–Colgate Natural Extracts (1450 ppm F); G3–Colgate Luminous White Activated Carbon (1450 ppm F); G4–Oral-B Whitening Therapy Charcoal (1100 ppm F); G5–Oral-B 3D White Mineral Clean (1100 ppm F); G6–Curaprox Black Is White (950 ppm F); and G7–erosion only (no abrasion, negative control). All samples were submitted to erosive pH cycles and G1 to G6 to abrasive challenges (15 seconds) using toothpastes' slurries plus 45 seconds of treatment for 7 days. The final profile was overlaid to the baseline one for the ETW calculation (μm). The data were subjected to analysis of variance/Tukey or Kruskal–Wallis/Dunn tests ($P < .05$).
Results: Oral-B 3D White (13.0 ± 1.0, 9.37 [1.36] μm), Oral-B Whitening Therapy (15.1 ± 1.2, 8.58 [1.71] μm), and Colgate Luminous White (13.6 ± 1.0, 7.46 [0.94] μm) toothpastes promoted the greatest enamel and dentin wear. On the other hand, Colgate Triple Action (12.2 ± 1.2, 5.30 [1.26] μm), Colgate Natural Extracts (10.8 ± 1.1, 4.16 [1.11] μm), and Curaprox Black Is White (11.5 ± 1.5, 4.06 [0.92] μm) toothpastes promoted lower wear values, similar to erosion only (4.16 [0.94] μm) in the case of dentin but not enamel (7.1 ± 0.8 μm).
Conclusions: Toothpastes containing charcoal combined with pyrophosphate may have a high abrasive effect on eroded tooth surfaces. Many patients influenced by digital marketing use toothpastes containing activated charcoal with the aim of bleaching their teeth. However, care should be taken when using these products, as they may have a high abrasive effect.

Introduction

Erosive tooth wear (ETW) is a clinical association between erosive and mechanical challenges (eg, dental abrasion) that together potentiate the loss of structure.[1–3] This dental condition has gained special attention from researchers and clinicians around the world due to the increase in its prevalence and clinical detection.[4–7] ETW can have a negative impact on quality of life[8–10] due to the loss of aesthetics or function or the appearance of dentin hypersensitivity.

Dental abrasion, previously mentioned as a factor related to the development of ETW, results from a mechanical process involving objects in contact with the dental structure. Rigorous brushing associated with the use of highly abrasive dentifrices can cause this pathologic wear.[11–14] Amongst the factors involved in abrasion, dentifrice abrasivity seems to be the most important one.[11,15,16]

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Whitening dentifrices may be considered abrasive compared to the conventional ones, especially those containing silica associated with pyrophosphate,[17,18] whilst others containing blue covarine are not abrasive.[17−19] Recently, charcoal-containing toothpastes have been extensivley marketed.[20,21] Products containing activated charcoal have been used for a variety of medical applications, primarily as an antidote to acute poisoning and drug overdose. Less frequently, activated charcoal has been used to treat foul-smelling wounds; it has also become fashionable as a food ingredient and food colouring.[20]

Dentifrices containing activated charcoal have been gaining popularity amongst patients,[20,22,23] especially for all the aesthetic appeal involved. It is believed that activated charcoal added to toothpastes binds to stains and deposits on the tooth surface, which would then be more easily removed by brushing.[24] However, the literature is not consistent regarding the safety of this compound on dental structures[20,21,23,25] and, in addition, another concern is the amount of nonfluoridated toothpastes containing activated carbon available on the market,[22,23] which implies lower efficacy against dental caries.[21,26,27]

There is no consistent information about the abrasivity of whitening toothpastes containing charcoal and fluoride and their effect on ETW in enamel[20] and eroded or sound dentin, respectively.[28,29] Considering the need to evaluate the abrasive potential of new dentifrices containing activated charcoal compared to other whitening dentifrices and even to conventional ones, the aim of this work was to compare dentifrices containing activated charcoal with a conventional dentifrice (pyrophosphate and calcium carbonate) on the development of ETW in vitro. The null hypothesis was that toothpaste containing activated charcoal is not more abrasive than conventional toothpaste on eroded enamel and dentin.

Material and Methods

Sample preparation

This project was submitted for approval by the Ethics Committee on the Use of Animals (#007/2021). One hundred thirty-two enamel and root dentin samples were prepared from bovine incisors donated by Frigol (Lençóis Paulista).

The crown and roots were separated, attached to a prefabricated silicone mould, and embedded in self-curing pink acrylic resin separately. After polymerisation, the samples were polished in a metallographic polisher (Aropol 2V, Arotec). To prevent the interference of grit of the sandpaper on the quality of the sample's surfaces, the tooth/disc assembly was washed in an ultrasonic-T14 ultrasound device (L&R Ultrasonic) at a frequency of 40 KHz for 2 minutes with deionised water.

The baseline profile was measured (5 readings with 3 mm running, and the distance of 250 μm between each reading) using a contact profilometer (Marh Surf XCR 20 software). To enable the repositioning of the samples during the different profile readings, 2 scalpel blade scratches were done to delimit the control and exposed surfaces, in addition to a small hole with a one-quarter drill bit, to indicate the beginning of the readings. A positioning device was used, from which it was possible to reproduce the x and y positions of the samples. This repositioning accuracy provides an adequate interposition between the baseline and final profile, enabling a correct calculation of tooth wear.

Then, two-thirds of the surfaces were protected with red nail polish (Risque), to save 2 control surfaces, indispensable for the measurement and comparison between the profiles.

Tested experimental groups

Enamel and dentin samples were randomly distributed in the following experimental groups (n = 12/dentifrice group; Table 1). The sample size was calculated based on previous studies done on this topic by our research group,[17,18] considering an α error of 5% and a β error of 20%. Activated charcoal toothpastes were selected based on their availability in the main supermarkets and pharmacies of Bauru, São Paulo, Brazil.

pH cycling and abrasive challenge

The samples were subjected to pH cycling for 7 days,[17,18] which was performed 4 times a day as follows: demineralisation by immersion 0.1% citric acid (pH 2.5) for 90 seconds (30 mL/sample) at 25 °C; washing in deionised water; and remineralisation by immersion in artificial saliva containing only minerals[30] (pH 6.8, 2 hours, 30 mL/sample) at 25 °C. The samples were immersed in artificial saliva overnight, completing 24 hours of cycling daily.

After the first and the last exposure to acid, treatment was performed using toothpaste suspension (1 toothpaste:3 water, 12 mL/sample) associated with abrasion. A brushing machine (Biopdi, São Carlos) was used, in which 12 manual brushes with a small head and extra-soft bristles (Curaprox, 5460 ultrasoft) were attached at an angle of 12° to the direction of brushing, allowing a better contact area of the bristles with the tooth surface.

In addition, the toothbrush heads were aligned on the brushing machine brackets so that they were parallel to the tooth surface. Each abrasive challenge was performed for 15 seconds, corresponding to 45 back-and-forth movements (~3 back-and-forth movements/s),[31] through reciprocal linear motion of the brushes, with the application of 150 g of weight on the centre of the brush holder, to provide a force of 1.5 N on the samples at 37 °C.[17,18,32] After the abrasion procedure, the samples remained in contact with the toothpaste slurry for further 45 seconds, then were washed with deionised water (5 seconds) and exposed to artificial saliva as described above.

Wear calculation

To determine the change in the tooth surface profile, the cosmetic nail polish was removed with an acetone solution (1:1, acetone:water), and 5 final readings were taken on the same areas of the baseline readings. The profiles were superimposed using specific software (Marh Surf XCR 20) to calculate

Table 1 – Composition of dentifrices used in the experiment.

Product/trademark	*Composition*
Colgate Triple Action pH 10.0 Batch number: 1317BR1214 - 1325BR1231 - 1322BR1211 Expiry date: 2024/11	Water, calcium carbonate, sorbitol, sodium lauryl sulfate, **sodium monofluorophosphate (1450 ppm F)**, flavor, cellulose gum, **tetrasodium pyrophosphate**, sodium bicarbonate, benzyl alcohol, sodium saccharin, xanthan gum, sodium hydroxide, CI 74260, CI 74160
Colgate Natural Extracts pH 7.3 Batch number: 1230BR1230 - 1284BR123D Expiry date: 2023/08 - 2023/10	Water, glycerin, **hydrated silica**, sodium lauryl sulfate, flavor (peppermint oil), cellulose gum, xanthan gum, sodium saccharin, **powdered charcoal**, benzyl alcohol, eugenol, **sodium fluoride (1450 ppm F)**
Colgate Luminous White Activated Charcoal pH 7.7 Batch number: 1203BR123B - 1260BR122B - 1281BR123B - 1321BR121B Expiry date: 2023/07 - 2023/09 - 2023/10 - 2023/11	Water, sorbitol, **hydrated silica**, PEG-12, sodium lauryl sulfate, flavor, cellulose gum, potassium hydroxide, **tetrasodium pyrophosphatase, phosphoric acid**, cocamidopropyl betaine, sodium saccharin, benzyl alcohol, **charcoal powder**, limonene, **sodium fluoride (1450 ppm F)**
Oral-B Whitening Therapy Charcoal pH 7.7 Batch number: L0122GR - L1021GR / L1038GR Expiry date: 2022/03 - 2022/12	Water, sorbitol, **hydrated silica, disodium pyrophosphate**, sodium lauryl sulfate, cellulose gum, flavor, sodium hydroxide, sodium saccharin, carbomer, titanium dioxide, **charcoal powder**, mica, limonene, sucralose, polysorbate 80, **sodium fluoride (1100 ppm F)**
Oral-B 3D White Mineral Clean pH 7.6 Batch number: 10704354P0 - 10684354P0 Expiry date: 2024/02	Water, sorbitol, **hydrated silica, disodium pyrophosphate**, sodium lauryl sulfate, cellulose gum, flavor, sodium hydroxide, sodium saccharin, carbomer, titanium dioxide, **powdered charcoal**, mica, limonene, sucralose, polysorbate 80, **sodium fluoride (1100 ppm F)**
Curaprox Black Is White pH 6.6 Batch number: 016MHD Expiry date: 2024/01	Water, sorbitol, hydrated silica, glycerin, **charcoal powder**, decyl glycoside, cocoamidopropyl betaine, **sodium monofluorophosphate (950 ppm F)**, tocopherol, xanthan gum, maltodextran, mica, **hydroxyapatite** (nano), acesulfame potassium, titanium dioxide, cellulose microcrystalline, sodium chloride, potassium chloride, lemon peel oil, sodium hydroxide, corn starch, amyloglucosidase, glucose oxidase, urtica dioica extract, potassium thiocyanate, cetostearyl alcohol, hydrogenated lecithin, methyl lactate, ethyl methane carboxamide, stearic acid, mannitol, sodium bisulfite, tin oxide, lactoperoxidase, limonene

the wear (μm). The average wear of the 5 readings per sample was calculated and used to compare the effect of dentifrices on the development of ETW.

Statistical analysis

GraphPad software was used for the statistical analysis. First, the data were analysed with respect to the normal distribution and homogeneity (Kolmogorov and Smirnov and Bartlett tests, respectively). Enamel wear was compared by analysis of variance followed by Tukey test. Considering the absence of homogeneity, the dentin wear values were compared by using Kruskal–Wallis test and Dunn multiple comparisons test. The level of significance adopted was set at 5%.

Results

Table 2 shows the mean and standard deviation of enamel wear (μm) promoted by the tested dentifrices on the eroded surfaces. The erosion-only group showed lower wear values compared to all other groups. Oral-B Whitening Therapy showed the greatest enamel wear, followed by Colgate Luminous White and Oral-B 3D White. The latter did not differ from Colgate Triple Action and Curaprox Black Is White, but it was different from Colgate Natural Extracts, which showed the lowest wear value. Colgate Triple Action and Curaprox Black Is White were similar to Colgate Natural Extracts on enamel wear.

The same Table shows the median and interquartile range of wear (μm) promoted by the tested dentifrices on the

Table 2 – Mean and SD or median and interquartile range of erosive tooth wear (μm) promoted by the tested dentifrices on eroded enamel and dentin samples, respectively.

Groups	Colgate Triple Action	Colgate Natural Extracts	Colgate Luminous White	Oral-B Whitening Therapy	Oral-B 3D White	Curaprox Black Is White	Erosion
Mean ± SD for enamel	12.2 ± 1.2^{bc}	10.8 ± 1.1^{b}	13.6 ± 1.0^{d}	15.1 ± 1.2^{e}	13.0 ± 1.0^{cd}	11.5 ± 1.5^{bc}	7.1 ± 0.8^{a}
Median (interquartile range) for dentin	$5.30\ (1.26)^{ab}$	$4.16\ (1.11)^{a}$	$7.46\ (0.94)^{bc}$	$8.58\ (1.71)^{c}$	$9.37\ (1.36)^{c}$	$4.06\ (0.92)^{a}$	$4.16\ (0.94)^{a}$

For enamel: One-way analysis of variance/Tukey test ($P < .0001$). Different letters within the same line show significant differences between the dentifrices.
For dentin: Kruskal–Wallis/Dunn ($P < .0001$). Different letters within the same line show significant differences between the dentifrices.

eroded dentin samples. The Oral-B 3D White, Oral-B Whitening Therapy, and Colgate Luminous White toothpastes promoted the greatest dentin wear compared to erosion only; the first 2 toothpastes were more abrasive than Colgate Triple Action. On the other hand, Colgate Triple Action, Colgate Natural Extracts, and Curaprox Black Is White toothpastes promoted wear similarly to erosion only, showing no additive effect on dentin wear (Table 2).

Discussion

The null hypothesis tested was partially rejected because the dentifrices containing activated charcoal were more abrasive than traditional ones on eroded tooth surfaces, but not compared to other whitening toothpastes. Colgate Triple Action, Colgate Natural Extracts, and Curaprox Black Is White did not potentialise dentin wear; they enhanced enamel wear compared to erosion only, but at lower level compared to the whitening dentifrices containing activated charcoal. On the other hand, Colgate Luminous White, Oral-B Whitening Therapy, and Oral-B 3D White dentifrices significantly enhanced ETW when compared to the erosion-only group. Oral-B whitening dentifrices were even more abrasive than the conventional dentifrice from Colgate (Colgate Triple Action). A conventional toothpaste containing monofluorophosphate was chosen due to its great popularity and low cost. Despite that the hydrolyse of monofluorophosphate is dependent on the enzymatic action, we did not include this control toothpaste focusing on a possible protective effect of fluoride, because conventional fluoride toothpastes, even those with sodium fluoride, have no relevant protective effect against ETW.[33–35] In addition, the effect of fluoride is influenced or even counteracted by the presence of abrasives.[35]

Oral health is an important issue related to the general health, well-being, and quality of life of individuals. Several dental products are commercially available for maintaining oral hygiene, including whitening dentifrices. The marketing of these products has been influenced by social media and celebrities, and amongst the current trends are dentifrices containing activated charcoal, with the promise of bleaching.

Some studies in the literature criticise the use of this type of dentifrice,[20,23,24] for reasons that include the unproven whitening effect,[23,36,37] the abrasive behaviour,[23,37] and the lack of fluoride in some of them.[20,24] In our study, fluoride-free dentifrices were not included precisely because they are against what is recommended in the literature for prevention of dental caries.[20]

Activated charcoal has been added to potentially whitening dentifrices with the premise of binding the deposits present on the tooth surface that, after brushing, would supposedly be more easily removed.[24] However, no data in the literature support this mechanism, and it is also not known whether brushing in the presence of charcoal could potentiate ETW.

Whilst some studies carried out on sound teeth reported no substantial difference in surface roughness or profile of tooth surfaces mechanically brushed either by conventional or charcoal-based dentifrice,[22,38] several other studies, also performed on sound surface, show the opposite,[23,37,39,40] which is in agreement with the findings of the present study.

Of interest, Koc Vural et al[37] compared the effects of different charcoal-based whitening dentifrices on colour and surface roughness of sound human enamel after 12 weeks of brushing. No differences were found amongst the groups in terms of colour change. However, a substantial increase in surface roughness was found by the action of charcoal. Corroborating this, Palandi et al[23] showed that although charcoal powder did not increase enamel roughness when included into toothpastes, the topography was negatively impacted by charcoal. Furthermore, charcoal was not able to achieve the whitening effectiveness of carbamide peroxide.[23]

Considering that root dentin can be exposed due to gingival recession caused by inflammatory processes or mechanical trauma,[41] this tissue can be easily lost due to the association between erosive and abrasive challenges.[1–3] Also, dentin has a lower surface hardness than enamel, as well as different anatomy and physiology. Thus, dentifrice with charcoal may be more harmful to this tissue than to enamel. In the literature, there is a recent study that evaluated the effect of dentifrices containing activated carbon on erosive/abrasive tooth wear by optical profilometry. When dentin was analysed, Viana et al[28] showed that Colgate Luminous White and Oral-B 3D White dentifrices promoted significantly less wear than the control, which differs from our results. Furthermore, for dentin, not only Colgate Luminous White and Oral-B 3D White but also Elmex Caries, Colgate Natural Extracts, and Curaprox Black Is White exhibited lower dentin loss values than the artificial saliva group.[28]

The difference between our work and the aforementioned study may be due to methodological issues. Viana et al[28] performed more aggressive erosive challenges than our study, so the erosion probably had more influence on tooth wear than the abrasive action. In our study, the treatment was performed in a total time of 1 minute, whilst in the work by Viana et al[28] the treatment lasted for 2 minutes. Furthermore, after the erosive challenge, Viana et al[28] left the specimens for 60 minutes in artificial saliva to later submit them to the abrasive challenge. This may have allowed a different action of the dentifrices on the surface affected by mineral presented in saliva in a way that resulted in nondifferentiation between activated charcoal–based toothpastes and brushing with artificial saliva in their study.

The size, distribution, shape, and hardness of activated carbon particles present in dentifrices, along with the force applied in brushing, can also influence the abrasiveness.[21] In addition, silica plays a very important role in the abrasive action of charcoal.[29] In our work, we did not have access to the details about the characteristics of the coal particles or about the abrasive agent; these factors should be investigated in the future.

So-called whitening dentifrices act via abrasive components to eliminate stains.[18,42] Thus, the presence of abrasive particles in the formulations of these dentifrices can increase their potential for damage when applied during brushing, especially when associated with an erosive challenge.[43] Previous work by our group has shown that some commercial whitening dentifrices, especially those containing pyrophosphate associated with hydrated silica, are capable of enhancing ETW,[17,18] in agreement with the present data, which showed that Colgate Luminous White, Oral-B Whitening Therapy, and Oral-B 3D White dentifrices were the dentifrices that induced the greatest tooth wear, due to the presence of hydrated silica and pyrophosphate in addition to activated carbon powder.

In fact, it is very complicated to explain the different abrasive potentials of each dentifrice due to the complex composition and interaction between ingredients. Furthermore, due to their complex composition, it is very challenging to find a suitable standard control dentifrice that is representative of all those tested.

On the other hand, Colgate Natural Extracts and Curaprox Black Is White dentifrices did not enhance ETW. Colgate Natural Extracts contains only hydrated silica in its composition; it does not contain pyrophosphate, which may explain the result. Curaprox Black Is White dentifrice, despite not having pyrophosphate, contains hydrated silica and also has hydroxyapatite (HA) in its composition. HA is a stable and biocompatible calcium phosphate with low solubility and is used for various applications such as tooth remineralisation, tooth sensitivity reduction, dental biofilm control, and even tooth whitening.[44] The nanocrystalline form of HA has a high surface area that can improve remineralisation and reduce sensitivity.[44] Currently, nanohydroxyapatite (nano-HA) has been used as a protective agent for oral care products because it is more reactive than the conventional particle[44] and can have a significant remineralising effect.[45–47]

In addition, nano-HA penetrates into the demineralised collagen matrix of dentin, acting as a support for remineralisation and providing a source of calcium and phosphate locally.[44] In this study, we did not evaluate possible effects of each compound present in the dentifrices with respect to the abrasive-erosive challenges; however, the presence of nano-HA in the Curaprox Black Is White dentifrice may have been important to minimise its abrasive potential.

In vitro models do not simulate some salivary properties such as acquired pellicle formation and buffering capacity. Furthermore, in clinical situations, saliva is present during both erosive and abrasive challenges, which was not simulated in the present study, since the samples were exposed to the remineralising solution only between challenges. Therefore, the results must be confirmed using in situ models in future works.

Conclusions

Within the limitations of the present study, it can be concluded that dentifrices containing activated charcoal associated with pyrophosphate increase ETW under this model. Therefore, it is important to raise awareness of patients with high susceptibility to ETW when choosing a dentifrice.

Conflict of Interest

None disclosed.

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Author contributions

Mariele Vertuan: conceptualisation; investigation and methodology; formal analysis; writing–original draft; and writing–review and editing.

Júlia França da Silva and *Ana Clara Mota de Oliveira:* conceptualisation; funding acquisition; investigation and methodology; formal analysis; and writing–review and editing.

Thayná Teodoro da Silva, Andreza Peres Justo, and Fernanda Laudares Silva Zordan: investigation and methodology.

Ana Carolina Magalhães: conceptualisation; funding acquisition; project administration; supervision; formal analysis; writing–original draft; and writing–review and editing.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.identj.2022.11.001.

REFERENCES

1. Kanzow P, Wegehaupt FJ, Attin T, Wiegand A. Etiology and pathogenesis of dental erosion. Quintessence Int 2016;47(4):275–8.
2. Ruben JL, Truin GJ, Loomans BAC, Huysmans MCDNJM. Mimicking and measuring occlusal erosive tooth wear with the "Rub&Roll" and non-contact profilometry. J Vis Exp 2018(132):56400.
3. Turssi CP, Binsaleh F, Lippert F, et al. Interplay between toothbrush stiffness and dentifrice abrasivity on the development of non-carious cervical lesions. Clin Oral Investig 2019;23(9):3551–6.
4. Salas MM, Nascimento GG, Huysmans MC, Demarco FF. Estimated prevalence of erosive tooth wear in permanent teeth of children and adolescents: an epidemiological systematic review and meta-regression analysis. J Dent 2015;43(1):42–50.
5. Salas MM, Nascimento GG, Vargas-Ferreira F, Tarquinio SB, Huysmans MC, Demarco FF. Diet influenced tooth erosion prevalence in children and adolescents: results of a meta-analysis and meta-regression. J Dent 2015;43(8):865–75.
6. Luciano LCO, Ferreira MC, Paschoal MA. Prevalence and factors associated with dental erosion in individuals aged 12-

30 years in a northeastern Brazilian city. Clin Cosmet Investig Dent 2017;16(9):85–91.
7. Wetselaar P, Wetselaar-Glas MJM, Katzer LD, Ahlers MO. Diagnosing tooth wear, a new taxonomy based on the revised version of the Tooth Wear Evaluation System (TWES 2.0). J Oral Rehabil 2020;47(6):703–12.
8. Papagianni CE, van der Meulen MJ, Naeije M, Lobbezoo F. Oral health-related quality of life in patients with tooth wear. J Oral Rehabil 2013;40(3):185–90.
9. Li MH, Bernabé E. Tooth wear and quality of life among adults in the United Kingdom. J Dent 2016;55:48–53.
10. Sterenborg BAMM, Bronkhorst EM, Wetselaar P, Lobbezoo F, Loomans BAC, Huysmans MDNJM. The influence of management of tooth wear on oral health-related quality of life. Clin Oral Investig 2018;22(7):2567–73.
11. Magalhães AC, Wiegand A, Buzalaf MA. Use of dentifrices to prevent erosive tooth wear: harmful or helpful? Braz Oral Res 2014;28:1–6.
12. Wiegand A, Schlueter N. The role of oral hygiene: does toothbrushing harm? Monogr Oral Sci 2014;25:215–9.
13. Sabrah AH, Turssi CP, Lippert F, Eckert GJ, Kelly AB, Hara AT. 3D-Image analysis of the impact of toothpaste abrasivity on the progression of simulated non-carious cervical lesions. J Dent 2018;73:14–8.
14. Krol GLS, Wetselaar P, Attin T, Papagianni CE, Wegehaupt FJ. Impact of brushing protocols on dentin abrasion caused by different abrasive slurries. Oral Health Prev Dent 2021;19 (1):345–51.
15. Wiegand A, Egert S, Attin T. Toothbrushing before or after an acidic challenge to minimize tooth wear? An in situ/ex vivo study. Am J Dent 2008;21(1):13–6.
16. Wiegand A, Schwerzmann M, Sener B, et al. Impact of toothpaste slurry abrasivity and toothbrush filament stiffness on abrasion of eroded enamel - an in vitro study. Acta Odontol Scand 2008;66(4):231–5.
17. Mosquim V, Souza BM, Foratori GA Jr, Wang L, Magalhães AC. The abrasive effect of commercial whitening toothpastes on eroded enamel. Am J Dent 2017;30(3):142–6.
18. Vertuan M, de Souza BM, Machado PF, Mosquim V, Magalhães AC. The effect of commercial whitening toothpastes on erosive dentin wear in vitro. Arch Oral Biol 2020;109:104580.
19. Shamel M, Al-Ankily MM, Bakr MM. Influence of different types of whitening tooth pastes on the tooth color, enamel surface roughness and enamel morphology of human teeth. F1000Res 2019;16(8):1764.
20. Brooks JK, Bashirelahi N, Reynolds MA. Charcoal and charcoal-based dentifrices: a literature review. J Am Dent Assoc 2017;148(9):661–70.
21. Machla F, Mulic A, Bruzell E, Valen H, Stenhagen ISR. In vitro abrasivity and chemical properties of charcoal-containing dentifrices. Biomater Investig Dent 2020;7(1):167–74.
22. Franco MC, Uehara J, Meroni BM, Zuttion GS, Cenci MS. The effect of a charcoal-based powder for enamel dental bleaching. Oper Dent 2020;45(6):618–23.
23. Palandi SDS, Kury M, Picolo MZD, Coelho CSS, Cavalli V. Effects of activated charcoal powder combined with toothpastes on enamel color change and surface properties. J Esthet Restor Dent 2020;32(8):783–90.
24. Greenwall LH, Greenwall-Cohen J, Wilson NHF. Charcoal-containing dentifrices. Br Dent J 2019;226(9):697–700.
25. Brooks JK, Bashirelahi N, Reynolds MA. More on charcoal and charcoal-based dentifrices. J Am Dent Assoc 2017;148(11):785.
26. ten Cate JM. Contemporary perspective on the use of fluoride products in caries prevention. Brit Dent J 2013;214(4):161–7.
27. Tembhurkar AR, Dongre S. Studies on fluoride removal using adsorption process. J Environ Sci Eng 2006;48(3):151–6.
28. Viana ÍEL, Weiss GS, Sakae LO, Niemeyer SH, Borges AB, Scaramucci T. Activated charcoal toothpastes do not increase erosive tooth wear. J Dent 2021;109:103677.
29. Osmanaj N, Petersen S, Eisenburger M, Greuling A. Abrasion behavior of different charcoal toothpastes on human dentin when using electric toothbrushes. Dent J (Basel) 2022;10(3):46.
30. Klimek J, Hellwig E, Ahrens G. Fluoride taken up by plaque, by the underlying enamel and by clean enamel from three fluoride compounds in vitro. Caries Res 1982;16:156–61.
31. Heath JR, Wilson HJ. Forces and rates observed during in vivo toothbrushing. Biomed Eng 1974;9:61–4.
32. Voronets J, Jaeggi T, Buergin W, Lussi A. Controlled toothbrush abrasion of softened human enamel. Caries Res 2008;42:286–90.
33. Huysmans MC, Young A, Ganss C. The role of fluoride in erosion therapy. Monogr Oral Sci 2014;25:230–43.
34. Lussi A, Carvalho TS. The future of fluorides and other protective agents in erosion prevention. Caries Res 2015;49(Suppl 1)):18–29.
35. Lussi A, Buzalaf MAR, Duangthip D, et al. The use of fluoride for the prevention of dental erosion and erosive tooth wear in children and adolescents. Eur Arch Paediatr Dent 2019;20 (6):517–27.
36. Vaz VTP, Jubilato DP, Oliveira MRM, 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.
37. 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 (10):5977–85.
38. Ghajari MF, Shamsaei M, Basandeh K, Galouyak MS. Abrasiveness and whitening effect of charcoal-containing whitening toothpastes in permanent teeth. Dent Res J (Isfahan) 2021;19 (18):51.
39. Pertiwi UI, Eriwati YK, Irawan B. Surface changes of enamel after brushing with charcoal toothpaste. J Phys: Conf Ser 2017;884:012002.
40. Korsuwannawong S, Vajrabhaya L, Teinchai C, Salee W. Comparison of enamel surface roughness after brushing with herbal and non-herbal toothpastes. World J Dent 2020;11 (3):215–20.
41. Addy M. Tooth brushing, tooth wear and dentine hypersensitivity—are they associated? Int Dent J 2005;55(4 Suppl 1):261–7.
42. Değer C, Müjdeci A. Whitening dentifrices: a review. Cyprus J Med Sci 2020;5(4):355–60.
43. Vieira GHA, Nogueira MB, Gaio EJ, Rosing CK, Santiago SL, Rego RO. Effect of whitening toothpastes on dentin abrasion: an in vitro study. Oral Health Prev Dent 2016;14(6):547–53.
44. Chen L, Al-Bayatee S, Khurshid Z, Shavandi A, Brunton P, Ratnayake J. Hydroxyapatite in oral care products-a review. Materials (Basel) 2021;14(17):4865.
45. Tschoppe P, Zandim DL, Martus P, Kielbassa AM. Enamel and dentine remineralization by nano-hydroxyapatite toothpastes. J Dent 2011;39(6):430–7.
46. Najibfard K, Ramalingam K, Chedjieu I, Amaechi BT. Remineralization of early caries by a nano-hydroxyapatite dentifrice. J Clin Dent 2011;22(5):139–43.
47. Bossù M, Saccucci M, Salucci A, et al. Enamel remineralization and repair results of biomimetic hydroxyapatite toothpaste on deciduous teeth: an effective option to fluoride toothpaste. J Nanobiotec 2019;17(1):17.