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Dentifrices.

Part 2: The Evidence

Abstract: The intricate formulations of modern dentifrices position them as one of the most sophisticated pharmaceutical products available today. Dental care professionals, tasked with providing evidence-based recommendations, encounter numerous challenges with this everyday product. This necessitates a thorough grasp of dentifrice formulations, familiarity with testing procedures, profound insights into (clinical) trials regarding proven efficacy and safety, and staying updated on current scientific literature. Additionally, recommendations must be tailored to integrate with each individual patient's oral health status, needs, and preferences.

CPD/Clinical Relevance: Dentifrices are complex formulations, carefully prepared by the industry, which need to be proven effective in (clinical) trials, receive evidence-based recommendation from professionals, and be appreciated by end users.

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Successful oral hygiene should rely on advice from the best, currently available evidence.¹ A dental care professional should then be able to advise each individual patient on which dentifrice is most appropriate in his/her particular situation.

All major brands sell products that are supported by a substantial body of evidence. Many scientific publications on dentifrice are published or sponsored by the dentifrice industry. A recent meta-review regarding the evidence behind dentifrices,² like most other scientific literature reviews, still does not include a recommendation for the individual consumer with respect to which specific dentifrice to choose and purchase.³ It is, therefore, debatable

whether the professional has the correct scientific information from dentifrice research to offer effective advice on a dentifrice based on the patient's requirements. There are several challenges, as outlined in Table 1.

Dentifrice formulations

The complex formulations of modern dentifrices make them one of the most sophisticated pharmaceutical products on the market today. The demands of the consumer, coupled with the complexity of the oral cavity, make it a challenging development process.⁴ Insufficient concentrations of the active ingredients

and/or chemical incompatibility within the dentifrice formulation may result in a lack of efficacy. Several challenges can be identified in formulating an effective fluoride dentifrice. Dentifrices of equal total fluoride concentration can significantly differ in their capacity to release bioavailable fluoride owing to differences in their formulation composition.^{5,6} Therefore, the bioavailable amount released is regarded as a more appropriate parameter than total fluoride content.^{6,7} Fluoride can appear in different ways in dentifrices. Soluble fluoride is the only one capable of interacting with the dental surface and causing an anti-carries effect.⁸ Fluoride is primarily known for its adherence to the tooth surface and its incorporation into the pellicle and dental plaque.⁹ Studies on the interaction of fluoride with oral soft tissues are sparse, which may be due to experimental design challenges. However, oral soft tissues are probably the main oral reservoir for fluoride.¹⁰

The most commonly used anionic surfactant ingredient in dentifrices is sodium lauryl sulphate (SLS),^{11,12} which can also

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There is limited unanimity in recommendations on the basic hygiene procedure as being brushing with dentifrice from dental professional organizations as well as dentifrice and toothbrush companies^{1,38}

A substantial amount of industry-initiated and -performed research is not available in the public domain and, if presented, is only referred to as 'data on file'. A positive exception of data transparency from a premier brand dentifrice company is GlaxoSmithKline (GSK). GSK is the first pharmaceutical company, and introduced its GSK Study Register in 2004 (<https://www.gsk-studyregister.com/en/>). Haleon (previously GSK Consumer Healthcare) has a similar platform (<https://haleon-study-register.idea-point.com/StudyRegister.aspx>). It provides supplemental documented information on protocols, summaries of results, including statistical analysis and regulatory overview documents, as well data sharing

Over time, small incremental advances in dentifrice formulations add up to improved efficacy. It is not feasible to test each small advance in dentifrice technology through the expensive route of a randomized controlled trial.³⁹ A related problem is that even when rigorous evaluation is attempted, the time for evaluation may take longer than the commercial lifetime of the dentifrice product.³⁹ By the time the evaluation is complete, the dentifrice may no longer be on the market³⁹

Moreover, the choice of the control dentifrice with which to compare dentifrices formulated for plaque control is important and could influence conclusions drawn from the clinical trials of such products.⁴⁰ A key principle in research ethics is that it should never include a placebo group when an effective product is available.^{41,42} Recently, a company that performed a trial with a placebo group that received a dentifrice without fluoride encountered strong international condemnation.^{41,42} Fluoride dentifrice is considered the gold standard in oral hygiene. When dentifrices are used in research, the full description ingredient label of the used product should be presented because this differs in time and per country

Another critical point of attention is the quality of dental research in general because the evidence suggests that the methodological and reporting aspects of clinical trials in dentistry fields are suboptimal.⁴³⁻⁴⁵ A recent review showed that significant deficiencies in all areas, such as design, conduct, analysis and reporting, are prevalent.⁴⁵ The results of suboptimally designed studies can misinform public policy⁴¹

For randomized trials in general, it is suggested that industry funding may be associated with more favourable results and conclusions.⁴⁶⁻⁴⁸ However, a recent systematic survey, including 121 dentifrice RCTs, found no relationship between positive conclusions and industry funding or conflict of interest⁴⁹

Table 1. Challenges in dentifrice recommendations: navigating industry research, clinical trials, and dental professional perspectives.

influence fluoride effectiveness, and may interfere with fluoride uptake by enamel.¹¹ SLS increases cleaning and foaming actions.¹² Dentifrices with strong flavour characteristics may also affect fluoride effectiveness. This may be primarily a result of excessive salivary stimulation from the strong taste and thus, an increased rate of fluoride clearance from the mouth by dilution.^{10,11}

Another dentifrice ingredient is calcium phosphate. A range of calcium phosphate technologies has been developed to enhance the ability of fluoride to promote remineralization.^{5,6,10} Dentifrices with only fluoride remineralize the surface layer of a caries lesion predominantly.⁵ Dentifrice with added calcium phosphate technologies remineralize the body of the lesion.⁵ However, a concern with adding calcium to dentifrice formulations is the potential for unwanted reactions. Calcium, fluoride, and phosphate may interact to form poorly soluble phases in a paste. During shelf life and when in use, this can reduce the bioavailability of the fluoride and/or the calcium ions.^{5,6}

Findings from *in vitro* studies suggest that adding baking soda to a dentifrice may

interfere with the reactivity of fluoride with enamel, mainly reducing the concentration of the CaF_2 formed.^{13,14} This illustrates the point that adding other active ingredients to a dentifrice, such as baking soda in this instance, requires careful formulation.

Ingredients in dentifrice that aim to inhibit calcium phosphate deposits and prevent the development of calculus are mainly pyrophosphates. Theoretically, pyrophosphates may negatively affect the demineralization–remineralization equilibrium at the tooth surface. Therefore, it is remarkable that in the past 20 years, no long-term, large-scale trials have been published to provide convincing evidence that pyrophosphates do not compromise the caries protection given by fluoride dentifrice. Manufacturers do, however, clearly indicate that products with pyrophosphates are not suitable for children under 12 years of age.¹⁵

Contemporary dentifrices

Dentifrice formulations often contain more than 20 ingredients. Their chemical compositions are constantly changing because of manufacturer competition,

commercial innovation and scientific development.¹⁶ To formulate a dentifrice, several ingredients are essential. Abrasive agents, modified silica abrasives or enzymes help to clean the teeth and may help to whiten teeth by removing surface stains. Examples are calcium carbonate, dehydrated silica gel, hydrated aluminium oxide, magnesium carbonate, phosphate salts and silicates.¹⁷ Detergents, such as SLS or sodium N-lauryl sarcosinate¹⁷ create a foaming action that may help to increase the solubility of plaque and accretions during brushing. SLS is also known to have a slight anti-plaque effect.¹¹

Flavouring agents and non-caloric sweeteners, such as saccharin, are used to improve the taste. Sugar or other cariogenic ingredients are not permitted in any ADA-accepted dentifrices. Humectants, such as glycerol, propylene glycol and sorbitol, are added to prevent dehydration in the dentifrice.¹⁷ Thickening agents or binders are added to stabilize the dentifrice formula. They include mineral colloids, natural gums, seaweed colloids and synthetic cellulose.¹⁷

Hydrogen and carbamide peroxides help to reduce intrinsic stains.¹⁷ Current

Particle size	The abrasivity of dentifrice is mainly determined by its composition with respect to the material, size, shape and amount of abrasive particles incorporated. ^{50,51} It has been shown that the abrasive wear rate increases linearly as the particle size increases up to a critical size, and then it becomes independent of size. ⁵² Different dentifrice formulations contain various abrasive agents, some of which are more abrasive than others ⁵³
RDA value	Since abrasives possess both beneficial and harmful effects, dentifrice abrasivity has been monitored for decades to control these effects.⁵⁴ <i>In vitro</i> studies showed that toothbrushing abrasion is primarily related to the abrasivity of the dentifrice.⁵⁵ However, in similar conditions, the wear produced can vary considerably as other ingredients, such as detergents or thickeners, might also influence and interact with abrasivity.⁵⁶ Moreover, differences in the type of fluoride compound might influence the resulting abrasive wear⁵¹ To measure the abrasive potential of dentifrices, standard laboratory methods have been developed. They have focused on safety to prevent dentifrices from causing harmful effects to dental structures.⁵⁷ The radioactive dentine abrasion (RDA) method has become the most recognized method for measuring dentifrice abrasivity. It is widely known and accepted as the gold standard.^{54,57,58} RDA is a numeric scale that indicates the degree of abrasivity and is useful for comparing different dentifrices. The principles of the RDA were adopted by the American Dental Association (ADA) and International Standard Organization (ISO), and they are widely used by the oral care industry.⁵⁷ Today, only four known laboratories perform RDA assessments according to the original protocols. Although RDA values may vary greatly among testing sites, these values are consistent in intra-laboratory observations.^{57,59,60} However, variability of between 15 and 20% should be expected for the same product tested at different times⁶⁰ The relative enamel abrasivity (REA) describes the abrasive potential of a dentifrice on dental enamel.⁵⁴ To determine the REA of a dentifrice, the same method and standard abrasive is used as in RDA.⁵⁴ However, RDA values are not good predictors of radioactive enamel abrasion.^{51,54,59} Therefore, it is suggested that even low RDA values can be associated with high REA values and vice versa.⁵⁹ A study of the abrasive or erosive effect of two dentifrices showed that both produced some loss of substance. However, there was no connection between laboratory abrasive values and clinical observations^{61,62} The upper limit of RDA defined by the ISO as being safe for daily use is 250.⁵⁷ All dentifrices with the ADA Seal of Acceptance have an RDA of 250 or less.⁶³ Nonetheless, RDA should not be used to rank the safety of dentifrices with RDA values below 250, because these values do not correspond to potential clinical effects, such as abrasion,⁶⁴ but solely to general safety. Care must be taken when extrapolating <i>in vitro</i> RDA data to the clinical situation.^{58,65} It has been suggested that a measuring method for the abrasiveness of dentifrices on eroded enamel should be developed with a respective value. Such a value might help dental professionals to recommend dentifrices that cause low or less abrasive wear in case of erosion.⁵¹ Tooth wear is, however, a multifactorial process, with a complex interplay between erosion, abrasion and attrition, although erosion is regarded as the dominant factor⁶⁵

Table 2. Particle size and RDA value.

dentifrices may also contain several active ingredients to help improve oral health. Desensitizing agents are used to reduce oral discomfort owing to hypersensitivity, with potassium nitrate and stannous fluoride commonly being used.¹⁷ Antimicrobial agents (such as stannous fluoride) are used to reduce gingivitis, and pyrophosphates and zinc citrate are included to reduce the build up of calculus.¹⁷

In an attempt to enhance the natural salivary antimicrobial defence mechanisms, enzymes and proteins have been added to dentifrices. Zendium dentifrice (Unilever, the Netherlands) contains a triple-enzyme system that includes amyloglucosidase, glucose oxidase and lactoperoxidase. This combination generates the natural antimicrobial agents of hydrogen peroxide and hypothiocyanite ions. The salivary proteins, lactoferrin and lysozyme, are also added to the dentifrice.^{18–20} A recent monadic

clinical study indicated that long-term use of this dentifrice was associated with better gingival health status than with the use of other dentifrices.¹⁸

Dentifrices and abrasivity

Dentifrice formulations include abrasives to improve the rheology of the dentifrice⁴ and to remove stained pellicles.^{21,22} Improved surface smoothness is conducive to a feeling of oral cleanliness. An increase in lustre of the tooth surface contributes to oral aesthetics. Brushing with a dentifrice without an abrasive often results in stained teeth.²³ Highly polished enamel appears whiter than duller enamel and is less receptive to the accumulation and retention of dental plaque, calculus, and extrinsic stain. The polishing ability of a dentifrice is therefore an important physical aspect associated with the abrasive system within

the composition.²⁴ Abrasive substances may alter the substantivity or the antimicrobial activity of active ingredients.^{25,26}

Low correlations between the abrasiveness of the dentifrices studied and their cleansing properties indicate that cleaning is not necessarily related to the abrasiveness of dentifrices.²⁷ For details on the particle size and radioactive dentine abrasion (RDA) value of dentifrices, see Table 2.

Alternative dentifrice formulations

Natural, herbal and organic dentifrices are an answer to consumer preferences and concerns about chemical ingredient safety. By emphasizing the use of plant extracts and non-synthetic substances in their branding, the idea is that these 'natural' ingredients are safe. However, terms such as 'natural' and 'herbal' can be used loosely without being

clear what it means, which can make it confusing for consumers.³

A modern example of a popular product framed as 'natural' is charcoal dentifrice. An increasing number of toothpastes with activated charcoal are commercially available.²⁸ It has been intensively promoted by influencers on social media. Internet advertisements have included unsubstantiated therapeutic claims, such as antibacterial, antifungal, antiviral and oral detoxification properties, as well as potentially misleading product assertions.²⁹ In the scientific literature, there is insufficient clinical and laboratory data to substantiate the safety and efficacy claims of charcoal and charcoal-based dentifrices.²⁹ Nevertheless, 96% of commercially available activated charcoal toothpastes claim to effectively whiten teeth in their marketing expressions.³⁰ Studies have identified other methods of whitening to be more effective.^{28,30} For instance, most dentifrices that are specifically formulated for tooth whitening have a beneficial effect in reducing extrinsic tooth surface discolouration.³¹ The possible health risks associated with the use of charcoal-based dentifrices have been considered to be related to the possible inclusion of human carcinogenic polyaromatic hydrocarbons in charcoal and the use of bentonite clay in some charcoal-based dentifrices.³² Charcoal, as an ingredient, may contain high concentrations of heavy metals.^{33,34} Also, charcoal has been recognized as an abrasive mineral to the teeth and gingiva.²⁹ A study that evaluated 50 charcoal-based dentifrices sold via the internet showed that only 8.0% of the products contained fluoride.²⁹ Furthermore, charcoal is a well-known absorptive agent capable of inactivating fluoride.²⁹ In effect, charcoal-based dentifrices will most likely not provide (sufficient) fluoride to the consumer. As fluoride is the main effective ingredient in dentifrice for caries prevention, this is very undesirable.^{29,32,35,36}

In contrast to popular 'green' orientated dentifrices, the well-known commercial fixed formulations of premier brands or their derivative white label dentifrices are generally well described and researched. However, recently, recognized brands have also started to sell charcoal dentifrice with fluoride added to the list of ingredients. These commercial companies are capitalizing on the popularity that began with little or no scientific support through the spread of fake news.³⁷ Such a marketing approach is not limited to just charcoal-

based dentifrices.³²

Consumer mistrust of several ingredients used in the industry has led to the development of a trend for homemade dentifrice.³⁴ A recent study collected 84 homemade dentifrice recipes from 504 websites.³⁴ All studied recipes were fluoride free. The quantities of substances to be used were imprecise. The recipes were difficult to make and impossible to control. Abrasivity, purity and microbial contamination could not be predicted and verified. The importance of professionals addressing the problem and warning consumers of the dangers involved was emphasized.³⁴

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

References

1. Van der Weijden FA, Slot DE. Efficacy of homecare regimens for mechanical plaque removal in managing gingivitis: a meta review. *J Clin Periodontol* 2015; **42 Suppl 16**: S77–91. <https://doi.org/10.1111/jcpe.12359>
2. Valkenburg C, Van der Weijden FA, Slot DE. Plaque control and reduction of gingivitis: the evidence for dentifrices. *Periodontol* 2000 2019; **79**: 221–232. <https://doi.org/10.1111/prd.12257>
3. De la Torre F. Toothpaste. 2020. Available at: www.ethicalconsumer.org/health-beauty/shopping-guide/toothpaste (accessed October 2020).
4. Aspinall SR, Parker JK, Khutoryanskiy VV. Oral care product formulations, properties and challenges. *Colloids Surf B Biointerfaces* 2021; **200**: 111567. <https://doi.org/10.1016/j.colsurfb.2021.111567>
5. Shen P, Walker GD, Yuan Y *et al*. Importance of bioavailable calcium in fluoride dentifrices for enamel remineralization. *J Dent* 2018; **78**: 59–64. <https://doi.org/10.1016/j.jdent.2018.08.005>
6. Shen P, Fernando JR, Yuan Y *et al*. Bioavailable fluoride in calcium-containing dentifrices. *Sci Rep* 2021; **11**: 146. <https://doi.org/10.1038/s41598-020-80503-x>
7. Levine RS. Fluoride in toothpaste – is the expressed total fluoride content meaningful for caries prevention? *Br Dent J* 2020; **228**: 795–799. <https://doi.org/10.1038/s41415-020-1540-8>
8. Valadas LAR, Sorazabal AL, Salgado PA *et al*. Fluoride concentration in dentifrices marketed in Argentina. *Int J Dent Hyg* 2023; **21**: 157–164. <https://doi.org/10.1111/idh.12570>
9. Kirsch J, Hannig M, Winkel P *et al*. Influence of pure fluorides and stannous ions on the initial bacterial colonization *in situ*. *Sci Rep* 2019; **9**: 18499. <https://doi.org/10.1038/s41598-019-55083-0>
10. Duckworth RM. Pharmacokinetics in the oral cavity: fluoride and other active ingredients. *Monogr Oral Sci* 2013; **23**: 125–139. <https://doi.org/10.1159/000350590>
11. Zero DT. Dentifrices, mouthwashes, and remineralization/caries arrestment strategies. *BMC Oral Health* 2006; **6 Suppl 1**: S9. <https://doi.org/10.1186/1472-6831-6-S1-S9>
12. Alli BY, Erinoso OA, Olawuyi AB. Effect of sodium lauryl sulfate on recurrent aphthous stomatitis: a systematic review. *J Oral Pathol Med* 2019; **48**: 358–364. <https://doi.org/10.1111/jop.12845>
13. Kashket S, Yaskell T. Effects of a high-bicarbonate dentifrice on intraoral demineralization. *Compend Contin Educ Dent Suppl* 1997; **18**: S11–16
14. Peres PE, Santos DC, Tabchoury CPM, Cury JA. Effect of bicarbonate on fluoride reactivity with enamel. *Rev Odonto Cienc* 2009; **24**: 6–9.
15. Levine RS. Pyrophosphates in toothpaste: a retrospective and reappraisal. *Br Dent J* 2020; **229**: 687–689. <https://doi.org/10.1038/s41415-020-2346-4>
16. de Groot A. Contact allergy to (ingredients of) toothpastes. *Dermatitis* 2017; **28**: 95–114. <https://doi.org/10.1097/DER.0000000000000255>
17. American Dental Association (ADA). Toothpastes. 2021. Available at: www.ada.org/resources/research/science-and-research-institute/oral-health-topics/toothpastes (accessed February 2024).
18. Pedersen AML, Darwish M, Nicholson J *et al*. Gingival health status in individuals using different types of toothpaste. *J Dent* 2019; **80 Suppl 1**: S13–S18. <https://doi.org/10.1016/j.jdent.2018.08.008>
19. Lynge Pedersen AM, Belstrøm D. The role of natural salivary defences in maintaining a healthy oral microbiota. *J Dent* 2019; **80 Suppl 1**: S3–S12. <https://doi.org/10.1016/j.jdent.2018.08.010>
20. Daly S, Seong J, Newcombe R *et al*. A randomised clinical trial to determine the effect of a toothpaste containing enzymes and proteins on gum health over 3 months. *J Dent* 2019; **80 Suppl 1**: S26–S32. <https://doi.org/10.1016/j.jdent.2018.12.002>
21. Vallotton CF. An acquired pigmented pellicle of the enamel surface: II. Clinical and histologic studies. *J Dent Res* 1945; **24**: 171–181.
22. White DJ, Schneiderman E, Colón E, St John S. A profilometry-based dentifrice abrasion method for V8 brushing machines. Part I: introduction to RDA-PE. *J Clin Dent* 2015; **26**: 1–6.
23. Davis WB. Cleaning and polishing of teeth by brushing. *Community Dent Oral Epidemiol* 1980; **8**: 237–243. <https://doi.org/10.1111/j.1600-0528.1980.tb01295.x>
24. Schemehorn BR, Moore MH, Putt MS. Abrasion, polishing, and stain removal characteristics of various commercial dentifrices *in vitro*. *J Clin Dent* 2011; **22**: 11–18.

25. Ozaki F, Pannuti CM, Imbrunio AV *et al.* Efficacy of a herbal toothpaste on patients with established gingivitis – a randomized controlled trial. *Braz Oral Res* 2006; **20**: 172–177. <https://doi.org/10.1590/s1806-83242006000200015>
26. Koenigs PM, Faller RV. Fundamentals of dentifrice: oral health benefits in a tube. Continuing Education Course. *Dental Care* 2013: 1–30.
27. Lobene RR. Effect of dentifrices on tooth stains with controlled brushing. *J Am Dent Assoc* 1968; **77**: 849–855. <https://doi.org/10.14219/jada.archive.1968.0298>
28. Epple M, Meyer F, Enax J. A critical review of modern concepts for teeth whitening. *Dent J (Basel)* 2019; **7**: 79. <https://doi.org/10.3390/dj7030079>
29. Brooks JK, Bashirelahi N, Reynolds MA. Charcoal and charcoal-based dentifrices: a literature review. *J Am Dent Assoc* 2017; **148**: 661–670. <https://doi.org/10.1016/j.adaj.2017.05.001>
30. 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. <https://doi.org/10.1590/1678-7757-2018-0051>
31. Soeteman GD, Valkenburg C, Van der Weijden GA *et al.* Whitening dentifrice and tooth surface discoloration—a systematic review and meta-analysis. *Int J Dent Hyg* 2018; **16**: 24–35. <https://doi.org/10.1111/idh.12289>
32. Greenwall LH, Greenwall-Cohen J, Wilson NHF. Charcoal-containing dentifrices. *Br Dent J* 2019; **226**: 697–700. <https://doi.org/10.1038/s41415-019-0232-8>
33. Zhen X, Ng WC, Fendy *et al.* Toxicity assessment of carbon black waste: a by-product from oil refineries. *J Hazard Mater* 2017; **321**: 600–610. <https://doi.org/10.1016/j.jhazmat.2016.09.043>
34. Couteau C, Domejean S, Lecoq M *et al.* A study of 84 homemade toothpaste recipes and the problems arising from the type of product. *Br Dent J* 2021. <https://doi.org/10.1038/s41415-021-2736-2>
35. Walsh T, Worthington HV, Glenny AM *et al.* Fluoride toothpastes of different concentrations for preventing dental caries in children and adolescents. *Cochrane Database Syst Rev* 2010; (1): CD007868. <https://doi.org/10.1002/14651858.CD007868.pub2>
36. Walsh T, Worthington HV, Glenny AM *et al.* Fluoride toothpastes of different concentrations for preventing dental caries. *Cochrane Database Syst Rev* 2019; 3(3): CD007868. <https://doi.org/10.1002/14651858.CD007868.pub3>
37. Dias da Silva MA, Walmsley AD. Fake news and dental education. *Br Dent J* 2019; **226**: 397–399. <https://doi.org/10.1038/s41415-019-0079-z>
38. Wainwright J, Sheiham A. An analysis of methods of toothbrushing recommended by dental associations, toothpaste and toothbrush companies and in dental texts. *Br Dent J* 2014; **217**: E5. <https://doi.org/10.1038/sj.bdj.2014.651>
39. Brunette DM. Alternative therapies: abuses of scientific method and challenges to dental research. *J Prosthet Dent* 1998; **80**: 605–614. [https://doi.org/10.1016/s0022-3913\(98\)70039-3](https://doi.org/10.1016/s0022-3913(98)70039-3)
40. Binney A, Addy M, McKeown S, Everatt L. The choice of controls in toothpaste studies. The effect of a number of commercially available toothpastes compared to water on 4-day plaque regrowth. *J Clin Periodontol* 1996; **23**: 456–459. <https://doi.org/10.1111/j.1600-051x.1996.tb00574.x>
41. Shaw D, Naimi-Akbar A, Astvaldsdottir A. The tribulations of toothpaste trials: unethical arginine dentifrice research. *Br Dent J* 2015; **219**: 567–569. <https://doi.org/10.1038/sj.bdj.2015.950>
42. Sykes L, Evans W, Gani F *et al.* Part 15. Secondary use of unethically obtained data: fifty shades of grey/aye/nay. *S Afr Dent J* 2017; **72**: 470–472. <https://doi.org/10.17159/2519-0105/2017/v72no10a5>
43. Pandis N, Polychronopoulou A, Eliades T. An assessment of quality characteristics of randomised control trials published in dental journals. *J Dent* 2010; **38**: 713–721. <https://doi.org/10.1016/j.jdent.2010.05.014>
44. Papageorgiou SN, Antonoglou GN, Martin C, Eliades T. Methods, transparency and reporting of clinical trials in orthodontics and periodontics. *J Orthod* 2011; **46**: 101–109. <https://doi.org/10.1177/1465312519842315>
45. Pandis N, Fleming PS, Katsaros C, Ioannidis JPA. Dental research waste in design, analysis, and reporting: a scoping review. *J Dent Res* 2021; **100**: 245–252. <https://doi.org/10.1177/0022034520962751>
46. Sackett DL, Rosenberg WM, Gray JA *et al.* Evidence based medicine: what it is and what it isn't. *BMJ* 1996; **312**: 71–72. <https://doi.org/10.1136/bmj.312.7023.71>
47. Ioannidis JP, Greenland S, Hlatky MA *et al.* Increasing value and reducing waste in research design, conduct, and analysis. *Lancet* 2014; **383**: 166–175. [https://doi.org/10.1016/S0140-6736\(13\)62227-8](https://doi.org/10.1016/S0140-6736(13)62227-8)
48. Flacco ME, Manzoli L, Boccia S *et al.* Head-to-head randomized trials are mostly industry sponsored and almost always favor the industry sponsor. *J Clin Epidemiol* 2015; **68**: 811–820. <https://doi.org/10.1016/j.jclinepi.2014.12.016>
49. Martins CC, Riva JJ, Firmiro RT, Colunga-Lozano LE *et al.* Conflict of interest is not associated with positive conclusions in toothpaste trials: a systematic survey. *J Clin Epidemiol* 2019; **108**: 141–143. <https://doi.org/10.1016/j.jclinepi.2018.11.026>
50. Lippert F. An introduction to toothpaste – its purpose, history and ingredients. *Monogr Oral Sci* 2013; **23**: 1–14. <https://doi.org/10.1159/000350456>
51. Wegehaupt FJ, Hoegger VGM, Attin T. Abrasion of eroded and sound enamel by a dentifrice containing diamond abrasive particles. *Swiss Dent J* 2017; **127**: 634–639.
52. 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>
53. Addy M. Tooth brushing, tooth wear and dentine hypersensitivity – are they associated? *Int Dent J* 2005; **55** (4 Suppl 1): 261–267. <https://doi.org/10.1111/j.1875-595x.2005.tb00063.x>
54. Hamza B, Attin T, Cucuzza C *et al.* RDA and REA values of commercially available toothpastes utilising diamond powder and traditional abrasives. *Oral Health Prev Dent* 2020; **18**: 807–814. <https://doi.org/10.3290/j.ohpd.a45085>
55. Wiegand A, Schlueter N. The role of oral hygiene: does toothbrushing harm? *Monogr Oral Sci* 2014; **25**: 215–219. <https://doi.org/10.1159/000360379>
56. Moore C, Addy M. Wear of dentine *in vitro* by toothpaste abrasives and detergents alone and combined. *J Clin Periodontol* 2005; **32**: 1242–1246. <https://doi.org/10.1111/j.1600-051x.2005.00857.x>
57. Sabrah AH, Lippert F, Kelly AB, Hara AT. Comparison between radiotracer and surface profile methods for the determination of dentifrice abrasivity. *Wear* 2013; **306**: 73–79. <https://doi.org/10.1016/j.wear.2013.07.001>
58. Hefferen JJ. A laboratory method for assessment of dentifrice abrasivity. *J Dent Res* 1976; **55**: 563–573. <https://doi.org/10.1177/00220345760550040301>
59. Dörfer CE. Abrasivity of dentifrices from a clinical perspective. *J Clin Dent* 2010; **21**: 54.
60. González-Cabezas C, Hara AT, Hefferen J, Lippert F. Abrasivity testing of dentifrices – challenges and current state of the art. *Monogr Oral Sci* 2013; **23**: 100–107. <https://doi.org/10.1159/000350476>
61. Volpe AR, Mooney R, Zumbunnen C *et al.* A long term clinical study evaluating the effect of two dentifrices on oral tissues. *J Periodontol* 1975; **46**: 113–118. <https://doi.org/10.1902/jop.1975.46.2.113>
62. Sangnes G. Traumatization of teeth and gingiva related to habitual tooth cleaning procedures. *J Clin Periodontol* 1976; **3**: 94–103. <https://doi.org/10.1111/j.1600-051x.1976.tb01855.x>
63. American Dental Association (ADA). Toothpastes. Available at: www.ada.org/resources/ada-library/oral-health-topics/toothpastes (accessed March 2024).
64. Maragliano-Muniz P. Protected by a safe RDA: setting the record straight about toothpaste abrasivity. 2016. Available at: www.rdhmag.com/patient-care/article/16409242/protected-by-a-safe-rda-setting-the-record-straight-about-toothpaste-abrasivity (accessed February 2024).
65. Joiner A. Review of the extrinsic stain removal and enamel/dentine abrasion by a calcium carbonate and perlite containing whitening toothpaste. *Int Dent J* 2006; **56**: 175–180. <https://doi.org/10.1111/j.1875-595x.2006.tb00091.x>