Review

# The mechanistic action of tooth whitening products used in dentistry and their potential side effects

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## Abstract

The popularity of tooth whitening is continuing to increase with images of white teeth becoming the norm on social media. However, the mechanistic action of tooth whitening products is not fully understood with several proposed theories as to what causes change in tooth shade. This review aimed to examine the mechanism by which tooth whitening products lead to whiter teeth. The adverse effects of tooth whitening products on the oral mucosa, dentition, and existing dental restorations are also reported.

This review found that whitening toothpastes modify tooth colour by using abrasive particles, optical agents, or chemical agents. The efficiency of abrasive particles is dependent on their hardness, shape, size, applied load and concentration. Optical agents such as Blue Covarine modify the visual perception of tooth colour by shifting the net colour towards white on the colour space model. Commercial toothpastes release less than 0.1% hydrogen peroxide, therefore do not produce significant tooth whitening. Hydrogen peroxide was thought to act through either the chromophore effect, interaction with the organic and inorganic tooth structure or via oxidisation of organic tooth tissue. Tooth whitening can also lead to sensitivity, damage to the oral mucosa and gingiva and potentially cause the release of harmful components from restorative materials.

This review highlights the importance of understanding the mechanism behind tooth whitening products and allows dental care practitioners to advise appropriate and safe methods to combat intrinsic and extrinsic staining.

## Abbreviations

*HAP - Hydroxyapatite*
*HGF - Human gingival fibroblasts*
*RDA - Relative dentine abrasivity*
*REA - Relative enamel abrasivity*

## Introduction

Dentistry has evolved from a profession primarily involved in the management and treatment of oral health and disease, to one that is increasingly involved in the provision of cosmetic procedures such as tooth whitening. This transition has been attributed to the popularity and societal acceptance of cosmetic interventions in order to enhance appearance.[1] The growing popularity of tooth whitening is reflected in the selection of whitening products available to patients and consumers.[2] Despite increased use, the underlying mechanism of tooth whitening is not well understood.[3] The review will further investigate the mechanism behind whitening agents and evaluate their potential side effects, ensuring the provision of safe whitening products with limited side effects on the dentition and oral tissues. Currently, the General Dental Council states that tooth whitening products that release between 0.1% and 6% hydrogen peroxide can only be sold to dental practitioners, with 6% being the maximum concentration dental practitioners can provide patients. These products cannot be used on patients younger than 18 years of age except for the purpose of treating or preventing disease.[4]

## Tooth discolouration

Tooth discolouration can be categorised into two groups: intrinsic and extrinsic staining. Extrinsic stains occur in tooth surface deposits, particularly the dental pellicle or at the tooth surface due to chemical interactions.[2] Extrinsic stains are caused by smoking, chromogenic beverages and foods, and exposure to metallic salts.[5] Intrinsic staining results from changes in how light is scattered and absorbed by enamel and dentine. This can be attributed to genetic disorders, antibiotics, fluorosis, pulpal trauma, tooth resorption and ageing.[5,6,7]

It is imperative dentists understand the vast aetiologies of tooth discolouration as this may influence the whitening products and techniques required to manage discolouration.

***The removal of extrinsic stains***

Extrinsic stains can be removed by dental prophylaxis and controlled by regular use of an effective whitening toothpaste.[8] Whitening toothpastes vary in formulations with a range of tooth-whitening technologies such as optical pigments and hydrogen peroxide.[9] Activated charcoal/carbon-based dentifrices also claim to cause tooth whitening. However, a recent review found insufficient clinical and laboratory data to verify the efficacy charcoal-based dentifrices.[10] The active ingredients in whitening toothpastes that modify tooth colour can be divided into three main groups: abrasives, optical agents and chemical agents.[11]

***Abrasives***

Abrasives are insoluble particles that become trapped between toothbrush bristles and the enamel surface. Abrasives are physically harder than stain particles allowing the abrasion of extrinsic stains from the tooth surface. Factors that affect the efficiency of abrasives include particle hardness, shape, size, applied load and concentration.[11]

Whilst abrasives can be efficient in removing stains, they also cause tooth wear. Studies have found that toothpastes with high relative dentine abrasivity (RDA) caused a statistically significant increase in mean dentine wear in comparison to toothpastes with a low RDA. However, these studies reported minimal abrasion to enamel and had low relative enamel abrasivity (REA).[12,13] Few studies in literature look specifically at the REA of toothpastes, this may be because enamel is harder than most abrasives in toothpastes (except for hydrated alumina, perlite and diamond powder). Therefore, most toothpastes have relatively low REA despite having high RDA.[14] Franzò et al[12] is an in-vitro study, therefore their results cannot be extrapolated in-vivo due to environmental differences such as the absence of saliva which can affect toothpaste concentration and pH, both factors known to affect the extent of dentine wear.[12,13] In contrast, Hooper et al[13] is an in-situ study which is able to replicate in-vivo conditions more accurately while retaining the sensitivity of laboratory analysis, therefore providing valid results regarding the effects of abrasives on dental wear.[15]

Excessive tooth wear can cause exposure of dentinal tubules resulting in dentine hypersensitivity.[16] However, Hooper et al[13] extrapolated mean enamel abrasion values to possible lifetime values and found that a lifetimes brushing would be equivalent to approximately 38µm of abrasion. This is clinically irrelevant as typically enamel thickness at the cervical margin is 130µm and is much thicker over the rest of the tooth.[13] Although, these predictions may vary greatly depending on the individual, their brushing habits and existing tooth wear.

***Optical agents***

Blue Covarine and other optical pigments found in whitening toothpastes mask the yellow appearance of dentine by depositing a semi-transparent blue layer on the pellicle-coated enamel surface. This modifies the visual perception of tooth colour as blue opposes yellow on the colour space model, as seen in **Figure 1**. This shifts the net colour towards white, resulting in the visually whiter teeth.[9,17,18] This may be ideal for patients with erosive tooth wear who have worn down their enamel. However, the colour space model suggests that Blue Covarine may not mask all stains unless they are on the yellow spectrum. Therefore, the nature of the stain is important to the efficacy of Blue Covarine as a tooth-whitening agent.

Joiner et al[17] found that 0.2% Blue Covarine treatment resulted in a significantly larger increase in mean vita shade change compared to water treatment. However, results vary as other studies have found no significant difference in mean vita shade change because of Blue Covarine treatment.[18,19] Further research is required to form a consensus on the whitening efficiency of Blue Covarine.

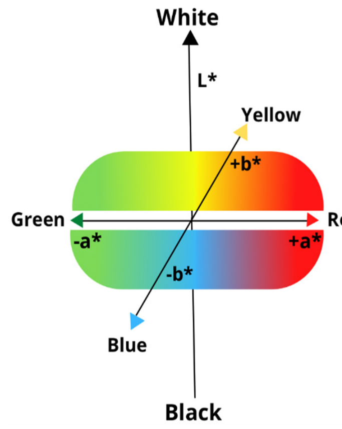


**Figure 1. Colour space model** Adapted from Joiner A, 2004[8], by Elsevier.

## The removal of extrinsic and intrinsic stains

***Chemical agents***

Staining can be removed by bleaching, which is performed by oxidising agents like hydrogen peroxide, this is the main agent in most tooth-whitening products.[3,4] Hydrogen peroxide can be directly or indirectly applied in the form of sodium perborate or carbamide peroxide.[4] Oxidising agents are used in whitening toothpastes, whitening strips and gels, whitening rinses, tray-based tooth whiteners, and in-office whitening procedures.[3,20] Hydrogen peroxide is a highly unstable molecule that decomposes, giving rise to free radicals, reactive oxygen species and hydrogen peroxide anions.[21] The production of these reactive molecules is influenced by light, pH, temperature and interactions with transition metals.[22]

The penetration of chemical whitening agents has been investigated by Kwon et al[23] where it was observed that Rhodamine B dye readily penetrated through the enamel- dentin complex via the interprismatic spaces in enamel and along the dentinal tubules in dentine. They theorised that Rhodamine B and hydrogen peroxide may demonstrate similar patterns of penetration, as Rhodamine B has a low molecular weight ($479 gmol^{-1}$) like that of hydrogen peroxide ($34 gmol^{-1}$). However, as this study did not use hydrogen peroxide, it cannot provide conclusive evidence for the penetration pattern of hydrogen peroxide. Kwon et al[23] is an in-vitro study that utilised extracted teeth therefore the dentinal tubules were absent of fluid. It is suggested that outward fluid flow from the tubules may rinse them free of inwardly diffusing substances.[24] Therefore, the diffusion pattern observed by Kwon et al[23] may differ in vital teeth.

## The interactions of chemical whitening agents

***Chromophore theory***

Whitening agents are thought to interact with intrinsically stained teeth according to the chromophore theory.[3] This would be the ideal mechanism of interaction as it only involves interaction of whitening agents with chromogens and preserves the tooth structure.

Tooth colour is determined by the combination of light reflected and scattered by semi-translucent enamel and the underlying dentine.[25] An object appearing white reflects all the colours of the visible light spectrum.[25] Chromogenic compounds like tannins, found in coffee, can have high molecular weights of up to 20,000g/mol.[26] These compounds absorb ambient visible light, decreasing the spectral reflectance of the tooth and resulting in the production of colour.[23] Hydrogen peroxide oxidises double bonds within chromogenic compounds converting them into simpler molecules that are colourless and soluble.[27,28] As a result, tooth tissue may display reduced light absorption and increased light reflection which helping to explain the whitening action of peroxides. However, the chromophore theory is not fully supported as studies using spectroscopy have failed to detect chromogens or their breakdown products within the tooth structure.[3]

***Interaction of organic compounds within dentine with peroxides***

Another theory is that peroxides may interact with the tooth's organic compounds.[29,30] Kawamoto et al[29] proposed that the whitening effect was due to the breakdown of amino acids and amides that compose polypeptide chains in the organic dentine matrix. They added amino acids like proline and alanine which form core components of dentine proteins to 30% hydrogen peroxide and found proline was completely degraded. Similarly, Ubaldini et al[30] found that 25% hydrogen peroxide treatment caused a decrease in amides I, II, and III absorption bands analysed using spectroscopy. Therefore, protein degradation could alter the structure of the organic dentine matrix, changing how light is scattered and absorbed within the dentine layer which may affect tooth colour.[26]

***Interaction of inorganic compounds with peroxides***

Alternatively, tooth mineral may be the predominant factor affecting tooth colour while tooth organic content is mainly transparent.[31] Therefore, the effects of peroxides on the organic dentine matrix would have negligible effects on tooth colour. Eimar et al[32] found that tooth hue was associated with hydroxyapatite (HAP) crystal size. In addition, they found that tooth chroma was associated with enamel carbonization, and tooth lightness was affected by both HAP crystal size and carbonization. Eimar et al[31] used extracted teeth due to the impracticality of performing tests on teeth inside patients' mouths. Therefore, these results may not be extrapolated to vital teeth, as tooth colour has shown to differ in extracted teeth compared to vital teeth.[33]

***Oxidation of organic tooth tissue***

Oxidation of organic tooth tissue may also contribute to tooth whitening. Eimar et al[31] argues that tooth-whitening is not caused by deproteinisation of the organic matrix nor modification of the tooth's inorganic contents but may result due to oxidation of the transparent organic matrix into an opaque whiter material. In this study, 60 teeth were divided into four groups and treated with one of the following solutions: NaOH (deproteinising), EDTA (demineralising), hydrogen peroxide (oxidising agent) and distilled water (control). They found that immersion in both NaOH and peroxide resulted in lighter teeth, however the change in lightness caused by peroxide was much greater than that by NaOH.

Despite the proposed theories regarding the mechanistic action underlying bleaching agents, there is no conclusive evidence that supports any one of these theories. Therefore, further research into existing mechanisms is required to establish the true mechanism/s.
Side effects of chemical whitening agents

Chemical agents used in tooth-whitening have a range of side effects due to their oxidative nature. Local side effects include pulp sensitivity, cervical resorption, release of components from restorative materials, and alteration to the enamel surface.[34]

***Tooth sensitivity***

Tooth sensitivity is a common side effect of tooth-whitening. In a randomised, double-blind clinical trial, 172 people bleached their teeth for 14 days with 10% carbamide peroxide. 47% of people reported sensitivity during the procedure, and the average number of days of sensitivity experienced was 3.1.[35] Chemin et al[36] found a higher agent concentration resulted in greater sensitivity whereas, others have found that the incidence of sensitivity is the same whether 10% or 30% of hydrogen peroxide is used.[37] This suggests other factors may play a greater role in determining sensitivity such as bleaching time.[38] Failure of studies to show a difference between sensitivity and agent concentrations may be due to the strict selection of patients without a previous history of sensitivity.[39]

The mechanism behind bleaching sensitivity is not fully understood. However, it is thought that hydrogen peroxide and its by-products can diffuse down the dentinal tubules into the pulp, resulting in reversible pulpitis and tooth sensitivity.[5,40] Although, other studies hypothesise that sensitivity is due to direct activation of pulpal sensory afferents via TRPA1 ion channels which respond to oxidising compounds like peroxides.[41]

***Oral mucosa and gingival effects***

Oxidative stress can lead to genomic damage in oral mucosal cells.[42] Klaric et al[42] observed an increase in genotoxicity markers in oral mucosal cells following bleaching. Although the increase in genotoxicity markers was statistically significant, it was relatively small considering the high variability of markers at basal levels. As oral mucosal cells have a short lifespan, bleaching likely has negligible genotoxic and carcinogenic potential.[41] Furthermore, Goldberg et al[34] found that genotoxicity and carcinogenicity only occurs at concentrations that are never reached during dental procedures.

The effect of bleaching on human gingival fibroblasts (HGF) in-vitro has been examined by several studies. Tipton et al[43] found that hydrogen peroxide concentrations as low as 0.025- 0.05% killed off HGF. Another study found that the reduction in the number of HGF became significant at even lower concentrations of 0.0015% hydrogen peroxide.[44] This raises concern, as currently, over the counter whitening products contain hydrogen peroxide concentrations of 0.1%.[45] These products are used without the guidance of dental professionals, which may result in improper use and harm to the gingiva. Although, it is thought that enzymes in the oral environment may be able to destroy hydrogen peroxide, thereby, protecting oral tissues from cytotoxicity.[44]

***Effects on restorations***

Khamverdi et al[46] found carbamide peroxide concentrations of 16% caused a significant increase in the release of mercury and silver from amalgam restorations. Released mercury may be absorbed by oral, respiratory, and gastro-intestinal mucosa, increasing the risk of toxic systemic side-effects.[46] However, it is suggested that the dental biofilm may reduce the release of mercury from dental amalgam in-vivo, reducing the risk of potential amalgam toxicity.[47]

## Conclusion

There are numerous whitening products and methods that alter tooth colour. The mechanism behind whitening agents used in dentifrices such as abrasives and optical dyes, is well established. However, the mechanism responsible for peroxide tooth-whitening is a complex phenomenon. Extensive research is required to establish how hydrogen peroxide oxidises the transparent organic contents of the tooth into an opaque whiter material. Further research is also needed to disprove other proposed mechanisms by which bleaching results in whiter teeth. However, for this to occur there are limitations that need to be addressed, such as the inability of current instrumental methods to detect the presence of chromophores within the tooth. The side effects of whitening agents are typically minimal/ temporary when used according to the manufacturer's guidelines. Due to the lack of literature regarding the in-vivo effects of hydrogen peroxide, its effects within the oral cavity are not yet fully established.

In summary, dentists should be able to give patient-specific advice regarding tooth-whitening, taking into consideration the type of staining, dietary habits, previous restorations and any oral or systemic conditions a patient may have. This is likely to minimise the potential side effects of agents and optimise tooth-whitening.

## Contribution statement

The author has made substantial contributions to the conception or design of the work, drafted the work, and gave final approval of the version to be included in Inspire.



## References

1. Theobald AH, Wong BK, Quick AN et al. The impact of the popular media on cosmetic dentistry. N Z Dent J. 2006;102(3):58-63.
2. Carey CM. Tooth whitening: what we now know. J Evid Based Dent Pract. 2014;14 Suppl:70-6.
3. Kwon SR, Wertz PW. Review of the Mechanism of Tooth Whitening. J Esthet Restor Dent. 2015;27(5):240-57.
4. GDC. What is the legal position on tooth whitening? 2016. Avaliable at: https://www.gdc-uk.org/docs/default-source/what-is-the-legal-position/tooth-whitening-position-statement.pdf Accessed: 12 March 2022
5. Kihn PW. Vital tooth whitening. Dent Clin North Am. 2007;51(2):319-31, viii.
6. Casado BGS, Moraes SLD, Souza GFM et al. Efficacy of Dental Bleaching with Whitening Dentifrices: A Systematic Review. International Journal of Dentistry. 2018;2018:7868531.
7. Manuel ST AP, Kundabala M. Etiology of tooth discoloration- a review. Nig Dent J. 2010;18(2):56-63.
8. Joiner A. Tooth colour: a review of the literature. Journal of Dentistry. 2004;32:3-12.
9. 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.
10. Brooks JK, Bashirelahi N, Reynolds MA. Charcoal and charcoal-based dentifrices: A literature review. The Journal of the American Dental Association. 2017;148(9):661-70.
11. Joiner A. Whitening toothpastes: A review of the literature. Journal of Dentistry. 2010;38:e17-e24.
12. Franzò D, Philpotts CJ, Cox TF et al. The effect of toothpaste concentration on enamel and dentine wear in vitro. Journal of Dentistry. 2010;38(12):974-9.
13. Hooper S, West NX, Pickles MJ et al. Investigation of erosion and abrasion on enamel and dentine: a model in situ using toothpastes of different abrasivity. Journal of Clinical Periodontology. 2003;30(9):802-8.
14. Hara AT, Turssi CP. Baking soda as an abrasive in toothpastes: Mechanism of action and safety and effectiveness considerations. The Journal of the American Dental Association. 2017;148(11, Supplement):S27-S33.
15. Hunter ML, Addy M, Pickles MJ et al. The role of toothpastes and toothbrushes in the aetiology of tooth wear. International Dental Journal. 2002;52(S5):399-405.
16. Addy M. Tooth brushing, tooth wear and dentine hypersensitivity--are they associated? Int Dent J. 2005;55(4 Suppl 1):261-7.
17. Joiner A, Philpotts CJ, Alonso C et al. A novel optical approach to achieving tooth whitening. Journal of Dentistry. 2008;36:8-14.
18. Dantas A, Bortolatto J, Roncolato Á et al. Can a bleaching toothpaste containing Blue Covarine demonstrate the same bleaching as conventional techniques? An in vitro, randomized and blinded study. Appl Oral Sci. 2015 Nov-Dec;23(6):609-13.
19. Torres CR, Perote LC, Gutierrez NC et al. Efficacy of mouth rinses and toothpaste on tooth whitening. Oper Dent. 2013;38(1):57-62.
20. Alqahtani MQ. Tooth-bleaching procedures and their controversial effects: a literature review. Saudi Dent J. 2014;26(2):33-46.
21. Xu B, Li Q, Wang Y. Effects of pH values of hydrogen peroxide bleaching agents on enamel surface properties. Oper Dent. 2011;36(5):554-62.
22. Torres CR, Crastechini E, Feitosa FA et al. Influence of pH on the effectiveness of hydrogen peroxide whitening. Oper Dent. 2014;39(6):E261-8.
23. Kwon SR, Wertz PW, Li Y et al. Penetration pattern of rhodamine dyes into enamel and dentin: confocal laser microscopy observation. Int J Cosmet Sci. 2011;34(1):97-101.
24. Pashley DH. Dynamics of the pulpo-dentin complex. Crit Rev Oral Biol Med. 1996;7(2):104-33.
25. Brook AH, Smith RN, Lath DJ. The clinical measurement of tooth colour and stain. Int Dent J. 2007;57(5):324-30.
26. Joiner A, Luo W. Tooth colour and whiteness: a review. Journal of Dentistry. 2017;67:S3-S10.
27. Kwon SR, Wertz PW, Dawson DV et al. The relationship of hydrogen peroxide exposure protocol to bleaching efficacy. Oper Dent. 2013 Mar-Apr;38(2):177-85.
28. Plotino G, Buono L, Grande NM et al. Nonvital tooth bleaching: a review of the literature and clinical procedures. J Endod. 2008;34(4):394-407.
29. Kawamoto K, Tsujimoto Y. Effects of the hydroxyl radical and hydrogen peroxide on tooth bleaching. Journal of Endodontics. 2004;30(1):45-50.
30. Ubaldini AL, Baesso ML, Medina Neto A et al. Hydrogen peroxide diffusion dynamics in dental tissues. J Dent Res. 2013;92(7):661-5.
31. Eimar H, Siciliano R, Abdallah M-N et al. Hydrogen peroxide whitens teeth by oxidizing the organic structure. Journal of Dentistry. 2012;40:e25-e33.
32. Eimar H, Marelli B, Nazhat SN et al. The role of enamel crystallography on tooth shade. Journal of Dentistry. 2011;39:e3-e10.
33. Greta DC, Colosi HA, Gasparik C et al. Color comparison between non-vital and vital teeth. The journal of advanced prosthodontics. 2018;10(3):218-26.
34. Goldberg M, Grootveld M, Lynch E. Undesirable and adverse effects of tooth-whitening products: a review. Clin Oral Investig. 2010;14(1):1-10.
35. Browning WD, Blalock JS, Frazier KB et al. Duration and timing of sensitivity related to bleaching. Journal of Esthetic and Restorative Dentistry. 2007;19(5):256-64.
36. Chemin K, Rezende M, Loguercio AD et al. Effectiveness of and dental sensitivity to at-home bleaching with 4% and 10% hydrogen peroxide: a randomized, triple-blind clinical trial. Oper Dent. 2018;43(3):232-40.
37. Dahl JE, Pallesen U. Tooth bleaching--a critical review of the biological aspects. Crit Rev Oral Biol Med. 2003;14(4):292-304.
38. Basting RT, Amaral FL, França FM et al. Clinical comparative study of the effectiveness of and tooth sensitivity to 10% and 20% carbamide peroxide home-use and 35% and 38% hydrogen peroxide in-office bleaching materials containing desensitizing agents. Oper Dent. 2012;37(5):464-73.
39. Bersezio C, Estay J, Jorquera G et al. Effectiveness of dental bleaching with 37.5% and 6% hydrogen peroxide and its effect on quality of life. Oper Dent. 2019;44(2):146-55.
40. Tredwin CJ, Naik S, Lewis NJ et al. Hydrogen peroxide tooth-whitening (bleaching) products: Review of adverse effects and safety issues. British Dental Journal. 2006;200:371.
41. Markowitz K. Pretty painful: Why does tooth bleaching hurt? Medical Hypotheses. 2010;74(5):835-40.
42. Klaric E, Par M, Profeta I et al. Genotoxic effect of two bleaching agents on oral mucosa. Cancer Genomics Proteomics. 2013;10(5):209-15.
43. Tipton DA, Braxton SD, Dabbous MK. Effects of a bleaching agent on human gingival fibroblasts. Journal of Periodontology. 1995;66(1):7-13.
44. Furukawa M, K-Kaneyama JR, Yamada M et al. Cytotoxic effects of hydrogen peroxide on human gingival fibroblasts in vitro. Oper Dent. 2015;40(4):430-9.
45. Lewis BB. Formocresol in dentistry. BDJ. 2008;204:477.
46. Khamverdi Z, Ebadi S, Movahhed Rad M et al. Effect of two bleaching agent products on mercury and silver Ion release from dental amalgam. Journal of Dentistry of Tehran University of Medical Sciences. 2009; 6.
47. Steinberg D, Blank O, Rotstein I. Influence of dental biofilm on release of mercury from amalgam exposed to carbamide peroxide. J Biomed Mater Res B Appl Biomater. 2003;67(1):627-31.

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I recently graduated from Cardiff University and will be completing my dental foundation training in Sussex. My special interests include restorative dentistry and oral surgery. Dentistry has progressed from a profession solely responsible for treating disease to one that is increasing concerned about aesthetics. As a result of this shift, I have become interested in the range of tooth whitening technologies available and the mechanism by which they whiten teeth. I am also interested in the influence of artificial intelligence on the field of oral maxillofacial radiology and its potential future uses in healthcare.