Stain removal and whitening by baking soda dentifrice
A review of literature

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Tooth color, especially for teeth in the maxillary anterior region, is commonly regarded as one of the key components in the perception of dental esthetics and personal attractiveness. The quest for whiter teeth is not a new fashion. Tooth discoloration was recognized in the literature as a dental problem more than 150 years ago, and the use of hydrogen peroxide ($\text{H}_2\text{O}_2$) solution to remove tooth stains can be traced back more than a century. Since the introduction of at-home tooth bleaching by Haywood and Heymann, consumers have been increasingly interested in tooth whitening. The continued demand by the public in turn has promoted advances in tooth-whitening technology, leading to a variety of peroxide-based tooth-bleaching gels and strips as well as specifically formulated whitening tooth-pastes containing peroxide or effective abrasive systems. Today, tooth whitening is recognized as an integral part of dentistry as well as a common practice in the general population.

Although the terms “tooth bleaching” and “tooth whitening” are often used interchangeably, both in the literature and clinical practice, they are technically not synonymous. Bleaching is a process involving an oxidative chemical that alters the light-absorbing or light-reflecting nature of a material structure, increasing its perception of whiteness. Therefore, bleaching, as defined by the
International Organization for Standardization, is the “removal of intrinsic or acquired discolorations of natural teeth through the use of chemicals, sometimes in combination with the application of auxiliary means.” In contrast, tooth whitening is the process that results in the teeth becoming whiter in perceived color, regardless of the means used. Therefore, tooth whitening can include bleaching with peroxides and mechanical approaches to remove surface stains using professionally applied abrasive prophylaxis pastes as well as tooth brushing with a whitening dentifrice. Over the last 2 decades, advances in research and technology have led to innovative formulations of whitening dentifrices, including those using sodium bicarbonate (baking soda) as the sole abrasive or as a component of an abrasive system.

In this article, I review the etiology of tooth stain, methods used for tooth whitening, and evidence in the literature on the clinical efficacy and safety of dentifrices for stain removal and whitening, with special emphasis on baking soda dentifrice formulations.

ETIOLOGY OF TOOTH STAINS AND DISCOLORATION
Tooth discoloration is caused by stains that may be intrinsic, extrinsic, or a combination of both in terms of the source. Extrinsic stains usually affect the entire dentition, whereas tooth discolorations caused by intrinsic stains may involve all or individual teeth. In addition, tooth discoloration can be associated with dental procedures. In general, discoloration of anterior teeth is the major reason to consider whitening.

Intrinsic tooth stains. Intrinsic tooth stains can occur to the entire dentition or an individual tooth, and they can be caused by a number of factors, including aging, systemic medications such as tetracycline, intrapulpal hemorrhage, calcific metamorphosis, pulp necrosis, and certain diseases or tooth defects. As people age, enamel becomes thinner owing to its use while dentin becomes thicker because of dentin apposition; such physiological changes of tooth structure affect optical properties of the tooth, resulting in progressive darkening of tooth color. In addition, enamel cracking, crazing, and wear tend to increase with the duration of use of teeth, consequently increasing the risk of cumulative extrinsic stains from food and beverages. Tetracycline was used extensively during the 1950s and 1960s for prophylactic protection and treatment of infections and was sometimes prescribed for daily intake for an extended period. It is now well known that ingested tetracycline during tooth formation is capable of causing severe, distinctive tooth discoloration. Although tetracycline is no longer used for prolonged periods during tooth formation, dentists still face the challenge of dealing with tooth discoloration in people who used it in their childhood before the recognition of its ability to cause severe tooth stains.

Intrinsic tooth stains also may be caused by certain diseases or conditions in which chromogenic substances are deposited within the tooth structure, such as erythroblastosis fetalis, thalassemia, sickle cell anemia, and porphyria. Severe dental fluorosis, a type of enamel hypoplasia caused by excessive exposure to fluoride during tooth formation, results in defects in enamel mineralization manifested as areas of brown discoloration.

Extrinsic tooth stains. Extrinsic tooth stains are most commonly caused by the colored components of various food and beverages, including coffee, tea, and red wine, and by the use of tobacco products. The role of acquired pellicle in tooth-surface staining has been well recognized. Extrinsic stains are located on the tooth surface and may be aggravated in areas in which the enamel is porous and rough. The structural defects in the enamel may alter optical properties of the tooth, which is consequently perceived as discolored, whereas the porous and rough surface of the defective enamel attracts extrinsic stains present in the oral cavity.

It is important to recognize that the etiology of extrinsic staining varies significantly among people and often is influenced by oral hygiene habits, diet, and lifestyle. A variety of chromogenic oral microorganisms are capable of producing pigment molecules and consequently are responsible for some tooth stains; for example, a 2010 article reported a case of blue tooth staining that was caused by Pseudomonas aeruginosa, a bacterium usually implicated in chronic pulmonary infections.

Tooth discoloration associated with dental procedures. Certain dental materials and inappropriate operating techniques can be the origin of tooth stains. Whereas the source of a stain that causes tooth discoloration is technically extrinsic, the discoloration is limited to the individual teeth restored with the dental material or those teeth that received a dental procedure. A stain related to an amalgam restoration not only is a dark metallic color but also can produce colored corrosion products over time to stain the restored tooth. It also has been reported that extended tooth bleaching with a gel of 10% carbamide peroxide caused green staining of the tooth-amalgam interface. For resin composite restorations, the restoration itself may become discolored with time; furthermore, microleakage, if present, attracts extrinsic stains and consequently causes tooth discoloration. Open margins allow stains to enter the interface between the restoration and the tooth structure, which consequently discolors the underlying dentin.

Another common cause of tooth discoloration is associated with endodontic procedures, such as the incomplete removal of remnants of obturating materials and sealers containing metallic components in the pulp chamber, resulting in dark discoloration of the tooth.\textsuperscript{18-20} Phenolics or iodoform-based medicaments sealed in the root canal and chamber are capable of causing internal staining of dentin. Such a medicament in direct contact with dentin, especially when placed for a long period, allows penetration and oxidation, resulting in discoloration of the dentin. Tissue remains left in the pulp chamber as a result of inappropriate endodontic procedures can disintegrate gradually and consequently cause tooth staining.

CURRENT MEASURES FOR STAIN REMOVAL AND WHITENING

Various methods and techniques have been used to remove tooth-surface stains to achieve a whitening effect. The correction of certain tooth discolorations, such as those associated with certain systemic conditions or dental procedures, requires treatment by dental professionals. In general, tooth whitening may be achieved by the removal of extrinsic and intrinsic stains using peroxide-based bleaching products and abrasive materials such as dental prophylactic pastes and dentifrices.

Tooth bleaching using peroxides. Little dispute exists about the whitening efficacy of peroxide-based tooth-bleaching materials, although the mechanisms of tooth bleaching remain unclear.\textsuperscript{1,21,22} It is generally hypothesized that free radicals produced by $\text{H}_2\text{O}_2$ are responsible for the bleaching effects. As $\text{H}_2\text{O}_2$ diffuses through the enamel and dentin, it produces free radicals, which react with pigment molecules to break their double bonds, consequently resulting in the perception of a lighter tooth color by human eyes. This assumption also helps explain the commonly observed shade rebounding shortly after a bleaching treatment, probably due to the reformation of the double bonds.

However, there have been safety concerns with the use of peroxides for tooth whitening, mainly due to potential toxicologic effects of oxidative free radicals.\textsuperscript{23-30} At this point, with the accumulation of research data, the safety issues with tooth bleaching largely have dissipated.\textsuperscript{31-33} However, adverse effects have been reported, and the risk appears to be associated with the quality of bleaching material, technique used, and people’s responses to the bleaching treatment.\textsuperscript{32-35} Commonly known risks associated with tooth bleaching are primarily local, including tooth sensitivity and gingival irritation as well as potential adverse effects on enamel and restorative materials. At present, a number of countries regulate peroxide-based tooth-bleaching products with a limit on peroxide content, and their availability is restricted to dental professionals. In recent years, there also have been ongoing debates and legal challenges in the United States over whether peroxide-based bleaching can be performed by providers without dental credentials.

Dental prophylaxis. Dental prophylaxis is a standard practice primarily intended to remove dental plaque and calculus for preventing dental caries and gingival inflammation. The abrasives in the prophylactic paste also clean stains on tooth surface, resulting in a whitening effect. Therefore, the recommended regular dental prophylaxis serves a dual purpose. Dental prophylaxis requires an office visit, and its primary objective is to remove dental plaque and calculus to maintain dental and gingival health.

Tooth-whitening dentifrice. Toothbrushing with dentifrice has long been recognized as an essential measure for maintaining personal oral hygiene. In addition to providing a clean and refreshing feeling in the oral cavity, the original purpose of daily practice of brushing teeth with a dentifrice was to remove food debris and dental plaque. It is interesting that a recent systematic review found, with moderate likelihood, that the adjunctive use of dentifrice with toothbrushing does not contribute to the effectiveness of mechanical removal of dental plaque.\textsuperscript{36} However, dentifrice can be a carrier of active ingredients for additional benefits. The use of dentifrice as a major vehicle for delivering fluoride for caries prevention and various agents for other effects such as anticalculus, reduction of oral malodor, desensitization, anti-inflammation, and tooth whitening has been well accepted.\textsuperscript{37-42}

Poor oral hygiene and inadequate toothbrushing not only increase risks of developing various dental and oral diseases but also facilitate staining. Certain dietary habits and smoking may further aggravate extrinsic tooth staining. Given consumers’ interest in whiter teeth, whitening dentifrice has become popular because of a number of advantages. Its use requires little additional effort, and it is readily available, simple to use, and relatively low in cost. The whitening dentifrice is also attractive to certain populations, such as smokers who incur extrinsic stains but may be advised against tooth bleaching because of controversies regarding the potential adverse effects of peroxide.\textsuperscript{30-32} A large variety of whitening dentifrices are available on the market. Most of these whitening dentifrices formulated with specially designed abrasive systems usually have a higher content of abrasives and detergents than standard dentifrices. Some of the products may also contain additional chemicals, such as low concentrations of $\text{H}_2\text{O}_2$, in an attempt to enhance abrasive cleaning by aiding the removal of extrinsic stains.

In contrast to tooth bleaching using peroxides, the primary mode of action of whitening dentifrice is the mechanical removal of stained pellicle along with extrinsic tooth surface stains and the polishing of enamel surface.\textsuperscript{34-43} Unlike dental plaque, extrinsic stains involve the staining of acquired pellicle, which is an
organic film and cannot effectively be removed by using only a toothbrush and water. Therefore, the abrasivity of a dentifrice is believed to be an important attribute of the whitening dentifrice, for which a certain amount of abrasivity is required to remove the pellicle-associated extrinsic stains to achieve whitening efficacy and to prevent or reduce restaining. The author of a 1968 in vitro study reported a strong correlation between stain-removal efficacy and dentifrice abrasivity. However, this finding has not been consistent; a study by Lobene found only weak correlations between abrasiveness and cleaning efficacy among the examined commercial dentifrices with varying abrasive systems. Using conventional in vitro procedures, researchers in a laboratory study evaluated the abrasivity, enamel-polishing properties, and stain-removal effectiveness of 26 commercial dentifrices of various compositions for cleaning, whitening, and polishing capabilities; they also examined the relationship between stain removal and abrasivity. Abrasivity was measured using the relative dentin abrasivity (RDA) method, and stain removal performance was determined by the pellicle cleaning ratio (PCR). The cleaning efficiency index value was calculated using the RDA and PCR values. The researchers found that all dentifrices removed extrinsic stain and produced some dentin abrasion, but both the RCA and PCR scores ranged widely among products, from 36 to 269 and 25 to 138, respectively. Furthermore, those dentifrices with high PCR scores often, but not always, had higher RDA values, whereas some with a lower RDA value, that is, lower abrasivity, produced a higher PCR score and thus a higher cleaning efficiency index value, that is, higher stain-removal efficiency. However, when considering the overall data, the researchers found no consistent relationship for these parameters that was associated with the abrasive systems. In general, whitening dentifrices were more abrasive, but there were exceptions, and a direct relationship was not always evident between a dentifrice’s stain-removal ability and abrasivity. Additional recent data have confirmed that a dentifrice with relatively low abrasivity is capable of providing significant cleaning efficacy and consequently a tooth-whitening effect. These findings indicate that the abrasivity of whitening dentifrice is important but not the only factor that determines its efficacy; more important to the stain-removal efficacy is the ability of the dentifrice to remove pellicle regardless of its abrasivity.

Efficacy of Baking Soda–Based Dentifrices for Stain Removal and Whitening

Baking soda has been used as an abrasive in dentifrices for decades. In recent years, it has become popular for specially formulated dentifrices, with or without peroxides, that are designed for removing tooth stains and, consequently, tooth whitening. Among the commonly used dentifrice abrasives (for example, anhydrous dicalcium phosphate, calcium carbonate, and calcium pyrophosphate), the abrasivity of baking soda is relatively lower. However, researchers in clinical studies have found that dentifrices containing baking soda are more effective in stain removal and whitening than some non–baking soda—containing dentifrices with a higher abrasivity. In addition, baking soda is biologically compatible with acid-buffering capacities and, at high concentrations, it is antibacterial.

There appears to be a correlation, to a certain limit, between the content of baking soda in a dentifrice and its efficacy for stain removal and whitening in vitro. Kleber and colleagues found that the ability of dentifrices for tooth whitening was enhanced by increasing the content of baking soda from 45% to 65% in a paste formulation; however, such a relationship began to dissipate for the pastes of higher concentrations of baking soda. The researchers also reported in the same study that a total of 30 minutes of brushing with baking soda dentifrices in vitro led to intrinsic stain removal and measurable tooth whitening.

Numerous clinical studies have been conducted to evaluate the efficacy of baking soda dentifrices for stain removal and tooth whitening. Koertge and colleagues conducted a longitudinal study to compare the efficacy of stain removal and tooth whitening by twice daily brushing with 1 of the 2 baking soda dentifrices with brushing with a regular silica-based dentifrice during a period of 12 weeks. The stain was measured by a modified stain index previously used by the same authors, and the tooth shade was assessed by the Vita Lumin-Vacuum Shade Guide. In addition, the b* value, which denotes the color dimension towards yellow (+b*) and blue (–b*) in the CIELAB color space, was quantified using a Minolta spectrophotometer. The results showed that the 2 baking soda dentifrices were more effective in reducing stain and increasing perception of whiteness in the tooth color than the regular silica-based dentifrice. Given that baking soda is less abrasive than silica, the resulting effectiveness in stain removal and whitening appear to involve unknown mechanisms in addition to the mechanical.

In a 1999 double-blind clinical study, researchers compared the efficacy for extrinsic tooth stain removal of 4 commercially available dentifrices, including 1 containing baking soda, 1 containing silica, and 2 containing other abrasive systems. Participants brushed their teeth twice daily for 1 minute with the assigned dentifrice using a soft toothbrush for 6 weeks. The researchers found a significantly lower level of extrinsic tooth stain in the baking soda dentifrice group than the non–baking soda and silica-based dentifrice group. The 2 groups using whitening dentifrices with other abrasive systems showed significantly lower levels of extrinsic tooth stain area than the silica-based group. The researchers detected no other significant differences among the 4 study dentifrices. The authors concluded that baking soda dentifrice was able to
provide significantly greater control of extrinsic tooth stain than the regular silica-based dentifrice.

In contrast, in a 3-month clinical trial, Isaacs and colleagues\textsuperscript{55} found no whitening effect as determined by tooth whiteness, $\Delta L^*$, which is the change of lightness (from 0 as black to 100 as white) in the CIELAB color space,\textsuperscript{56} but only a benefit of maintaining tooth color when participants used a silica-based tartar control whitening dentifrice and a tartar-control baking soda peroxide--whitening dentifrice for 3 months. The authors attributed the discrepancy in their findings from those by Kleber and colleagues\textsuperscript{57} to their use of an in vitro system. However, there was no discussion regarding the disagreement in the results with those reported by researchers in clinical studies in earlier years.\textsuperscript{55,57}

In a 6-week, double-blind clinical trial, researchers evaluated a baking soda dual-phase dentifrice containing calcium and phosphate for its effectiveness in removing existing extrinsic tooth stains compared with a commercial silica-based dentifrice.\textsuperscript{59} Participants brushed their teeth without supervision twice daily using the assigned dentifrice, and the extrinsic stain was assessed at the baseline and after 2, 4, and 6 weeks of product use. The authors found significant reductions in extrinsic tooth stain in the participants using the baking soda dual-phase dentifrice at 2, 4, and 6 weeks compared with the baseline, whereas the silica-based dentifrice control group did not attain significant reductions from baseline at any of the follow-up examinations. In addition, the baking soda dual-phase dentifrice group showed significantly lower levels of extrinsic tooth stain than the silica-based control group at both the 4- and 6-week examinations. The authors concluded that the baking soda dual-phase dentifrice is significantly more effective than the silica-based dentifrice for removing naturally acquired extrinsic tooth stain.

In 2015, Ghassemi and colleagues\textsuperscript{60–62} published 3 clinical studies on the efficacy of baking soda dentifrice for removing extrinsic stain and tooth whitening. In contrast to most previous reports, 1 study\textsuperscript{60} evaluated the reduction of extrinsic stain by using a baking soda whitening dentifrice with a powered toothbrush. The authors reported that compared with the use of a regular dentifrice with a manual toothbrush, brushing with the baking soda whitening dentifrice and a powered toothbrush was significantly more effective in removing tooth stains after 2 and 14 days. There were no clinical adverse effects detected during the study period, indicating that the combined use of the baking soda whitening dentifrice with a powered toothbrush for stain removal is safe and effective. The same team also reported the clinical efficacy in 2 additional studies on baking soda dentifrices, and they found in both studies that baking soda dual-phase dentifrices had significantly superior stain removal and whitening efficacy compared with the silica-based dentifrice.\textsuperscript{61,62} The researchers in these studies also provided evidence of clinical safety of the investigated baking soda dual-phase dentifrice.

More recently, researchers in a clinical study investigated the effect of a dentifrice containing 67% baking soda on stains induced by 0.2% chlorhexidine digluco-nate mouthwash.\textsuperscript{63} This 6-week randomized, examiner-blinded trial involved 160 patients, with 150 completing the study. At 6 weeks, patients using the 67% baking soda dentifrice had a significantly lower composite stain score for the facial side of the teeth than those in the control group. In another clinical study, researchers compared the safety and stain-removal effectiveness of a whitening baking soda dentifrice with that of a regular and a whitening control dentifrice.\textsuperscript{64} The patients brushed with their assigned dentifrice for 2 minutes, twice daily, for 5 days. The researchers found that the baking soda and positive control whitening dentifrice groups produced significant composite stain reduction from baseline to day 5. The stain score of the regular dentifrice control group was virtually unchanged. In addition, the baking soda group had greater stain removal than the whitening dentifrice control group, although the differences were not statistically significant.

Attempts have been made to further enhance the whitening efficacy of baking soda dentifrices by adding other ingredients. The most commonly used additive is H$_2$O$_2$, usually at a low concentration. In a 6-week clinical study reported in 2012, Ghassemi and colleagues\textsuperscript{65} evaluated the safety and efficacy of a dentifrice with baking soda and 1% peroxide as sodium carbonate peroxide for removing extrinsic stain and whitening teeth. The study was further extended for 2 weeks to determine whether the whitening or stain-prevention effect of the dentifrice would persist after the cessation of use. The researchers reported that the whitening dentifrice group had significant reductions in mean shade score of 1.82 and 2.57 from baseline to weeks 4 and 6, respectively, whereas the score for the negative control dentifrice group was virtually unchanged. The whitening dentifrice group also showed significant reductions in stain score from baseline at both 4 and 6 weeks. Patients who continued to use the whitening dentifrice for an additional 2 weeks gained further reductions in tooth shade and stain scores, whereas patients who switched to the regular control dentifrice showed smaller reductions in shade and stain score. The additional stain removal and whitening effects were significant for both groups, indicating an enhanced efficacy by adding a low content of peroxide to the baking soda dentifrice.

In a 2017 article,\textsuperscript{63} researchers reported an in vitro study in which they investigated the effects of baking soda combined with 1.5% H$_2$O$_2$ and casein phosphopeptide-amorphous calcium phosphate fluoride (CPP-ACP) on color and microhardness of enamel using bovine incisors. The researchers artificially stained the samples by immersing them in a tea solution for 7.5
days and then treated them with dentifrices containing 94% baking soda, with or without 1.5% H₂O₂ and CPP-ACPF. They performed the whitening procedure once daily for 10 days, and then immersed the samples again in a tea solution for 10 minutes. They performed color assessment at baseline, after the first staining process, after the whitening procedure, and after the second staining process. They finally measured the specimens for microhardness. The researchers found a significant difference in the color change between after the first staining process and after the whitening procedure among the study groups, with the greatest improvement observed in the group treated by the dentifrice of 94% baking soda with 1.5% H₂O₂ and CPP-ACPF. Microhardness was significantly greater in the dentifrice groups of 94% baking soda plus 1.5% H₂O₂ with or without CPP-ACPF.

In a June 2017 systematic review and meta-analysis of articles published up to April 2017, the authors assessed the effect of whitening dentifrice relative to a regular dentifrice on the reduction of natural extrinsic tooth surface discoloration in healthy adults 18 years or older. Among the 851 articles collected, 21 met the criteria and were analyzed. The authors found that almost all dentifrices specifically formulated for tooth whitening provided a beneficial effect in reducing tooth discoloration, irrespective of whether a chemical agent was added, when compared with a regular dentifrice, brushing with a whitening dentifrice significantly reduced tooth-surface stain, resulting in a significant whitening effect. The authors concluded that, on the basis of the evidence provided in the systematic review and meta-analyses of the available data in the literature, whitening dentifrices can be effective and are thus recommended for patients with naturally occurring extrinsic tooth-surface discoloration, and the use of whitening dentifrice may reduce the need for professional dental prophylaxis for esthetic reasons.

At appropriate concentrations, baking soda is bacteriostatic and H₂O₂ is bactericidal. In an in vitro study, researchers examined the effect of baking soda and H₂O₂ on the cariogenic bacteria Streptococcus mutans and found that baking soda, H₂O₂ and the baking soda and H₂O₂ combination were all capable of preventing growth of S. mutans, indicating that dentifrices containing these agents are capable of providing antimicrobial potential against S. mutans. The authors suggested that dentifrices containing baking soda and H₂O₂ might be useful to caries-prone patients.

SAFETY OF BAKING SODA–BASED DENTIFRICES FOR STAIN REMOVAL AND WHITENING

Baking soda is biologically compatible and considered to be safe as an ingredient in dentifrices. Its low abrasivity with significant efficacy of tooth stain removal also makes it a desirable abrasive system for dentifrices, because excessive abrasivity may be harmful to dental tissues. In addition, to date, there have been no reported adverse effects detected by researchers in clinical studies on baking soda dentifrices. Consequently, the evidence for the safety of baking soda dentifrices is considered adequate.

CONCLUSIONS

Baking soda is a desirable abrasive for stain-removal and tooth-whitening dentifrices. Its relatively low abrasivity along with clinically proven stain-removal and whitening efficacy provides a unique balance in helping achieve maximal benefits with minimal risks. Most research efforts so far have focused on stain-removal and tooth-whitening efficacy and clinical safety of baking soda dentifrices used with manual toothbrushes, with only a few studies investigating their effects using power brushes, for which further research is encouraged.

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