In-office tooth bleaching has been a dental procedure for more than a century; however, at-home tooth bleaching was not available until 1989, when it was introduced by Haywood and Heymann.\textsuperscript{1,2} With its demonstrated efficacy, lower cost than in-office bleaching, and the convenience of self-application, at-home bleaching quickly gained popularity and has now become an integrated procedure in aesthetic dentistry.\textsuperscript{3} Nowadays, in addition to the bleaching products available from dental professionals, over-the-counter (OTC) and infomercial at-home bleaching products are available directly to consumers, and they can be applied with a custom or preformed tray, with a brush, or as a strip. In recent years, tooth bleaching similar to in-office procedures but performed under nondental settings, such as mall kiosks, spas, and cruise ships, has become available.\textsuperscript{4}

Current tooth bleaching materials, whether used in office or at home, almost exclusively use peroxide compounds as the active ingredient, with carbamide peroxide and hydrogen peroxide (H$_2$O$_2$) being the most common.\textsuperscript{2,5} Chemically, carbamide peroxide is composed of approximately 3.5 parts of H$_2$O$_2$ and 6.5 parts of urea, so that a bleaching material of 10\% carbamide peroxide contains approximately 3.5\% H$_2$O$_2$. Attempts were made to introduce at-home whiteners that claimed to contain no peroxide; however, such products did not gain acceptance because of the lack of evidence on their efficacy and controversy over their nonperoxide claim.\textsuperscript{5} Typically, H$_2$O$_2$ concentrations of in-office bleaching products range from 25\% to 38\%, whereas at-home formulations contain 3.0\% to 7.5\% H$_2$O$_2$. However, in the recent years, there has been a trend of elevating the H$_2$O$_2$ concentration in at-home bleaching materials, and products containing up to 15\% H$_2$O$_2$ have now become available directly to consumers for home use.

The efficacy of peroxide-containing tooth bleaching products has been debated. In general, data accumulated over the last 2 decades also suggest that tooth bleaching is...
a relatively safe procedure. However, controversy concerning its safety has continued since the introduction of the home-use materials, and there have been reports of adverse effects of bleaching on oral tissues and restorative materials.6–10 This article provides an overview of safety controversies in bleaching in relation to the biologic properties of H2O2 and discusses the proper use of bleaching to maximize benefits while minimizing potential risks.

**BIOLOGICAL PROPERTIES OF H2O2 AND SAFETY CONCERNS WITH BLEACHING**

H2O2 is a well-investigated chemical. It was discovered in 1818 and detected in human respiration in 1880. The well-known Fenton reaction was proposed in 1894. Peroxidase and catalase, which are 2 important enzymes in H2O2 metabolism, were discovered in 1898 and 1901, respectively. Shortly after the discovery of another enzyme, superoxide dismutase (SOD), in 1969, H2O2 was recognized as an important by-product in oxygen metabolism, and the research efforts on the biologic properties of H2O2 have been significantly increased since then.

H2O2 is a normal intermediate metabolite in the human body, with a daily production of approximately 6.48 g in the liver. One of the key characteristics of H2O2 is its capability of producing free radicals, including hydroxyl radicals that have been implicated in various stages of carcinogenesis. Oxidative reactions of free radicals with proteins, lipids, and nucleic acids are thought to be involved in several potential pathologic consequences; the damage by oxidative free radicals may be associated with aging, stroke, and other degenerative diseases.11,12 To prevent potential damage to cells during oxidative reactions and repair any damage sustained, there are various defensive mechanisms available at cellular and tissue levels. Enzymes such as catalase, SOD, peroxidase, and selenium-dependent glutathione peroxidase, which exist widely in body fluids, tissues, and organs, effectively metabolize H2O2.13 Human saliva also contains these enzymes. In fact, salivary peroxidase has been suggested to be the body’s most important and effective defense against the potential adverse effects of H2O2.14 A study on infants, juveniles, adults, and adults with impaired salivary flow found rapid decomposition of H2O2 in dentifrices.15 After brushing for 1 minute with 1 g dentifrice, less than 2% of the prebrushing dose of H2O2 (30 mg) was detectable in the oral cavity of the subjects.

Much of the safety concerns with home-use bleaching originate from H2O2 used in the materials, especially the known toxicology of free radicals. The oxidative reactions and subsequent damage in cells caused by free radicals are thought to be the major mechanisms responsible for the observed toxicity of H2O2. There have been concerns of potential systemic adverse effects if the bleaching material is ingested as well as local adverse effects on enamel, pulp, and gingiva because of the direct contact of the material with the tissues.2 The safety controversies over peroxide-based tooth bleaching have prompted not only scientific deliberations but also legal challenges to its use in dentistry.16,17

**CONCERNS WITH SYSTEMIC EFFECTS OF H2O2 IN BLEACHING**

Considering the dosage and application mode of tooth bleaching, the exposure to the material during the bleaching procedure is inadequate to cause acute systemic toxicity. Although H2O2 is found to be mutagenic in the in vitro Ames test without S9 rat liver microsomes, it is not genotoxic in the same test when S9 is incorporated; it is not genotoxic in various animal models either.2

With the available data on the toxicity of H2O2 as well as the research on bleaching materials and the assessment of their exposure in bleaching, concerns with potential
systemic health risks have largely diminished, including the acute, subacute, and chronic toxicities associated with the use of materials containing 10% carbamide peroxide. This reduction is mainly because H$_2$O$_2$ exposure from bleaching is limited to the oral cavity and is incapable of reaching a systemic level. The possible exposure dose of H$_2$O$_2$ has been estimated at approximately 3.5 mg for a treatment of both arches with a whitener containing 10% carbamide peroxide,$^2$ whereas the oral cavity is capable of decomposing more than 29 mg H$_2$O$_2$ within 1 minute.$^{15}$

**CONTROVERSY OVER CARCINOGENICITY OF H$_2$O$_2$ IN BLEACHING**

The issue of carcinogenicity of H$_2$O$_2$ is controversial in the literature, and the published results are contradictory in some studies.$^{17}$ Most studies found no evidence of carcinogenicity of H$_2$O$_2$; a few showed that H$_2$O$_2$ was anticarcinogenic, whereas several reported carcinogenicity or cocarcinogenicity of H$_2$O$_2$. The studies that have been cited most frequently as the evidence of carcinogenicity and cocarcinogenicity of H$_2$O$_2$ were reported by Ito and colleagues$^{18–20}$ and Weitzman and colleagues.$^{21}$ However, evaluation of these studies found significant deficiencies in design and conduct of the experiments as well as in the assessment of the results; consequently, the findings of these 4 studies were determined to be inadequate to substantiate their conclusions.$^{17}$

It is obvious that the carcinogenic and cocarcinogenic potential of a tooth bleaching agent constitutes a significant health risk. Because of the potential significance of the study by Weitzman and colleagues,$^{21}$ which used local application of H$_2$O$_2$ on the oral mucosa of Syrian golden hamsters, the same study was repeated using proper design and methods; the results found no evidence of carcinogenicity or cocarcinogenicity of 3% H$_2$O$_2$. Consequently, bleaching using 10% carbamide peroxide is regarded to be of no significant carcinogenic or cocarcinogenic risks. The overall data on bleaching obtained from more than 20 years also seem to support this conclusion. However, because of the significance of the carcinogenicity and relatively limited data available on the topic for bleaching, questions and debates over the carcinogenic risks of bleaching arise periodically. Future research is encouraged to help clarify the controversy and concerns with the topic.

**POTENTIAL LOCAL ADVERSE EFFECTS ASSOCIATED WITH BLEACHING**

Tooth bleaching requires direct contact of the material with the enamel surface. Although the gingival contact with the bleaching material is not intended, it often occurs when the material is applied at home by consumers. For some at-home systems, such as strips, the gingival contact is inevitable. Some bleaching regimens also involve a continued contact period of up to 7 to 8 hours (overnight). Consequently, possible adverse effects of bleaching on the enamel, pulp, and gingiva have been suggested and investigated.

*Potential Adverse Effects on Enamel*

The effects of bleaching on enamel were primarily examined in vitro using extracted human or bovine teeth. Bleaching seems to have minimal or no effects on enamel microhardness and mineral content; however, the results on enamel surface change are inconsistent.$^{23–26}$ Most scanning electron microscopic studies showed little or no morphologic changes of enamel surfaces associated with bleaching, whereas several studies reported significant alteration of enamel surfaces, including depression, porosity, and erosion, after bleaching. In most cases, however, the observed enamel surface alterations varied with the bleaching products used and seemed to
be associated with those patients using acidic prerinse or gels of low pH. The clinical relevancy of the observed changes in the enamel surface morphology has also been questioned. Studies have shown that some soft drinks and fruit juices are capable of causing comparable or greater demineralization and surface alteration of the enamel than those reported for bleaching agents. To date, no clinical evidence of adverse effects of professional at-home bleaching systems on enamel has been reported; however, there have been 2 clinical cases of significant enamel damage associated with the use of OTC bleaching products.

**Potential Adverse Effects on Gingiva**

H$_2$O$_2$ at high concentrations is an irritant and also cytotoxic. In cell culture experiments, H$_2$O$_2$ is cytotoxic at concentrations ranging from 1.7 to 19.7 $\mu$g/mL (0.05–0.58 mmol/L). At concentrations of 10% or more, H$_2$O$_2$ is potentially corrosive to the mucous membranes or skin, causing a burning sensation and tissue damage. Studies also reported that commercial peroxide-based gels induced cytotoxicity.

During the in-office bleaching procedure, which routinely involves the use of H$_2$O$_2$ at a concentration of 25% or more, adequate barriers are necessary to protect the gingiva from mucosal damage. If a leakage exists, serious tissue burn can occur. Because of this potential risk, local anesthesia should not be used for in-office bleaching, so that the patient can alert the dentist when the gel seeps through the barriers to cause a burning sensation or pain. However, simply relying on the patient’s response is inadequate; clear instructions to the patient to report any discomfort, careful examination of the seal of the barrier after the gel application, and frequent monitoring of the seal throughout the bleaching process are all necessary to minimize the risk of gingival damage and irritation.

Gingival irritation is also common in at-home tooth bleaching. A study found a higher (33.3%) prevalence of gingival irritation in patients using strips of 6.5% H$_2$O$_2$ compared with those using at-home tray bleaching with 10% carbamide peroxide (3.5% H$_2$O$_2$). A separate study found that 50% of patients using the 6.5% H$_2$O$_2$ strips reported gingival irritation, which was about 3 times of those using the 5.3% strips (16.7%). These data indicate that the risk of gingival irritation in at-home bleaching is associated with the H$_2$O$_2$ concentration in the bleaching gel, that is, there is a higher prevalence of gingival irritation while using bleaching gels of higher peroxide concentrations. In most cases, the gingival irritation is mild to moderate, tends to be transient, and dissipates when the application discontinues. So far, studies on professional at-home bleaching reported no significant or permanent gingival damage.

**Potential Adverse Effects on Pulp and the Risk of Tooth Sensitivity**

Recent research, most of which used in vitro models, has shown that H$_2$O$_2$ in the bleaching gel applied on the enamel surface is capable of penetrating through the enamel and dentin to reach the pulp chamber. An amount of less than 30 $\mu$g H$_2$O$_2$ may reach the pulp after the application of gels containing up to 12% H$_2$O$_2$ on the enamel surface for up to 7 hours. Although the amount of H$_2$O$_2$ detected in the pulp chamber tends to increase with the time and H$_2$O$_2$ concentration in the gel, such a relationship is not proportional. It was suggested that an amount of 50,000 $\mu$g H$_2$O$_2$ would be needed to inhibit pulpal enzymes, so the detected amount of H$_2$O$_2$ that penetrated into the pulp chamber seems unlikely to cause significant damage to pulp tissues. However, there is a lack of in vivo studies on this topic, and long-term effects of such H$_2$O$_2$ exposure on pulp are yet to be determined.
Tooth sensitivity to temperature changes is a commonly observed clinical side effect in bleaching, and it has been suggested as an indication of possible pulp response to \( \text{H}_2\text{O}_2 \) that penetrates through the tooth hard tissue and reaches the pulp, although its mechanisms are not fully understood. Tooth sensitivity may or may not occur with gingival irritation.\(^{41}\) In some cases, the patient may mistake gingival irritation for tooth sensitivity, or vice versa; therefore, careful examination and differential diagnosis are necessary for appropriate treatment regimens.

In general, up to 1 in 2 people may experience temporary tooth sensitivity as a result of tooth bleaching.\(^{41-44}\) The development of tooth sensitivity does not seem to be related to the patient’s age or sex, defective restorations, enamel-cementum abrasion, or the dental arch treated; however, the risk increases in patients with the frequency of daily application. The incidence and severity of the sensitivity may also depend on the quality of the bleaching material, the techniques used, and an individual's response to the bleaching treatment methods.\(^4\) The sensitivity, usually mild and transient, often occurs during the early stages of tooth whitening, and for most patients it is tolerable to complete the treatment. So far, there are no reported cases of pulp necrosis caused by tooth bleaching; however, teeth with caries, with exposed dentin, in close proximity to pulp horns, or suspected to have cracks are potentially at risk for developing severe sensitivity and thus are not advisable for bleaching. In addition, defective restorations should be replaced before bleaching, and extra caution should be applied to children and adolescents because of their relatively larger pulp chamber.\(^{45}\)

**Potential Adverse Effects on Restorative Materials**

Numerous studies have reported that tooth bleaching may adversely affect physical and/or chemical properties of restorative materials, including increased surface roughness, crack development, marginal breakdown, release of metallic ions, and decreased tooth-to-restoration bond strength. Potential adverse effects of bleaching on bonding strength have been well recognized.\(^{9,46,47}\) A plausible mechanism is the inhibition of adequate polymerization of the bonding agent by the residual oxygen formed during bleaching. Similar effects are also applicable to other resin-based restorative materials that require in situ polymerization. The post-bleaching inhibitory effects on polymerization dissipate with time, and an interval of 2 weeks is found to be adequate to avoid such adverse effects.

A relevant safety concern is the mercury release from amalgam restorations during and after bleaching.\(^{48-50}\) Although not much debate exists regarding whether bleaching causes mercury release, the reported amount of mercury release associated with bleaching varies greatly. The issue on potential health implications of the mercury released remains controversial and yet to be determined. Because of the known toxicity of mercury, as a general rule, it is not advisable to perform bleaching for those whose teeth are restored extensively with amalgam.

**SAFETY CONCERNS WITH BLEACHING WITH NO INVOLVEMENT OF DENTAL PROFESSIONALS**

Largely because of the clinically visible efficacy of at-home bleaching, an ever increasing number of OTC home bleaching products have become available directly to consumers shortly after the introduction of the night guard tray bleaching that was originally performed by dental professionals. There are various forms of these OTC bleaching products, including gels applied using a tray or paint-on brush, mouth rinses, chewing gums, toothpastes, and strips. Similar products are also available
through infomercials and the internet. More recently, tooth bleaching has become available in mall kiosks, salons, spas, and even cruise ships, which usually simulate the in-office bleaching settings, often involving the use of light but being performed by individuals with no formal dental training and not licensed to practice dentistry. This practice has come under scrutiny in several states and jurisdictions, resulting in actions to reserve the delivery of this service to dentists or appropriately supervised allied dental personnel.4

Basically, no scientific research is available on bleaching performed at mall kiosks, salons, spas, and cruise ships, whereas a significant amount of clinical data on the OTC bleaching products are available in the literature.5,33,34,43 Overall, data indicate that adverse effects associated with the use of OTC bleaching products seem to be rare. There have been only 2 reports on irreversible enamel damage caused by OTC bleaching products.6,7 However, it is unclear whether the low incidence of adverse effects associated with the use of the OTC bleaching products is the result of their low risk or the lack of means to detect and report adverse effects. The data available in the literature were collected from studies conducted by dental professionals, which were not intended for these OTC products. In addition, consumers are not generally aware of how to report adverse events through the US Food and Drug Administration’s MedWatch system.4 It is a reasonable assumption that when an individual purchases and uses an OTC bleaching product, some adverse effects, such as enamel surface changes, may go unnoticed; even those effects felt or detected by the user remain most likely unreported. More of a concern is the tendency of overusing or abusing an OTC bleaching product. Research efforts are encouraged to define the risks of OTC bleaching products, if any, under relevant scenarios intended for these products.

**ROLES OF DENTAL PROFESSIONALS IN TOOTH BLEACHING**

It is highly recommended that tooth bleaching involves dental professionals. Initial evaluation and examination of tooth discoloration are necessary for proper diagnosis and treatment; bleaching materials can affect restorative materials and may also result in color mismatch of teeth with existing restorations or crowns. Such evaluations cannot be performed or determined by consumers themselves or nondental individuals. Discoloration, particularly intrinsic stains, may not simply be an aesthetic problem,5,51 and bleaching may not be the appropriate or the best choice for treatment. For at-home bleaching using trays, professionally fabricated, custom-fit trays reduce the amount of gel needed for maximal efficacy while minimizing the gel contact with gingiva. In addition, periodic evaluation of bleaching progress by dentists allows early detection of any possible side effects and reduces the risk of using poor-quality bleaching materials, inappropriate application procedures, and any temptation to overuse or abuse the product. The American Dental Association encourages all patients interested in tooth bleaching to seek advice from a dental professional.4,52

**SUMMARY**

Tooth bleaching is intended for improving tooth color and has become an accepted and popular dental procedure in aesthetic dentistry. Data accumulated over the last 20 years also indicate no significant, long-term oral or systemic health risks associated with professional at-home tooth bleaching using materials containing 10% carbamide peroxide, which is equivalent to 3.5% H₂O₂.

However, as with any dental procedure, bleaching involves risks. Tooth sensitivity and gingival irritation can occur in a significant portion of the patients, although in most cases they are mild to moderate and transient. When gels of
high H₂O₂ concentrations, such as those for in-office bleaching, are used without adequate gingival protection, severe mucosal damage can occur. Although rare, potential adverse effects are possible with inappropriate application, abuse, or the use of inappropriate at-home bleaching products. H₂O₂ is capable of producing various toxic effects, so that potential risks exist and need to be recognized. So far, little data are available on the safety of OTC at-home bleaching that simulates the intended application mode of these products, and the safety of bleaching performed at mall kiosks, salons, spas, and cruise ships is of particular concern because the procedure is similar to that of in-office bleaching but performed by nondental individuals.

Effective and safe tooth bleaching requires correct diagnosis of the problems associated with tooth discoloration or stains. Furthermore, tooth sensitivity and gingival irritation may occur during the course of bleaching treatment. To minimize risks and maximize benefits, the involvement of dental professionals in bleaching treatment is necessary.

REFERENCES

The invention of tooth bleaching was designed to be a more cost-effective and less invasive procedure. The mechanism of the bleaching isn’t fully understood but the principle concept is almost universally accepted. The active ingredient is either HP (hydrogen peroxide), or CP (carbamide peroxide) which breaks down into 33% HP and is thus a weaker version of the former. An oxygen species which can vary between perhydroxyl anion (H02-), hydroxyl radical (HO-) and various other radicals subsequently forms from the HP. The structure of the radical depend... BLEACHING AND SOURCES OF CONCERNS

Safety concerns with tooth bleaching were initially raised with the rapid growth of at-home bleaching. The primary source of the safety concerns with tooth bleaching originated from the known toxicity of H2O2, especially its capability to produce free radicals, including hydroxyl radicals. Studies indicate that oxidative reactions of free radicals with proteins, lipids and nucleic acids, with the consequential potential pathological damage, may be associated with ageing, stroke and other degenerative diseases.  

American Dental Association. Tooth bleaching using peroxide-based materials is an effective procedure in dentistry. Studies provide evidence on the safety of bleaching by dental professionals. However, concerns and controversy remain regarding the safety of bleaching systems that do not involve dental professionals, especially those available at mall kiosks, salons, spas, and cruise ships. Bleaching causes tooth sensitivity and/or gingival irritation in a significant portion of patients. Bleaching requires proper examination, diagnosis, and treatment plan, which can be performed appropriately only by dental professionals; therefore, involvement of dental professionals in bleaching is necessary to maximize the efficacy and minimize potential risks.  
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