An overview of tooth-bleaching techniques: chemistry, safety and efficacy

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Tooth discolouration results from varied and complex causes that are usually classified as being either intrinsic or extrinsic in nature. Extrinsic discoloration arises when external chromogens are deposited on the tooth surface or within the pellicle layer. Intrinsic discoloration occurs when the chromogens are deposited within the bulk of the tooth (usually in the dentine) and are often of systemic or pulpal origin (1, 150). A third category of ‘stain internalization’ has been described to include those circumstances where extrinsic stain enters the tooth through defects in the tooth structure (1).

Tooth discoloration creates a wide range of cosmetic problems, and, as the dental profession and the public strive for a more esthetically pleasing appearance, considerable amounts of time and money are being invested in attempts to improve the appearance of discolored teeth. A study assessing the impact of teeth on personal esthetic satisfaction found that dental variables (including tooth color) were more important than orthodontic variables, suggesting that the appearance of the teeth was a greater contributing factor to an esthetic smile than their position within the arch (101). In another study, of 254 patients, it was found that the appearance of the dentition was more important to women than to men and that the esthetics of the dentition was more important to younger patients (147).

The methods available to manage discolored teeth range from the removal of surface stain, bleaching or tooth-whitening techniques and surgical techniques to camouflage of the underlying discoloration, using veneers and crowns.

The use of a variety of bleaching techniques has attracted most interest from the dental profession because these techniques are noninvasive and relatively simple to carry out. Contemporary bleaching systems are based primarily on hydrogen peroxide or one of its precursors, notably carbamide peroxide, and are often used in combination with an activating agent such as heat or light. Bleaching agents can be applied externally to the teeth (vital bleaching), or internally within the pulp chamber (nonvital bleaching) (41, 54). Both techniques aim to bleach the chromogens within the dentine, thereby changing the body color of the tooth.

Tooth discoloration

Natural color of teeth

Teeth are made up of many colors, with a natural gradation from the darker gingival third to the lighter incisal third of the tooth. This variation is affected by the thickness and translucency of enamel and dentine, as well as by the reflectance of different colors. Typically, canine teeth are naturally darker than central and lateral incisors and teeth become darker with age, whereas lighter teeth are common in younger people, especially in the primary dentition.

The color of teeth is primarily determined by the dentine but is influenced by the color, translucency and varying degrees of calcification of enamel as well as its thickness, which is notably greatest at the occlusal or incisal edge. The normal color of teeth is determined by the blue, green and pink tints of enamel and is reinforced by the yellow through to brown shades of the dentine beneath.

Classification of tooth discoloration

The appearance of teeth depends on their absorptive or reflective properties of light and is influenced by
all the structures that make up the tooth, including the enamel, dentine and pulp. Any changes to these structures during formation or throughout development and post-eruption (3 months in utero to 20 years) can cause a change in the light-transmission properties and hence discoloration.

Table 1 shows the types of tooth discoloration and the typical tooth colors they produce.

<table>
<thead>
<tr>
<th>Types of discolouration</th>
<th>Colour produced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extrinsic (direct stains)</strong></td>
<td></td>
</tr>
<tr>
<td>Tea, coffee and other foods</td>
<td>Brown to black</td>
</tr>
<tr>
<td>Cigarettes / cigars</td>
<td>Yellow / brown to black</td>
</tr>
<tr>
<td>Plaque / poor oral hygiene</td>
<td>Yellow / brown</td>
</tr>
<tr>
<td><strong>Extrinsic (indirect stains)</strong></td>
<td></td>
</tr>
<tr>
<td>Polynvalent metal salts and cationic antiseptics (e.g. chlorhexidine)</td>
<td>Black and brown</td>
</tr>
<tr>
<td><strong>Intrinsic</strong></td>
<td></td>
</tr>
<tr>
<td><em>Metabolic causes</em> (e.g. congenital erythropoietic porphyria)</td>
<td>Purple / brown</td>
</tr>
<tr>
<td><em>Inherited causes</em> (e.g. amelodentinogenesis)</td>
<td>Brown or black</td>
</tr>
<tr>
<td><em>Iatrogenic causes</em></td>
<td>Banding appearance</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>Classically yellow, brown, blue, black or grey</td>
</tr>
<tr>
<td>Fluorosis</td>
<td>White, yellow, grey or black</td>
</tr>
<tr>
<td><em>Traumatic causes</em></td>
<td>Brown</td>
</tr>
<tr>
<td>Enamel hypoplasia</td>
<td>Grey black</td>
</tr>
<tr>
<td>Pulpal haemorrhage products</td>
<td>Pink spot</td>
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<tr>
<td>Root resorption</td>
<td>Yellow</td>
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<tr>
<td><strong>Ageing causes</strong></td>
<td></td>
</tr>
<tr>
<td>Caries</td>
<td>Orange to brown</td>
</tr>
<tr>
<td>Restorations</td>
<td>Brown, grey, black</td>
</tr>
</tbody>
</table>

**Metabolic causes of discoloration**

A number of metabolic disorders, such as alkaptonuria, congenital erythropoietic porphyria and congenital hyperbilirubinemia, cause tooth discoloration. Alkaptonuria is an inborn error of metabolism that results in a brown discoloration of the permanent dentition (79), whereas congenital erythropoietic porphyria, a rare, recessive, autosomal metabolic disorder, gives a red/purple–brown discoloration of teeth (37). Congenital hyperbilirubinemia is characterized by yellow–green discoloration caused by the deposition of bile pigments in calcifying dental hard tissues, particularly at the neonatal line, as a result of massive hemolysis in rhesus incompatibility.

**Inherited causes of discoloration**

Amelogenesis imperfecta is a hereditary condition in which the mineralization or matrix of enamel formation is disturbed. There are currently 14 different subtypes based on clinical appearance, with the majority inherited as an autosomal-dominant or X-linked trait with varying degrees of expressivity (139, 158, 160). The appearance can be badly affected with hypoplastic thin enamel that is yellow to yellow–brown in color or the enamel can be quite mildly hypomineralized (‘snow-capped’), depending on the type of amelogenesis imperfecta present. The color of the teeth is presumed to reflect the degree of hypomineralization of the enamel: the darker the color the more severe the degree of hypomineralization (18).

Dentine defects can either be inherited or caused by environmental factors (120). Genetically determined defects may occur in isolation or may be associated with a systemic disorder.

Dentinogenesis imperfecta is an inherited disorder of dentine, which may or may not be associated with osteogenesis imperfecta (18). Dentinogenesis imperfecta type I is associated with osteogenesis imperfecta (mixed connective tissue disorder of type I collagen) and is characterized by opalescent primary teeth, especially when the condition is the result of a dominant inheritance pattern. Dentinogenesis imperfecta type II or hereditary opalescent dentine may be more severe in the primary than in the secondary dentition, the pulp chambers often become obliterated and the dentine undergoes rapid wear once the enamel has chipped away. Clinically, the appearance is an amber, grey to purple–blue discoloration or opalescence, thought to be a result
of the absorption of chromogens into the porous dentine after exposure of the dentine. This condition is clearly demonstrated by opalescence on transillumination.

Unlike dentinogenesis imperfecta type II, dentinogenesis imperfecta type I shows enamel that is much less prone to fracture and the dentine seldom obliterates pulp chambers; hence, radiographic examination can differentiate between the two types. A third type of dentinogenesis imperfecta has been described (157) that is similar in appearance to dentinogenesis imperfecta types I and II but with the radiographic appearance of ‘shell teeth’ with multiple pulpal exposures in the primary dentition.

There is some controversy as to whether dentinal dysplasias are a separate entity from dentinogenesis imperfecta (18). The primary and secondary dentitions in type I dentinal dysplasia are of normal shape and form but have an amber translucency. The pulp chambers in the primary dentition are frequently obliterated while only crescentic pulpal remnants are found parallel to the cemento–enamel junction of the secondary dentition. Type II dentinal dysplasias are thought to involve thistle-shaped pulp chambers and pulp stones with a brown tooth discoloration (126).

Iatrogenic causes of discoloration

Tetracycline staining results from systemic administration of the drug and its subsequent chelation to form complexes with calcium ions on the surface of hydroxylapatite crystals primarily within dentine, although enamel is also affected (140). Tetracycline should be avoided in expectant and breast-feeding mothers, and in children up to the age of 12 years, to avoid discoloration of the developing teeth. The discoloration produced depends on the type of tetracycline used, the dosage and the period of time for which it is taken, as well as the age of the patient at the time of administration. Generally, the affected teeth tend to be yellow or brown–grey in color and the appearance is worse on eruption and diminishes with time. This is because once erupted the teeth are susceptible to color changes by photo-oxidation (exposure to light), causing lightening of the intrinsic stain. Various analogues of tetracycline produce different color changes, for example, chlorotetracycline produces a slate-grey color, and a creamy discoloration is produced by oxytetracycline (10, 94).

Tetracycline staining has also been classified according to the extent, degree and location of the tetracycline involvement (64).

- degree I: there is minimal expression of tetracycline stain, which is uniformly confined to the incisal three-quarters of the crown and is light yellow in color.
- degree II: there is more variability in staining, ranging from a highly uniform deep yellow to a grey-banded discoloration in which a distinctive difference in discoloration is noted between the cervical region and the incisal four-fifths of the crown.
- degree III: there is very dark blue or grey uniform discoloration.

Post-eruptive staining with minocycline used for the treatment of acne in adolescents and adults has been described as a result of chelation with iron to form insoluble complexes (14) or by the formation of complexes of the drug with secondary dentine (117).

Fluorosis may be the result of the natural occurrence of fluoride in water supplies or from fluoride in mouthrinses, tablets or toothpastes. This type of staining is most often confined to the enamel, varying from areas of floculation to diffuse opaque mottling superimposed onto a chalky white or dark brown–black background. The dark discoloration is thought to be post-eruptive by a process of internalization of extrinsic stain into the porous enamel (151). The severity of the discoloration is related to the age and dose administered and can affect both the primary and secondary dentitions in endemic cases of fluorosis.

Traumatic causes of discoloration

One of the most common causes of tooth discoloration seen in everyday general practice is that caused by pulpal hemorrhagic products following trauma. The major cause of the discoloration is thought to be the accumulation of the hemoglobin molecule or hematin molecules in the traumatized tooth, and their penetration into the dentine determines the severity of the discoloration.

Root resorption following trauma often presents as a pink spot lesion at the cemento–enamel junction in an otherwise symptomless tooth. The resorption always begins at the root surface but may be internal (of pulpal origin) or external (of periodontal origin).

Enamel hypoplasia in permanent teeth may be the result of disturbance of the developing tooth germ following trauma or infection of the deciduous tooth, giving rise to a localized enamel defect. Pitting or grooving may predispose to later internalization of external chromogens. Generalized hypoplasia may result from any disturbance of the developing tooth germ by many different fetal or maternal conditions,
such as rubella infection or even drug intake during pregnancy. The defect is usually directly related to the degree of the systemic upset and can be chronologically traced back to the time of the upset.

Dentine hypercalcification may result following trauma temporarily disturbing the blood supply of a tooth and affecting the odontoblasts, giving rise to excessive irregular dentine deposition in the pulp chamber and canal walls. The tooth gradually decreases in translucency and becomes yellow or yellow–brown in color but is still vital (113).

**Idiopathic causes of discoloration**

Molar incisor hypomineralization is a condition of unknown etiology that is characterized by severely hypomineralized enamel affecting the incisors and permanent first molars (154). The appearance of the hypomineralized enamel is asymmetrical, affecting one molar severely while leaving the contralateral molar relatively unaffected or only with minor subsurface defects (152). The incisors also show asymmetry but not usually with loss of enamel substance. The enamel defects can vary from white to yellow or brownish areas, but they always show a sharp demarcation between sound and affected enamel (153). The enamel is porous and brittle, breaking down shortly after eruption under masticatory forces, and often resembles enamel hypoplasia but is distinguished by having irregular borders with normal enamel as opposed to smooth borders with hypoplastic lesions (153).

The suggestions of possible etiologies for molar incisor hypomineralization include environmental changes during a limited time period, infections during early childhood, dioxin in breast milk and genetic factors.

**Ageing causes of discoloration**

The natural darkening and yellowing of teeth with age, and the change in their light-transmission properties, is the result of a combination of factors involving both enamel and dentine. The enamel undergoes both thinning and textural changes (96), while the deposition of secondary and tertiary dentine and pulp stones all contribute to the darkening process of ageing.

**Extrinsic discoloration**

External staining may be divided into two main categories: direct staining by compounds incorporated into the pellicle layer and producing a stain as a result of the basic color of the chromogens; and indirect staining where there is chemical interaction at the tooth surface with another compound that produces the stain.

**Direct staining**

Direct-staining chromogens derived from dietary sources such as tea and coffee are taken up into the pellicle and their natural color imparts the stain onto the tooth surface. Smoking or chewing tobacco, medicines, spices, vegetables and red wine are also known to cause direct staining. It is the polyphenolic compounds found in food that are thought to give rise to the color of the stain (105). The actual mechanism of staining is not fully understood but certainly involves pellicle constituents. Naked enamel does not take up chromogens easily and pellicle proteins are often cited as reacting with chromogens, but how specific this reaction is has not been clarified and some degree of nonspecificity is probable; the chromogen is merely incorporated within the pellicle layer much as a sponge can soak up and hold fluids. Dentine chromogens may be absorbed into the tissue itself as dentine is more porous than enamel, both in respect of intertubular dentine and the tubules themselves (125).

Traditionally, extrinsic tooth discoloration has been classified according to its origin and whether it is metallic or nonmetallic (47).

Nonmetallic extrinsic stains caused by beverages, tobacco, mouthrinses and other medicines are adsorbed on to the tooth surface by incorporation into the plaque or the acquired pellicle. Chromogenic bacteria have also been implicated in extrinsic staining in children who have poor oral hygiene (causing green and orange stains) and in those who have good oral hygiene (causing black–brown stains) but the mechanism involved has not been established (150).

**Indirect staining**

Indirect dental stains are associated with cationic antiseptics and metal salts that are either colorless or a different color from the stain produced as a result of a chemical interaction with another compound.

Polyvalent metal salts are known to be associated with extrinsic staining, such as the black discoloration seen in people using iron supplements and in iron foundry workers exposed occupationally to these metal salts. Other examples include the green dis-
coloration resulting from use of mouthrinses containing copper salts or the violet–black color resulting from the use of potassium permanganate-containing mouthrinses (149).

Cationic antiseptics, such as chlorhexidine, hexetidine, cetylpyridinium chloride and others mouthrinses, also cause staining after prolonged use. Chlorhexidine, for example, produces the brown–black discoloration seen around the labial and lingual surfaces of anterior teeth after only about 7–10 days of use.

The mechanism of staining by metal salts, and particularly by cationic antiseptics, has attracted much interest from the dental profession and has been much debated (1, 150). The majority of the data drawn from randomized controlled laboratory and clinical studies support a dietary etiology. Thus, staining is thought to be a result of the precipitation of anionic dietary chromogens, such as polyphenols, onto adsorbed cationic antiseptics or polyvalent metal salts on the tooth surface (1, 150).

Internalized discoloration

Extrinsic stains are taken up into the enamel or dentine via a developmental or acquired defect. The incorporation of extrinsic stain into the porous tooth structure of developmental defects has already been discussed under the intrinsic staining section above.

Acquired defects of teeth resulting from function and parafunction, dentinal caries and restorative materials can all lead to tooth discoloration, directly or indirectly.

• tooth wear and gingival recession: the loss of enamel and dentine by erosion, abrasion and attrition can result in the exposure of dentine to extrinsic chromogens. The exposure of dentine, or the loss of enamel, gives rise to darker looking teeth as more of the yellow color of dentine is apparent. Cracks as a result of trauma to the enamel, or gingival recession and exposure of dentine, predispose the teeth to extrinsic stain internalization.

• dentinal caries: the progression of the carious lesion is usually associated with changes in color, ranging from the initial white spot lesion to the black arrested lesion that picks up stain from an extrinsic source (145).

• restorative materials: the classic grey–black discoloration seen around old amalgam restorations is thought to be caused by the migration of tin into the dentinal tubules (155). Eugenol-containing medictions cause an orange–yellow stain, and silver points in root canals give a grey or pink appearance to a root-treated tooth.

Development of night guard vital bleaching

A successful home bleaching technique using hydrogen peroxide was first described by Klusmier in 1968 (52) when it was noticed that teeth became whiter after treatment of a mouth injury with Glyoxide (hydrogen peroxide mouthwash) in an orthodontic retainer. The results were lighter teeth in addition to healing of the injury. However, this technique received worldwide acceptance when described in 1989 by Haywood & Heyman (53), who employed 10% carbamide peroxide in a custom-made tray worn at night: the ‘night guard vital bleaching technique’ (53).

Development of power bleaching

In-surgery bleaching techniques used since the early 1900s were further modified in 1991 with the introduction of 30% hydrogen peroxide gels activated by conventional light-curing units rather than a heat source. This technique is often referred to as ‘power bleaching’. Although these power gels could be controlled easily compared with the liquids used previously, full-mouth isolation was still needed to protect the gums and the surrounding soft tissues. Power bleaching was frequently combined with home-use tray systems to maximize the bleaching effect and give a kick start to the whitening procedure before the patient continued with night guard vital bleaching at home.

A further modification to the power bleaching system was the use of an argon laser as an activating light source to replace conventional curing lights (110). The present-day systems are activated by a variety of light sources: plasma arc lamps, Xenon-halogen, light emitting diode (LED) light and diode lasers. However, light sources are not essential and there are systems that require chemical activation only and are merely painted onto the teeth with the usual use of gingival and mucosal isolation (22).

Current bleaching materials

The home bleaching materials currently available are a combination of different concentrations and fla-
vours of both carbamide peroxide or hydrogen peroxide used in either custom-made trays or ‘one size fits all’ type trays. In addition to these are the relatively new hydrogen peroxide gels on polyethylene strips (Whitestrips; Procter & Gamble, Cincinnati, OH, USA), which are applied like medical plasters onto the surface of the labial tooth and lap over the incisal edges of the teeth. Other over-the-counter bleaching agents include paint-on carbamide peroxide preparations of various concentrations used in a similar way to the bleaching strips. Disposable trays that are prefilled with 9% hydrogen peroxide with inbuilt gingival protection have recently been introduced (Ultradent Products Inc., South Jordan, UT, USA).

Glycerine-based home bleaching solutions have now been largely replaced because they dehydrate the tooth, increasing the risk of thermal sensitivity. Less viscous solutions of both hydrogen peroxide and carbamide peroxide are now available that are applied for shorter time periods, but their low viscosity may lead to leakage onto the gingivae, increasing the potential gingival irritation (76).

The ‘deep bleaching technique’ has recently become popular among the profession, with its proclaimed predictability of shade B1 (Vita, Zahnfabrik, Germany) results for every patient. This technique involves night guard vital bleaching for 14 nights using 16% carbamide peroxide in specially made trays that is followed, on the 15th day, by a 1-h in-surgery power bleaching session using 9% hydrogen peroxide in the same trays. The manufacturers claim that the home bleaching conditions the teeth by increasing their permeability so that the in-surgery procedure is a lot more effective. The trays are made by first taking impressions in metal trays by increasing their permeability so that the in-surgery procedure is a lot more effective. The trays are made by first taking impressions in metal trays using a medium-bodied silicone for greater accuracy. The reservoirs on the trays are made by adding a colored stone to the cast models instead of the resin usually used in this procedure. This, coupled with the use of a greater force/pressure in the vacuum moulding machine, gives rise to a better seal to the bleaching tray about 1 mm below the gingival margin. It is this better sealing of the tray, enabling the bleaching agent to be active all night, which is believed to be key to the procedure. In addition, the patient must continue with the home bleaching for 14 consecutive days and, to reduce the inevitable sensitivity, the patient is given a desensitizing agent containing benzalkonium chloride and fluoride. There is no scientific evidence yet available to support the claims made regarding this technique.

**Bleaching chemistry**

Hydrogen peroxide acts as a strong oxidizing agent through the formation of free radicals, reactive oxygen molecules and hydrogen peroxide anions (32). These reduce or cleave pigment molecule double bonds to either break down pigments to small enough molecules that diffuse out of the tooth or to those that absorb less light and hence appear lighter. Such pigmented molecules tend to be organic, although inorganic molecules can be affected by these reactions.

Hydrogen peroxide forms a loose association with urea to produce urea peroxide (carbamide peroxide), which is easily broken down in the presence of water to release free radicals that penetrate through the enamel pores and into the dentine to produce the bleaching effect. The urea can theoretically be further decomposed to carbon dioxide and ammonia, which elevates the pH to facilitate the bleaching procedure further (138). This can be explained by the fact that, in a basic solution, lower activation energy is required for the formation of free radicals from hydrogen peroxide, and the reaction rate is higher, resulting in an improved yield compared with an acidic environment (27).

The breakdown of hydrogen peroxide into free radicals is summarized in Fig. 1.

Stains caused by inorganic substances locked into the crystal lattice of the enamel structure, or held superficially by salivary protein interactions, require the oxidation of the sulphide or thiolate bonds via suitable catalysts, such as Fe(II), before they are receptive to bleaching agents. Often these catalysts are either unavailable or in short supply, causing the degradation of hydrogen peroxide to proceed very

\[
\text{A} \\
\text{H}_2\text{O}_2 \rightarrow \text{2HO}'
\]

\[
\text{HO}' + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{O} + \text{HO}'_2
\]

\[
\text{HO}'_2 \rightleftharpoons \text{H}^+ + \text{O}'_2
\]

\[
\text{B} \\
\text{2 H}_2\text{O}_2 \rightleftharpoons \text{2H}_2\text{O} + 2\{\text{O}\} \rightleftharpoons \text{2H}_2\text{O} + \text{O}_2
\]

\[
\text{C} \\
\text{H}_2\text{O}_2 \rightleftharpoons \text{H}^+ + \text{HOO}'
\]

Fig. 1. Hydrogen peroxide forms free radicals like hydroxyl and perhydroxyl radicals and superoxide anions (A), reactive oxygen molecules that are unstable and transformed to oxygen (B), and hydrogen peroxide anions (C).
slowly, and therefore extended treatment times are usually required for these stains (103).

The perhydroxyl (HO₂•) free radical is thought to be the most reactive species in tooth bleaching, the formation of which is favoured by high pH, but this is rarely the situation as the product shelf life is adversely affected under these conditions. Although the perhydroxyl free radical is a very reactive species, it does need metal trace elements in the mouth to catalyse its action.

With use of both carbamide peroxide and hydrogen peroxide the teeth should ideally be dry and free of debris because enzymes and proteins found in saliva are capable of catalyzing the nonbleaching breakdown of peroxides to water and oxygen.

In addition to their use in nonvital bleaching techniques, perborates in gel form, very much like carbamide peroxide, have been used for tray-applied vital bleaching. However, when dispatched in powder form, perborates can be incorporated into a paste after mixing with water, saline or hydrogen peroxide and placed in the pulp chambers of nonvital teeth. Sodium perborate is stable when in the form of a dry powder but in the presence of acid, moist air or water it decomposes to form metaborate, hydrogen peroxide and nascent oxygen (Fig. 2). Hydrogen peroxide, mixed with sodium perborate potentiates its effect and is believed to produce a better bleaching effect (103, 114), although no evidence to support this is available. These compounds have also been shown to remove chlorhexidine-induced extrinsic stain both in vitro and in vivo (2). Other products marketed as peroxide-free bleaching agents employ an oxygen complex made up of a mixture of sodium perborate, sodium chlorite and oxygen.

**Bleaching safety**

A number of authors have investigated the safety of bleaching procedures (11–13, 22, 28, 60, 61, 66–69, 73, 89, 90, 97, 118, 122, 123, 131, 162) but have tended to concentrate mainly on the use of carbamide peroxide used in at home bleaching systems (11, 13, 28, 60, 66–69, 89, 90, 97, 118, 122, 123, 162). The evidence on safety published to date on the whole tend to suggest that bleaching is a relatively safe procedure (28, 60, 61, 67–69, 73, 90, 97, 122, 131, 162) but some workers have voiced concerns about potential structural changes that may occur as a result of bleaching (11–13, 89, 123). Adverse effects reported by frequency for all home bleaching products show that 27% of patients suffer an unpleasant taste and a further 27% complain of a burning palate sensation. Other adverse effects included burning throat or gingival tissues, gingival ulceration and tooth sensitivity (60). All such ill effects usually resolve on cessation of treatment.

A number of studies have reported an increase in gingival health following bleaching procedures (109) and two reasons have been put forward for this. The first is that the bleaching solution is toxic to the bacteria within the gingival crevice (8) and the second is that patients undergoing bleaching might take more interest in their teeth and as a result may improve their oral hygiene during the treatment.

**Tooth sensitivity**

The sensitivity of teeth in some individuals during bleaching is a problem that has attracted little research attention, even though two-thirds of patients generally experience sensitivity during home bleaching, which usually lasts between 1 and 4 days (67, 99, 112, 119). However, a number of studies have assessed the occurrence of the sensitivity relative to its time of onset and duration of the symptoms. The incidence of sensitivity ranges from 11 to 93% of patients using 10% carbamide peroxide (32, 71, 73, 79) and the average first report of sensitivity was after 4.8 days (±4.1 days), usually lasting for 5 days (±3.8 days) (142).

Tooth sensitivity is believed not to relate to exposed root surface or dentine or caries, but instead is explained by the easy passage of the hydrogen peroxide molecules through the enamel and dentine into the pulp (50). This results in pulpal inflammation affecting the pulpal sensory nerves that trigger in response to stimuli, such as cold drinks, until the inflammation subsides. However, dentine exposure may be a factor in tooth sensitivity as it is often misdiagnosed as not being present clinically (9). In fact, other workers (65) have correlated the incidence and severity of thermal sensitivity with gingival recession and the frequency, not actual duration, of the treatment (76).

Risk factors for the development of tooth sensitivity and gingival irritation that are associated with night guard vital bleaching were reported by Leonard et al. (74). No statistical relationship existed between age, gender or tooth characteristics, with the dental arch bleached and the development of side effects. Initially, a statistically significant association existed.

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Na_3B_2O_2\cdot(OH)_4] + 2H_2O \rightarrow 2Na BO_3^+ + 2H_2O_2
\]

*Fig. 2. The formation of hydrogen peroxide from sodium perborate.*
between the side effects and the whitening solution used. However, when the analysis was controlled for usage pattern, this relationship disappeared. Patients who changed the whitening solution more than once a day reported more statistically significant side effects than did those who did not change the whitening solution during their usage time.

Schulte et al. (119) reported on a clinical study involving the use of 10% carbamide peroxide on 28 people. Four subjects discontinued bleaching because of thermal sensitivity, whereas the remainder showed no change in pulpal readings recorded before the start of the treatment and at any time during the study. Sterrett et al. (129) found that all the individuals experienced mild, transient sensitivity during a 3-week trial. However, the consensus view from other trials was that two-thirds of patients experienced mild, transient thermal sensitivity, which disappeared on the cessation of bleaching (67, 99, 112, 119). The penetration into the pulp of various commercially available 10% carbamide peroxide bleaching products has been shown to differ significantly and may therefore account for the varying levels of sensitivity reported (144).

Although there is a widely held belief that higher concentrations of bleaching agents produce a greater prevalence of tooth sensitivity, studies reported disprove this theory (68, 86).

Cohen & Parkins (24) monitored vital bleaching for six children with tetracycline-stained teeth involving heat and hydrogen peroxide application for eight consecutive 30-min sessions at 1-week intervals. Pre-treatment and post-treatment vitality tests were performed on test and control teeth, and no changes in vitality were found throughout the study.

Cohen (23) also attempted to relate the prevalence of tooth sensitivity in vital bleaching with possible histological pulpal changes. The study involved 19 patients in whom 51 premolars were bleached with 35% hydrogen peroxide and heat in 30-min sessions. All test and control teeth were extracted for orthodontic reasons and subsequently histologically examined. Of the patients treated, 78% experienced some form of sensitivity, lasting for 24 h, from bleaching; in one individual the discomfort lasted for 48 h. Histological findings from the study showed that all pulps were normal except for moderate vasodilation and aspiration of odontoblast nuclei into the dental tubules, which was found to occur with equal frequency in both test and control teeth. Cohen (23) concluded that sensitivity and discomfort during and after bleaching procedures are caused by heat application increasing the intrapulpal pressure that leads to the sensation of pain. Histological changes to the pulp after night guard vital bleaching with 10% carbamide peroxide have recently been reported to be minor; they did not affect the overall health of the pulp tissue and were reversible within 2 weeks post-treatment (40). In a previous study in which the pulps were evaluated after overnight bleaching with 10% carbamide peroxide for either 4 or 14 days, mild inflammatory changes were demonstrated in four out of 12 teeth, irrespective of treatment duration (46). However, in those teeth treated for 14 days, followed by a rest period of 14 days, no inflammation was detected.

In a clinical study monitoring post-operative discomfort associated with vital bleaching, Nathanson & Parra (99) found that 30% of patients had no sensitivity, whereas the majority of the others only experienced mild symptoms lasting less than 24 h, with patient age having no effect on the degree of sensitivity experienced. This was contrary to the widely held view that younger patients with wider pulp horns would develop more sensitivity.

The efficacy of desensitizing agents used in patients who experience tooth sensitivity during tooth whitening has been reported in a study of such patients who had pre-existing symptoms prior to the start of the whitening procedure (76). This study suggested that the use of a 3% potassium nitrate and 0.11% fluoride desensitizing agent for 30 min prior to whitening may decrease tooth sensitivity when compared with a placebo gel.

Effects on the pulp

A study of the penetration of hydrogen peroxide reported that the compound enters readily through the enamel and dentine to reach the pulp chamber of extracted teeth (16). Bowles & Thompson (15) have shown that hydrogen peroxide concentrations as low as 5% can dramatically inhibit pulpal enzyme activity. These enzymes were quite sensitive to the combination of hydrogen peroxide and heat, but the quantities required to produce this inhibitory effect were in the region of 50 mg. A follow-up study then went on to show that although dental hard tissues exhibited substantial permeability to hydrogen peroxide, especially with the application of heat, the quantities that diffuse into the pulp chamber were in the order of only micrograms: too low to produce inhibitory effects on enzymes and therefore unable to cause permanent pulpal damage (16). The effects of carbamide peroxide penetration were also studied and it was found that for the same effective concentration, there was less
penetration of the pulp from carbamide peroxide than from free hydrogen peroxide (26).

The effects of light-enhanced bleaching on the in vitro surface and on intrapulpal temperature rise have been reported (4, 134, 137). Baik et al. (4) investigated the effect of the presence, absence and ageing of heat-enhancing colorant added to the bleaching gel on the temperature rise of the gel itself, as well as on the temperature rise within the pulp chamber, when a tooth was exposed to a variety of lights. The results showed that the freshness of this bleaching agent influences the temperature rise of the bleaching gel and may also increase the intrapulpal temperature. Use of the lights elevated the bleach temperature, which resulted in an increased intrapulpal temperature that may further impact on patient sensitivity and pulpal health. A variety of different bleaching lights, including a diode laser, were investigated by Sulieman et al. (134, 137) who found that these lights did not increase the intrapulpal temperature above the critical 5.5 °C (161) as long as they were used within the manufacturers’ guidelines.

**Root resorption**

Cervical resorption is seen occasionally in bleached, root-filled teeth and has been attributed to a combination of trauma and bleaching with high-concentration hydrogen peroxide (30%) and heat (39). Heithersay et al. (57, 58) studied the radiographs and records of 204 teeth from 158 patients who had received tooth-bleaching treatment in a specialist endodontic practice in the past 1–19 years. Seventy-eight per cent of these teeth had prior incidents of traumatic injury. All teeth were bleached using a combination of thermocatalytic or heat-activated 30% hydrogen peroxide and walking bleach techniques. Only four of these teeth (2%) had developed invasive cervical resorption during the review period, which might have been a result of the original trauma.

**Effects on physical properties**

Scanning electron microscopy of enamel bleached with carbamide peroxide showed little or no change in morphology (55), whereas other work showed areas of shallow erosions (54) or more substantial changes in enamel structure (11, 12, 123). Surface hardness and wear resistance has also been investigated with results showing a lack of agreement on the overall effect of bleaching. The results range from no effect on toothwear (70, 73, 156) to a significant decrease in the hardness and fracture resistance of enamel (13, 89). Bleaching does not cause any perceptible etching of the teeth, and morphological changes in the outer 25 μm of the enamel are clinically insignificant (90, 146). Abrasion, erosion, surface hardness and morphological changes of enamel and dentine following power bleaching using 35% hydrogen peroxide were investigated (131). There were no significant changes following the bleaching procedure as the high concentration of hydrogen peroxide did not affect the abrasion, erosion or hardness of both enamel and dentine. One possible reason for the reported deleterious effect on enamel and/or dentine of bleaches is not the bleach itself but the pH of the formulation used. The pH of various commercially available tooth-whitening agents was analysed in a study by Price et al. (108) who found the range was from highly acidic (pH 3.67) to highly basic (pH 11.13), with the over-the-counter preparations having a significantly different pH to both the at-home and in-surgery bleaching materials. The over-the-counter bleaching agents have been found to have very acidic pH values, which may cause erosion of the enamel, and the toothpastes supplied with them can be quite abrasive (62).

There may be a loss of organic components from bleached enamel and dentine surfaces. The calcium:phosphate ratio of dentine was found to be significantly reduced by bleaching with 30% hydrogen peroxide and 10% carbamide peroxide in a study by Rotstein et al. (115). In another study, by McCraken & Haywood (90), teeth exposed to 6 h of bleaching using carbamide peroxide lost an average of 1.06 μg/mm² of calcium, which was found to be similar to the amount lost from the enamel after a 2-min exposure to carbonated cola, orange juice or carbonated diet cola (48). The potential for remineralization in vivo could counteract these effects but to date this has not been investigated.

Bleaching has no effect on the erosion and demineralization of enamel (17, 80, 106, 123), but the methods of assessment have been debated as microhardness has often been the sole method of measurement. The argument is that measuring only the softened portion of the lesion is unable to quantify the bulk loss of tissue, which would require assessment methods such as profilometry.

**Effects on enamel/dentine bonding**

Bonds to enamel/dentine may be altered following bleaching because of the presence of hydrogen
peroxide. Resin tags in bleached enamel are less numerous, less well defined and shorter than those in unbleached enamel (100). Bonding to dentine may be altered after bleaching (33) and the smear layer may be removed (61). Bonding between glass ionomer and dentine may also be affected by the possible precipitation of hydrogen peroxide and collagen that forms on the cut dentine surface after tooth bleaching (100).

The residual oxygen in the tooth surface also inhibits the polymerization of the composite resin and disrupts the surface (62, 93). However, bond strength improves if the procedure is delayed for 2 weeks post-bleaching.

**Effects on restorative materials**

The effects of bleaching agents on composite resins are conflicting, ranging from no effect (7, 67, 83) to alteration of surface hardness (5, 42), surface roughening/etching (127) and changes in tensile strength (31). However, these effects were very small and considered unlikely to be clinically significant (140).

Prolonged bleaching treatment may cause micro-structural changes in amalgam surfaces and this may increase exposure to the patient of toxic by-products (115). Existing amalgams may change in color from black to silver, but not all combinations of amalgam and bleaching agents result in higher mercury levels.

Little effect is reported on gold or porcelain restorations; however, the glass ionomer matrix may show alteration in its matrix (63). Provisional crowns made of methyl methacrylate may discolor to become orange, but other materials are not affected (111).

**Toxic effects**

Carbamide peroxide administered as a home bleaching agent breaks down to produce hydrogen peroxide and urea in the mouth. The toxicology of hydrogen peroxide has been reviewed by the European Centre for Ecotoxicology and Toxicology of Chemicals (36), and others (77), who reported that hydrogen peroxide is found to occur naturally in many vegetables and is produced in humans during normal metabolism of aerobic cells. In addition to this, phagocytic cells, such as neutrophils and macrophages, provide an important source of endogenous hydrogen peroxide and play an essential role in defence against various pathological microorganisms (148). However, free radical oxidative reactions with proteins, lipids and nucleic acids have a number of potential pathological consequences (38). To prevent these potential dangers, the body has a number of defense mechanisms at the tissue and cellular level that work to repair any damage sustained. Enzymes such as catalase, peroxidase and superoxide dimutase are commonly found in body fluids, tissues and organs to metabolize hydrogen peroxide (37, 57). Salivary peroxidase has been suggested to be the body’s most important and effective defence against potential adverse effects (19). The hydrogen peroxide exposure dose has been estimated to be approximately 3.5 mg for a treatment of both arches using 10% carbamide peroxide (77), while the oral cavity is capable of decomposing more than 29 mg of hydrogen peroxide per minute (84).

The dermal toxicity of hydrogen peroxide is low, with concentrations of up to 35% not considered as being irritant to rabbit skin; however, concentrations of greater than 50% are corrosive. Various mouth rinses and oral antiseptics (10 and 15% carbamide peroxide, and hydrogen peroxide up to a concentration of 3%) have been used for some time with no detectable ill effect on humans and have been approved by the US Food and Drug Administration since 1979. On the contrary, reports are of beneficial effects on gingival irritation and plaque accumulation, and an anticariogenic action (124).

Hydrogen peroxide has been found not to be carcinogenic, mutagenic or teratogenic (37, 78, 159), and concerns of toxicity or serious damage to soft tissues appear to be unfounded (49). Initially, concerns were raised about the role of hydrogen peroxide in mutagenesis on the basis of some in vitro tests that were not reproduced in vivo (67). In fact, the frequency of genetic mutation induced by 10% carbamide peroxide is not significantly different from that of a physiological saline control (159). The only side effect reported from ingesting large quantities of a carbamide peroxide home bleaching product was a laxative effect from the presence of glycerine found within the gel (3).

**Evidence of efficacy of tooth-whitening techniques**

A variety of case reports and small clinical studies have shown that a 10% carbamide peroxide gel used in night guard vital bleaching techniques produces predictable results (66, 69, 74, 75, 85, 88, 104, 109, 116) as do hydrogen peroxide strips (44). Similarly, ‘power bleaching’ using 35% hydrogen peroxide, with
or without light and/or heat activation, has also been shown to be effective (60, 130, 131, 133).

Heyman et al. (59) reported a mean change of 7 units on the Vita shade guide after bleaching with a 10% carbamide peroxide gel over 7 days. However, there was a wide range of responses, ranging from 3 to 13 units, which highlights the unpredictable nature of teeth. Papathanasiou et al. (104) reported a mean change of 8 Vita units when using a 15% in-office hydrogen peroxide system, whereas Gerlach & Zhou (44) reported a mean change of 5.5 units when using a whitening strip, but 25% of their sample had a shade change in excess of 8 units.

Clinical and laboratory studies have also reported tooth-whitening changes using the L*a*b* system of measurement (25). For example, an in vitro study on dentine by White et al. (156) reported an improvement of ∆L* of 7 units when a 10.5% carbamide peroxide gel was used for 30 h. Similarly, Gerlach & Zhou (44) reported an improvement of ∆L* of 2 units with a whitening strip product.

Various workers have compared two or more night guard vital bleaching agents clinically; very similar results were obtained, usually in the magnitude of about 7 shade guide units improvement (82). Rosenstiel et al. (112) reported on a single power bleaching session in a group of 20 young adults, which produced an average whitening effect of 6.2 L* units (as measured using a colorimeter) that was still detectable 6 months post-treatment. In-surgery bleaching has been compared with night guard vital bleaching using 10% carbamide peroxide in a 3-month single blinded clinical study (163). Comparisons were made of the color change, color relapse as well as tooth and gum sensitivity. A 14-day home treatment was compared with 60 min of in-surgery bleaching consisting of two clinical bleaching sessions of three 10-min applications. The at-home bleaching produced significantly lighter teeth, but significantly higher cervical sensitivity. Colour relapse for both bleaching techniques stabilized by 6 weeks.

Long-term results of bleaching efficacy were reported by Leonard (72), with at least 43% shade retention without retreatment at 10 years.

The effect of the lights used for in-surgery bleaching techniques have been the subject of various debates as to their efficacy in improving the bleaching process (6, 70, 81). Hein et al. (56) reported that the three lights used in their study (halogen curing light, Xe-halogen light and metal halide light) did not lighten teeth more than their bleach gels alone and concluded that output from any of the lights used resulted in heat or light that catalysed breakdown of the gels. They also concluded that proprietary chemicals added to the gels caused them to perform differently from the 35% aqueous hydrogen peroxide liquid controls used in the laboratory tests. Furthermore, these chemicals were also probably responsible for the reduced time required to bleach with the Xe-halogen light. Contrary to these results, Luk et al. (81) reported that color and temperature changes were significantly affected by an interaction of the bleach and light variables. The application of lights significantly improved the whitening efficacy of some bleaching materials but it caused a significant temperature increase in the outer and inner tooth surfaces. Other workers have also reported a study on the use of lights for in-surgery bleaching and concluded that the use of lights with the peroxide gel significantly lightened teeth more than peroxide or light treatment alone (143). The results of this study must be interpreted with caution as the reported shade improvement with light-only application was 4.9 shade guide units, which was probably the result of a great deal of tooth dehydration. In another in vitro study, it was found that an activating light source did improve the whitening effect but the freshness of the hydrogen peroxide was probably more of a contributing factor (135).

Researchers at Procter & Gamble have reported on many trials using a whitening strip and various concentrations of carbamide peroxide (44). In general, the magnitude of the whitening response decreased with age and, on average, for every 10 years of aging, individuals should expect approximately 0.3 units less whitening benefit. Baseline color also affected the response, with the greatest average whitening seen in individuals with more yellow teeth. For both strip and tray systems used, increasing the peroxide concentration was observed to improve the whitening response (47, 48, 141). When treatment time was doubled to 28 days using these whitening strips, an additional 29% whitening effect was achieved compared with the normal treatment duration of 14 days (34, 50). Pre-brushing teeth prior to the application of whitening strips was also found to yield a significantly more efficacious whitening result (50), although no explanation for this was offered.

After the introduction of a new higher-concentration whitening strip (14% hydrogen peroxide), which was thinner and incorporated a smaller volume of bleaching gel, various comparative trials were reported in a pooled report (43). Efficacy results for these strips were significantly better than placebo or pooled positive controls evaluated in clinical trials.
assessing tooth shade. The reported irritation and patient tolerability were similar to those reported with previous lower-concentration strips and other marketed positive bleaching controls.

Hydrogen peroxide (8.7%), carbamide peroxide (18%) and sodium percarbonate (19%) paint-on-bleaching agents have been introduced directly to the public as over-the-counter preparations. The shade improvements with these agents were reported to be about 4 shade guide units from baseline (41) with a reduction in yellowness (Delta b*) of about −0.95 units (43).

Long-term efficacy has been reported by Leonard (72), with shade retention without retreatment in at least 43% of subjects at 10 years post-treatment. The initial efficacy of the night guard vital bleaching technique was 98% for non-tetracycline-stained teeth, and, with extended treatment times for tetracycline-stained teeth, 86% of these teeth were lightened.

Laboratory studies have reported on the efficacy of different concentrations of carbamide peroxide. Although higher concentrations of 10 and 16% produced a quicker 2-shade shift than a 5% concentration, the eventual result on whitening was the same for all concentrations (75). Other studies that compared various concentrations of carbamide peroxide and hydrogen peroxide also found that the eventual result was the same, but the time taken to reach that end point was quicker with high concentrations of bleaching agents (130, 136). In a similar clinical study on patients with tetracycline-stained teeth, more rapid bleaching effects were achieved with a higher concentration of carbamide peroxide (15 and 20%) but the end results were the same as those for a lower concentration of carbamide peroxide (10%) (87). In a separate study comparing the clinical effect of 10 and 15% carbamide peroxide using three different shade-assessment methods, results at 2 weeks showed a significantly better shade improvement for the higher-concentration product. However, by 6 weeks there were no statistical significant differences between the two concentrations (86).

To establish the efficacy of both 20% carbamide peroxide and the equivalent concentration of 7.5% hydrogen peroxide used in an in vivo study of daytime use of bleaching agents, it was found that there were no significant differences between the two products in terms of tooth lightness, and gingival and tooth sensitivities (95).

The mechanism of tooth color change during bleaching is poorly understood. Many workers suggest that tooth color is primarily determined by the dentine, which can be changed by bleaching techniques (121, ten Bosch and Coops, 1995). Some studies, using 35% hydrogen peroxide, have reported color changes in both enamel and dentine (3, 52, 91, 92, 98, 132). Others dispute the idea of color change in dentine and believe that this occurs in enamel only, thereby masking the unchanged dentine (21). However, the successful bleaching of tetracycline-stained teeth, and those with dentinogenesis imperfecta (30, 61), add weight to the argument that the color change takes place primarily within dentine. McCaslin et al. [1999] reported on a study using 10% carbamide peroxide and its effect on dentine color changes, and found that the color change in dentine occurred at a uniform rate.

A study by Carrillo et al. (20), of inside/outside bleaching of nonvital teeth and the surrounding vital teeth, reported an average Vita shade change of 15 and 6 for the nonvital and vital teeth respectively. Friedman (39) also reported very favourable shade changes for nonvital bleaching, but was cautious over long-term results (1–5 years) with 50% shade relapse observed.

**Indications and contraindications for bleaching**

Nearly every patient can have their teeth bleached, but not every case is guaranteed to have a successful outcome or be enough to satisfy the esthetic needs of the patient. The indications for bleaching are basically the same for both in-surgery and home bleaching but the clinician must decide which method is best suited to the patient’s needs.

**Indications**

- generalized staining.
- ageing.
- smoking and dietary stains such as those of tea and coffee.
- fluorosis.
- tetracycline staining.
- traumatic pulpal changes.
- pre-restorative and post-restorative treatments.

Very severe tetracycline staining may not be amenable to bleaching alone and therefore combination treatments, such as bleaching and veneers, may be considered. Prior bleaching reduces the amount of tooth substance removed in preparation for the veneers, which would otherwise have been necessary in order to mask the stain and allow for porcelain build
up. Fluorosis with multiple spots of varying colors may require a combination of bleaching and micro-abrasion using hydrochloric acid and abrasives/polishes (29). Bleaching is also indicated prior to extensive restorative cosmetic work in the anterior region of the mouth in order to allow general improvement of the shade of the teeth, which are then matched with the new restorative restorations. Bleaching can also be used post-restoratively when patients present with incorrectly made restorations whose shades are lighter than the natural dentition.

As mentioned above, bleaching can be undertaken in most cases but some contraindications are worthy of mention. Patients with high expectations may never be satisfied and should be identified by asking a simple question as to what they hope to achieve with the bleaching procedure. Patients who reply ‘dazzling white’ or words to that effect should be treated cautiously, while more reasonable replies may be ‘a freshening look to the teeth’ or a ‘little lighter’. Decay, peri-apical lesions and sensitivity does not preclude those patients from bleaching, but these conditions have to be resolved prior to bleaching.

**Contraindications**

- patients’ high expectations.
- decay and peri-apical lesions.
- pregnancy.
- sensitivity, cracks and exposed dentine.
- existing crowns or large restorations in the smile zone.
- elderly patients with visible recession and yellow roots.

Existing crowns or restorations that need to be changed following bleaching may be considered as a contraindication for patients who do not want or cannot afford this extra financial burden. It is not always necessary to change composites following bleaching because some types of composites display a chameleon effect, taking on the shade of the surrounding tooth and blending in well, if not quite perfectly. The other contraindications mentioned above can be rectified before embarking on a bleaching course of treatment. For instance, in the case of decay, a restoration can be preformed and resurfaced for the correct bleached shade about 2 weeks post-bleaching once the end shade has stabilized and to allow for the dissipation of the residual oxygen that may inhibit the composite bond to enamel/dentine. Similarly, apical lesions should be treated and the root canal filling sealed effectively using a glass ionomer material prior to bleaching.

The sensitive patient can have fluoride-desensitizing gels applied to teeth in the bleaching trays for a period of a few weeks prior to bleaching. Elderly patients with yellow receded roots present a problem in that the roots do not bleach as readily compared with the crowns, leaving an obvious mismatch that requires to be corrected by restorative dentistry. If the patients are aware of this and are willing to undergo restorative work to address this issue, then it cannot be considered as a contraindication.

**Who best to bleach?**

Although it is difficult to predict the result of bleaching teeth for every individual, there are some guidelines gained from various studies, reports and personal experience. For instance, the effect of bleaching in older patients who have teeth with small pulps and various accumulated dietary stains, as well as the aging discoloration caused by secondary dentine deposition, is relatively predictable. In the authors’ experience, teenagers with yellow teeth or with basically white teeth except for the yellow canines tend to respond well to bleaching. Browns stains are more difficult to bleach but generally respond to longer bleaching regimens than stains caused by nicotine (51). White fluorosis spots tend not to bleach but will become less obvious as a result of the lightening of the surrounding tooth area (51).

Severe tetracycline staining may be very difficult to bleach but mild-to-moderate tetracycline staining tends to respond to extended bleaching regimes of 3 to 6 months (51). Different brands of tetracycline present with different colored tooth banding, which is especially difficult to treat as not all respond well to bleaching, leaving the possible need to use restorations to cover the nonresponsive band (51). Figure 3 shows an example of fluorosis brown stain removed using 10% carbamide peroxide.

**Bleaching protocol**

Diagnosis of the cause of the discoloration should be made and recorded in the patient’s notes. The options for treatment can be extrinsic stain removal, bleaching or both. Other options, such as veneers and crowns, should also be discussed with the patient and recorded in the notes.

The teeth that are to be bleached should be identified and checked for the following:

- vitality.
- caries.
cracks.
- recession, exposed dentine.
- developmental defects such as white spots.

In addition, the presence of composite fillings, veneers, crowns or highly translucent teeth should be noted. Patients must be warned that these will not change shade but their margins may merely be cleaned up by the bleaching agent acting on the surrounding tooth structure. Hence, they may need replacement following the bleaching treatment. Highly translucent teeth do not bleach well and sometimes appear greyer rather than whiter (45). Patients need to be aware of all these points and the information again needs to be recorded in the notes.

Some authors advocate the use of full-mouth periapical radiographs to document the size and vitality of pulps to predict sensitivity levels or check for periapical pathology (51). In view of the current ionization radiation regulations and the unnecessary exposure of the patient to high levels of radiation, other forms of vitality testing, such as ethyl chloride or electric pulp testers, are advised instead. Any teeth that require root canal therapy should have this carried out prior to the bleaching procedure. Following the assessment of the teeth, the shade should be agreed with the patient and recorded in the notes. A pre-operative photograph with the shade tab in situ should always be taken under standardized lighting conditions without using the dental operating light, which would result in washout of the shade. After all the relevant explanations, options, limitations and prognosis have been discussed with the patient, a consent form should be signed and the patient referred for a hygiene session about 7–10 days prior to the bleaching procedure.

**Home bleaching**

**Bleaching material/regimen**

Nearly all the bleaching materials on the market have been shown to work to a comparable extent (82). Generally, the higher-concentration, thicker, more viscous materials produce a lightening effect more quickly than lower-concentration, less viscous materials. However, higher concentrations tend to produce more cases of thermal sensitivity (107).

The choice of material to use depends on a number of factors, including the type of discoloration present and how dark the teeth are initially. However, the most important consideration has to be the patient, their lifestyle, the time available for bleaching and whether there are existing problems with tooth sensitivity.

The bleaching regimen is therefore determined by the patients’ lifestyle, preference and schedule. If the patient is happy and able to wear trays overnight, then 10% carbamide peroxide worn for 8 h overnight is the treatment of choice (Fig. 4). However, if time is at a premium, this regimen is not recommended as bleaching will take about 4 weeks in total as the top and the bottom teeth are bleached separately. In the authors’ experience, some patients are able to wear both upper and lower trays simultaneously overnight, thereby achieving a satisfactory result in half the time. Other regimens of 3% hydrogen peroxide, which are available over the counter, are also given in this session.

**Fig. 3. The use of 10% carbamide peroxide to remove a brown fluorotic stain from a maxillary right central incisor.**

**Fig. 4. Loaded tray inserted into the patients mouth before removal of excess bleaching agent.**
and increased salivary flow may dilute the gel (35). The maximum bleaching effect, but both occlusal pressure and frequent replenishment of the bleaching gel for maximum bleaching effect, but both occlusal pressure and increased salivary flow may dilute the gel (35).

**Home bleaching side effects**

Some patients experience problems with gingival or soft tissue irritation during home bleaching, but the vast majority of problems are those of tooth sensitivity, which have been reported to affect about two-thirds of patients (61, 99). Painful gums may be the result of incorrectly fitting trays impinging on them or the use of excess material in the trays. The trays can be easily trimmed back and polished, while the patient can be instructed to use less material if other areas of mucosa or soft tissues are irritated. Some patients who bleach teeth overnight report a metallic taste sensation immediately following tray removal, but this usually disappears after about 2 h (42).

Thermal tooth sensitivity is a common side effect noticed by patients as early as the third day of bleaching following the removal of trays and may persist for 3–4 h afterwards. Patients who experience severe sensitivity should be advised to stop bleaching and the sensitivity should be treated. Treatment can take the form of fluoride-containing toothpastes or neutral sodium fluoride gels in the bleaching trays worn overnight. Desensitizing potassium nitrate, or potassium nitrate and fluoride-containing gels, are also available for use in trays for about 2 h before or after the bleaching procedure. Potassium nitrate in toothpastes takes about 3 weeks to reduce sensitivity measurably, but when put in a tray for 10–30 min, relief is almost immediate. Lower degrees of sensitivity can be treated with desensitizing toothpaste rubbed or brushed onto the cervical necks of the affected teeth.

Fluoride acts primarily as a blocker of dentinal tubules, which acts to slow down the dentinal fluid flow that causes sensitivity, while potassium nitrate acts like an anesthetic by preventing the nerve from repolarizing after it has depolarized in the pain cycle (51).

Other forms of treating sensitivity are passive in terms of not involving specific desensitizing products; they are aimed at reducing the concentration and amount of bleaching gel used, or the bleaching time. The trays are trimmed back, if necessary, and less gel is used in the trays with the excess thoroughly removed. The patients can be instructed to apply the bleaching materials only on alternate nights, or even every third night, to reduce the problems of sensitivity. This can delay the treatment time but ensures that the patient is comfortable with the bleaching regime.

**Nonvital bleaching techniques**

There are a number of nonvital bleaching techniques available, which include ‘walking bleach and modified walking bleach’, nonvital power bleaching, also known as ‘thermo/photo bleaching’, and ‘inside/outside bleaching’.

**Walking bleach technique**

First described by Spasser (128), the walking bleach technique involved sealing into the tooth a mixture of sodium perborate with water by introducing it into the pulp chamber. After 1 week the patient would return and the procedure would be repeated until the desired whitening had occurred. The technique was modified using a combination of 30% hydrogen peroxide and sodium perborate sealed into the pulp chamber for 1 week ‘modified or combination walking bleach technique’ (102, 103). Sodium perborate is stable when in the form of a dry powder, but in the presence of acid, warm air or water it decomposes to form metaborate, hydrogen peroxide and nascent oxygen. Hydrogen peroxide mixed with sodium perborate potentiates its effect and produces a better bleaching effect (114).

Prior to any bleaching procedure the nonvital tooth must be radiographed to assess the quality of the root canal obturation and the apical tissues. Any deficiencies must be rectified before bleaching.

The ‘combination bleach technique’ differs from the above only in that sodium perborate is mixed with 30% hydrogen peroxide (or lower concentrations), instead of water, to form a thick paste that is sealed into the cavity. The procedure is quicker acting and hence can produce results after 1 week. The current walking bleach technique involves sealing in 10% carbamide peroxide instead of sodium perborate without needing to mix the product, simply syringing the gel into the cavity and reviewing the patient in 3 days.
Internal nonvital power bleaching

This technique is the least favoured because of its use of high temperatures and the probable increased risk of internal resorption. Hydrogen peroxide gel at a concentration of 30–35% is applied into the pulp chamber and activated either by light or heat. The temperature is usually between 50 and 60 °C and maintained for 5 min before the tooth is allowed to cool down for a further 5 min before the gel is removed by washing with water for a further minute (114). The tooth is dried and the ‘walking bleach technique’ is used between visits until the tooth is reviewed 2 weeks later to assess if further treatment is necessary.

A variation of this technique uses 35% hydrogen peroxide gel applied both internally to the pulp chamber and externally to the labial surface of the tooth, with light activation internally and externally. High temperatures are not involved and the same preparation protection techniques are used on the tooth. Light activation both internally and externally can be in the form of a conventional halogen-curing light, plasma arc lamp or a diode laser. Following this procedure, the tooth is washed and dried before being sealed with a temporary restoration. The patient is reviewed 2 weeks later when the shade would have stabilized and the tooth is ready for a definitive restoration to be placed or is bleached further if required.

Inside/outside bleaching

This technique is a combination of internal bleaching of nonvital teeth using the home bleaching technique. The preparation of the nonvital tooth is exactly the same as for the ‘walking bleach technique’ in that a protective barrier is placed over the root canal system using glass ionomer material and the access cavity is completely cleaned in readiness for the bleaching procedure.

The advantage of this technique for bleaching nonvital teeth is that it utilizes both an internal and an external approach for the bleaching agent. The use of a lower concentration of bleach, usually 10% carbamide peroxide, is thought to reduce the risk of external resorption. There is no need for frequent changes in temporary dressings, as experienced with the walking bleach when the oxygen build up within the pulp chamber dislodged the dressing. Additionally, the technique achieves the lightening effects within a matter of days compared with weeks.

The main disadvantages of this technique are the need for patient compliance and a little degree of manual dexterity to place the bleaching agent into the cavity. Coupled to the ease with which overuse can lead to overbleaching the tooth, and with the potential for external resorption still existing, although reduced, this technique is by no means without its risks.

As with the modified bleaching technique, the inside/outside bleaching technique has been modified by use of varying concentrations of carbamide peroxide, such as 5, 16, 22 or 35%, as used in the waiting room technique. Figure 5 shows a typical example of the results achieved using this technique.

Power bleaching

The power bleaching technique is used on those patients who do not have the necessary time available for home bleaching, who have a problem with wearing trays that may cause them to gag or who even find the taste of the home bleaching gel not to their liking. Another advantage is that the immediate results produced in power bleaching can be used to motivate the patient to continue with home bleaching top-up treatment. It must be emphasized that although there is an immediate result with power bleaching, it is by no means necessarily the end point.
in terms of tooth whiteness and further bleaching sessions may be necessary. It can be likened to the home bleaching procedure that produces results within the first 4 days for most people but over the next couple of weeks this is further enhanced until it reaches a terminal end point where the tooth shade does not improve any further.

The increased surgery time required for in-surgery bleaching is obviously a disadvantage, as it makes the procedure more expensive for the patient. Some reports also highlight that power bleaching causes dehydration of the teeth, thereby giving a falsely lighter shade immediately post-treatment (6). This causes further problems, with patients perceiving that there is color regression or rebound following rehydration of the teeth. Some manufacturers have addressed this problem by producing gels that contain 10–20% water, which rehydrates the teeth throughout the bleaching procedure, while others have tackled the problem by using lower concentrations of hydrogen peroxide (15%), which is a water-based solution, thereby increasing the water content by 20%. However, by far the biggest disadvantage of the power bleaching procedure is the caustic nature of the 35–50% hydrogen peroxide used. The need for a meticulous protocol in handling, applying, removal and disposal of these materials is essential. The risk of tissue burns to the lips, cheeks, gingiva, the rest of the face or eyes makes isolation and protection techniques mandatory (Fig. 6).

The main safety issue concerning the activating lights used in power bleaching is heat generation and its effect on the pulp. Recent research showed that the increase in the intrapulpal temperature with most bleaching lamps was below the critical threshold of a 5.5 °C increase thought to produce irreversible damage. The only lamp that produced an intrapulpal temperature increase above this threshold was the laser-based lamp, and this was also found to be below the critical temperature once the power output was reduced from 3 to 2 W (137).

There are many different materials available, but broadly speaking they are either based on 35% carbamide peroxide or hydrogen peroxide of the same or higher concentration. Hydrogen peroxide is more widely used as the power bleaching agent, but the range of concentrations in current use varies from about 17–50% and the bleaching time for which they are used also varies. Thirty-five per cent carbamide peroxide yields approximately 10% hydrogen peroxide and is used in certain bleaching systems, sometimes known as ‘waiting room bleach’, because the patient wears the custom-made trays full of the material and waits in the waiting room of the surgery.

Thirty-five per cent hydrogen peroxide is available in a powder–liquid combination mixed together to produce a gel, or in a ready-made gel to which liquid is added. There are many different combinations available depending on the system or activation method used.

**Light activation**

Various types of curing lights are used to activate the bleaching gel or expedite the whitening effect. Initially, conventional curing lights were used but these were quickly joined by lasers and plasma arc lamps. In addition, some systems are activated by a chemical reaction upon mixing two gels, while others utilize a dual-activation system.

Halogen curing lights can be used with a number of different systems and generally activation is via the light’s bleach mode for 30 s per tooth and the application involves three 10-min passes. Plasma arc lamps are also used in a similar way to halogen curing lights but, with the aid of a full smile illuminator, they can act in the same way as Xenonhalogen lights, irradiating both arches at the same time, which is generally three 10-min passes. Similarly, metal halide lamps are used with a two-part 25% hydrogen peroxide gel in a dual-arch technique employing three 20-min passes followed by the application of sodium fluoride gel.

Diode lasers of 830 and 980 nm wavelengths can be used for tooth bleaching in combination with 35–50% hydrogen peroxide gel. The gel is produced by mixing the hydrogen peroxide liquid with a powder containing mainly fumed silica and a blue dye. The blue dye absorbs the laser wavelength and heats up to cause the controlled breakdown of the hydrogen peroxide to oxidizing perhydroxyl free radicals.

![Fig. 6. Isolation of teeth and gums typically used in a power bleaching procedure.](image-url)
Waiting room bleach technique

Thirty-five per cent carbamide peroxide is activated by holding the syringe under hot running water for a few minutes prior to use. The gel is transferred into the custom-made tray and the excess material removed from the patients’ mouth before asking the patient to sit in the waiting room for about 30–60 min. After this time has elapsed the patient returns and the gel is suctioned and rinsed off the teeth. The procedure can be repeated two or three times more in the one session.

Power bleaching may frequently require more than one visit to produce an optimal result. However, for many patients a single visit is enough to satisfy their esthetic needs and no further treatment is required. Power bleaching should be used in cases where time is at a premium with patients requiring faster results and in cases where it is felt that the patient needs a ‘kick start’ before continuing with home bleaching. It can also be used on teeth with different stain etiologies, but must be carried out with meticulous care and attention as a result of the caustic nature of the 35% hydrogen peroxide used.


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The goal of modern dentistry is maximum preservation of tooth substance with excellent esthetics. Bleaching alone, or in combination with minimally invasive adhesive dentistry, very often fulfills this goal without the need to progress to the much more destructive techniques of veneers, crowns and bridges.

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