## Review Article

# Nonvital Tooth Bleaching: A Review of the Literature and Clinical Procedures

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## Abstract

Tooth discoloration varies in etiology, appearance, localization, severity, and adhesion to tooth structure. It can be defined as being extrinsic or intrinsic on the basis of localization and etiology. In this review of the literature, various causes of tooth discoloration, different bleaching materials, and their applications to endodontically treated teeth have been described. In the walking bleach technique the root filling should be completed first, and a cervical seal must be established. The bleaching agent should be changed every 3–7 days. The thermocatalytic technique involves placement of a bleaching agent in the pulp chamber followed by heat application. At the end of each visit the bleaching agent is left in the tooth so that it can function as a walking bleach until the next visit. External bleaching of endodontically treated teeth with an in-office technique requires a high concentration gel. It might be a supplement to the walking bleach technique, if the results are not satisfactory after 3–4 visits. These treatments require a bonded temporary filling or a bonded resin composite to seal the access cavity. There is a deficiency of evidence-based science in the literature that addresses the prognosis of bleached nonvital teeth. Therefore, it is important to always be aware of the possible complications and risks that are associated with the different bleaching techniques. *(J Endod 2008; 34:394–407)*

## Key Words

Bleaching, discoloration, in-office bleaching, root filled teeth, thermocatalytic technique, walking bleach technique

## History of Bleaching Teeth

Reports on bleaching discolored nonvital teeth were first described during the middle of the 19th century (1), advocating different chemical agents (2). Initially, chlorinated lime was recommended (3), followed later by oxalic acid (4, 5) and agents such as chlorine compounds and solutions (6–8), sodium peroxide (9), sodium hypochlorite (10), or mixtures consisting of 25% hydrogen peroxide in 75% ether (pyrozone) (11, 12). An early description (1884) of the use of hydrogen peroxide was reported by Harlan (13). Superoxol (30% hydrogen peroxide) had been mentioned by Abbot (14) in 1918. Prinz (15) in 1924 recommended using heated solutions consisting of sodium perborate and Superoxol for cleaning the pulp cavity. Some authors proposed using light (16, 17), heat (16, 18, 19–22), or electric currents (23, 24) to accelerate the bleaching reaction by activating the bleaching agent.

Sodium perborate in the form of monohydrate, trihydrate, or tetrahydrate is used as a hydrogen peroxide–releasing agent. It has been used since 1907 as an oxidizer and bleaching agent, especially in washing powder and other detergents. The whitening efficacy of sodium perborate monohydrate, trihydrate, or tetrahydrate mixtures with either water or hydrogen peroxide is not different (25).

## Causes of Tooth Discoloration

The correct diagnosis of the cause of discoloration of teeth is of great importance because it has a profound effect on the treatment outcome. It is therefore necessary that dental practitioners have an understanding of the etiology of tooth discoloration to arrive at a correct diagnosis leading to an appropriate treatment plan (26).

Tooth color is determined by a combination of phenomena associated with optical properties and light (27). Essentially, tooth color is determined by the color of dentin (28) and by intrinsic and extrinsic colorations (26). Intrinsic color is determined by the optical properties of enamel and dentin and their interaction with light (28). Extrinsic color depends on material absorption on the enamel surface (29). Any change in enamel, dentin, or coronal pulp structure can cause a change of the light-transmitting properties of the tooth (30).

Tooth discoloration varies in etiology, appearance, location, severity, and affinity to tooth structure (31). It can be classified as intrinsic, extrinsic, or a combination of both, according to its location and etiology (32).

### Extrinsic Causes

The principal causes are chromogens derived from habitual intake of dietary sources, such as wine, coffee, tea, carrots, oranges, licorice, chocolate, or from tobacco, mouth rinses, or plaque on the tooth surface (26, 32).

### Intrinsic Causes

Systemic causes are 1) drug-related (tetracycline); 2) metabolic: dystrophic calcification, fluorosis; and 3) genetic: congenital erythropoietic porphyria, cystic fibrosis of the pancreas, hyperbilirubinemia, amelogenesis imperfecta, and dentinogenesis imperfecta.

Local causes are 1) pulp necrosis, 2) intrapulpal hemorrhage, 3) pulp tissue remnants after endodontic therapy, 4) endodontic materials, 5) coronal filling materials, 6) root resorption, and 7) aging.

Extrinsic stain is found on the tooth surface and for this reason can be removed with relative ease. Affinity of materials to the tooth surface plays a critical role in the deposition of extrinsic stain. The types of attractive forces include long-range interactions such as electrostatic and van der Waals forces and short-range interactions such as hydration forces, hydrophobic interactions, dipole-dipole forces, and hydrogen bonds (33). These interactive forces allow the chromogens to get close to the tooth surface and determine whether adhesion will occur. The affinity of chromogen adhesion varies with the material, and the mechanisms that determine the strength of adhesion are not clearly understood (34). For example, clinical evidence has shown that tea and coffee stains become more difficult to remove with aging (34).

In the past, extrinsic tooth discoloration has been classified as metallic or nonmetallic stain (35). There are several problems with this classification. First, it does not explain the mechanism of discoloration; second, the extent of staining is variable and might depend on multiple factors; third, all metals do not cause extrinsic discoloration. To overcome these problems, a new classification based on the chemistry of dental discoloration has been proposed (34).

The most commonly used procedure to remove discoloration from a tooth surface is by using abrasives (such as prophylactic pastes) (31) or a combination of abrasive and surface active agents such as toothpastes (36). These methods prevent stain accumulation and to a certain extent remove extrinsic stains (34); however, satisfactory stain removal depends on the type of discoloration (36). Unfortunately, the chemical interactions that determine the affinity of different types of materials that cause extrinsic dental stains are not well-understood (34).

Unlike extrinsic discolorations that occur on the surface, intrinsic discoloration is due to the presence of chromogenic material within enamel or dentin, incorporated either during odontogenesis or after eruption (31). This type of stain can be divided into 2 groups, pre-eruptive and posteruptive (31, 34). The most common type of pre-eruptive staining is endemic fluorosis caused by excessive fluoride ingestion during tooth development. A method for removal of dental fluorosis stains, on the basis of the structural characteristics of the fluorotic tooth, has been reported to be effective (37). It encompassed 3 principal stages: enamel etching with 12% hydrochloric acid, application of pure sodium hypochlorite, and filling the chemically opened microporosities with a light-cured dental adhesive. Staining caused by tetracycline administration also occurs during odontogenesis and is a result of antibiotic interactions with hydroxyapatite crystals during the mineralization phase. Malformation of dental tissues occurring as a result of inherited conditions such as dentinogenesis imperfecta and amelogenesis imperfecta can also cause pre-eruptive dental stain. Hematologic disorders such as erythroblastosis fetalis, thalassemia, and sickle cell anemia might also cause pre-eruptive stain because of the presence of coagulated blood within the dentinal tubules.

Traumatic events that influence tooth formation can represent another cause of pre-eruptive discoloration (31). Teeth might acquire posteruptive intrinsic stains in a similar way. Normal aging can also cause posteruptive dental stain caused by the deposition of secondary dentin, tertiary dentin, and pulp stones (38). It has also been reported that dental procedures might lead to tooth discoloration, owing to release of metals from, for instance, amalgam restorations or incomplete obturation of the pulp chamber after endodontic treatment (34).

## Causes of Intrinsic Local Discoloration
### Pulp Necrosis

Bacterial, mechanical, or chemical irritation of the pulp might result in tissue necrosis, causing release of noxious by-products that can penetrate tubules and discolor the surrounding dentin (39). The degree of discoloration is directly related to the duration of time that the pulp has been necrotic. The longer the discoloration compounds are present in the pulp chamber, the greater the discoloration. This discoloration can usually be bleached intracoronally (40).

## Intrapulpal Hemorrhage

Pulp extirpation or severe tooth trauma can cause hemorrhage in the pulp chamber caused by rupture of blood vessels. Blood components subsequently flow into the dentinal tubules, causing a discoloration of the surrounding dentin (41, 42). Initially, a temporary color change of the crown to pink can be observed. This is followed by hemolysis of red blood cells. The released heme then combines with the putrefying pulpal tissue to form iron (26, 43). The iron in turn can be converted by hydrogen sulfates that are produced by bacteria to dark-colored iron sulfates, which discolor the tooth grey. These products can penetrate deep into the dentinal tubules and can cause discoloration of the entire tooth.

Grossman (44) asserted in 1943 that the depth of dentinal penetration determines the degree of discoloration, although there was little, if any, scientific evidence to support this hypothesis (26). In vitro studies have recently shown that the major cause of discoloration of noninfected traumatized teeth is the accumulation of the hemoglobin molecule or other hematin molecules (45). In the absence of infection, the release of iron from the protoporphyrin ring is an unlikely event, because there are no reactions caused by bacterial by-products. An understanding of the nature of tooth staining after trauma is of importance for the manufacturing of bleaching agents with specific activity.

If trauma is the cause of pulpal necrosis, the discoloration becomes more severe over time. However, if not, the discoloration can be reversed, and the tooth can regain its original shade (26). It has been shown that the pinkish hue seen initially after trauma might disappear in 2–3 months if the tooth becomes revascularized (18).

## Pulp Tissue Remnants after Endodontic Treatment

The same events that characterize intrapulpal hemorrhage can be caused by trauma inflicted during pulp extirpation and failure to remove all pulp remnants. Tissues remaining in the pulp chamber disintegrate gradually, and blood components can flow into the tubules, causing discoloration. If the access cavity is inadequate, some pulp remnants can remain inside the pulp chamber, in particular in the pulp horns, causing coronal discoloration (46, 47).

Removal of all tissues and correct intracoronal bleaching in these cases are usually successful, but they are unnecessary and can be avoided if all pulpal remnants are removed from the access cavity.

## Endodontic Material

Incomplete removal of filling materials and sealer remnants (48–52) or medicaments containing tetracycline (53) from the pulp chamber can cause endodontically treated teeth to discolor. This is a frequent occurrence but can easily be prevented by removing all materials to a level just below the bone. Filling material and intracanal medicaments sealed in the pulp chamber are in direct contact with dentin, sometimes for long periods, allowing penetration into dentinal tubules. These materials need to be in direct contact with dentin for a period of time before it is possible to appreciate any visible coronal shade alteration. Although there is no penetration in the enamel, it is still possible to see a change in tooth color (38).

Although intracoronal bleaching is the treatment of choice, the prognosis, however, depends on the type of sealer and duration of discoloration (49). For example, stains made by metallic ions are difficult to remove with bleaching treatment. Therefore, the need to re-

move all remnants using burs to clean the chamber walls before starting bleaching procedures cannot be emphasized enough.

## Coronal Filling Materials

Microleakage of old resin composite restorations might cause dark discoloration of margins and, over time, of dental tissues. Amalgam used as filling material after endodontic therapy can turn the dentin dark grey, owing to dark-colored metallic components. When used to restore lingual access preparation or a developmental groove in anterior teeth, as well as in premolar teeth, amalgam might discolor the crown. This type of discoloration is difficult to bleach and tends to reappear over time because of the tenacity of the oxidizing products to dental tissues. Sometimes the dark appearance of the crown is caused only by the amalgam restoration that can be seen through the tooth structure. In such cases, replacing the amalgam with an esthetic restoration usually corrects the problem (40).

Metal posts used to construct a core might cause discoloration because of transparency of enamel or because of released metallic ions. Frequently, dark-pigmented dentin can be seen when these restorations are removed (40).

## Root Resorption

Root resorption, while clinically asymptomatic, might occasionally exhibit an initial pink appearance (pink spot) at the cementoenamel junction (CEJ) that can serve in the differential diagnosis of the origin of the discoloration (26).

## Aging (Dystrophic Calcification)

During the natural aging process the physiologic deposition of secondary dentin affects the light-transmitting properties of teeth, resulting in a gradual darkening (26) based on a narrowing of the pulp space, resulting in an increase in tooth structure that in turn affects opacity. In addition, the chemical structure of teeth changes over time.

## Bleaching Agents for Whitening of Root-filled Teeth

The bleaching agents that are most commonly used for whitening of root-filled teeth are hydrogen peroxide, carbamide peroxide, and sodium perborate.

Hydrogen peroxide is the active ingredient in currently used tooth bleaching materials. It might be applied directly or can be produced by a chemical reaction from carbamide peroxide (54) or sodium perborate (55).

Peroxides can be classified as organic and inorganic. They are strong oxidizers and can be considered as products of hydrogen peroxide ($H_2O_2$) when substitution of hydrogen atoms with metals (inorganic peroxides) or with organic radicals (organic peroxides) takes place (40).

Hydrogen peroxide is used in dentistry as a whitening material at different concentrations from 5%–35%. At a high concentration hydrogen peroxide is caustic, burns tissues on contact, and can release free radicals. High-concentration solutions must be handled with care because they are thermodynamically unstable and might explode unless refrigerated and kept in a dark container. Because of its low molecular weight, this substance can penetrate dentin and can release oxygen that breaks the double bonds of the organic and inorganic compounds inside the dentinal tubules (56, 57).

The breakdown of hydrogen peroxide into active oxygen is accelerated by application of heat, the addition of sodium hydroxide, or light (58, 59). Hydrogen peroxide–releasing bleaching agents are therefore chemically unstable. Only fresh preparations should be used, which must be stored in a dark cool place.

Carbamide peroxide [$CO(NH_2)_2H_2O_2$] is an organic white crystalline compound and is formed by urea and hydrogen peroxide and used in different concentrations. In a hydrophilic environment it breaks down into approximately 3% hydrogen peroxide and 7% urea. Currently, the most popular commercial bleaching preparations containing carbamide peroxide usually also include glycerin at different concentrations because this makes it more chemically stable compared with hydrogen peroxide. Ten percent carbamide peroxide bleaching agents also demonstrated higher antibacterial effect than a 0.2% chlorhexidine solution (60).

Sodium perborate is an oxidizing agent available as a powder. It is stable when dry; however, in the presence of acid, warm air, or water, it breaks down to form sodium metaborate, hydrogen peroxide, and nascent oxygen. Sodium perborate is easier to control and safer than concentrated hydrogen peroxide solutions.

## Comparison Studies

Several studies have reported bleaching effectiveness by comparing mixtures of sodium perborate with distilled water or hydrogen peroxide in different concentrations. Rotstein et al (61, 62) and Weiger et al (63) did not report any significant difference in the effectiveness between sodium perborate mixed with 3%–30% hydrogen peroxide and the sodium perborate–distilled water mixture. However, the whitening effect of the second mixture can take longer, so that more frequent changes of the bleaching agent might be necessary. The shade stability of teeth treated by a mixture of perborate and water is as high as the shade stability of teeth in which a mixture of sodium perborate with 3% or 30% hydrogen peroxide was used (25, 62). Other surveys found that mixing sodium perborate with 30% hydrogen peroxide was more effective than mixing with water (64, 65). Freccia et al (66) showed that the walking bleach technique with a mixture of 30% hydrogen peroxide and sodium perborate was as effective as the thermocatalytic technique.

Other hydrogen peroxide–separating agents such as sodium percarbonate can be used to bleach discolored teeth. Suspensions consisting of sodium percarbonate and water or 30% hydrogen peroxide had a good bleaching effect on teeth that were artificially stained in vitro by iron sulfide (67). However, clinical studies with sodium percarbonate have not been reported.

Aldecoa and Mayordomo (68) described good clinical success when using a mixture consisting of sodium perborate and 10% carbamide peroxide gel. This suspension was used as a temporary intracoronal filling after application of a regular walking bleach paste with sodium perborate and hydrogen peroxide. The authors claimed that this procedure led to long-term stability of the tooth whitening therapy.

An in vitro study reported that sodium perborate and Superoxol combinations were more effective than sodium perborate alone. Although the difference was not statistically significant, this study reported 20% difference in the effectiveness between freshly refrigerated and 1-year-old agents (64).

## Clinical Bleaching Techniques for Endodontically Treated Teeth

Bleaching of endodontically treated teeth that present with chromatic alterations is a conservative alternative to a more invasive esthetic treatment such as placement of crowns or veneers. Furthermore, when metal-free restorations are planned, bleaching of the prosthetic core can be useful in improving the final esthetic results. These materials not only depend on light transmission characteristics but also on the color of the teeth that are being restored.

## Extrinsic Stain Treatment

The most commonly used procedure to treat extrinsic stains is by a professional hygiene treatment and by polishing tooth surfaces with prophylactic cups and more or less aggressive abrasive pastes.

## Intrinsic Stain Treatment

Intrinsic stains from systemic causes are difficult to treat without a prosthetic rehabilitation.

The microabrasion technique can be successfully used to treat superficial discolored enamel defects (69). At the present time, enamel microabrasion is considered a conservative technique to improve the esthetic appearance of teeth with surface defects. Because this technique removes superficial external enamel, a correct diagnosis is of utmost importance (70).

For intrinsic stains to be removed, chemicals such as hydrogen peroxide are required because they penetrate enamel and dentin and decolorize or solubilize the chromogens (31).

Internal discoloration of teeth represents the primary indication for whitening of root-filled teeth (41).

## Preliminary Treatment

It is important to determine the cause of tooth discoloration. First, the surface of the tooth should be cleaned thoroughly to determine the degree of external discoloration. For that reason it is very important to have a preliminary professional hygiene treatment before starting the bleaching. The patient should be informed that the results of bleaching therapy are not predictable, and that complete recovery of color is not guaranteed in all cases (71). Furthermore, information should be provided concerning the different treatment stages, possible complications, and the fact that application of the bleaching agent often needs to be repeated to obtain optimum results (39). It is very helpful to take pre-treatment and post-treatment photographs to show the patient the results obtained at the end of the treatment.

Before treatment a radiograph should be made to check the quality of the root filling. The filling should not only prevent coronal-apical passage of microorganisms but also prevent bleaching agents from reaching the apical tissues, potentially having detrimental effects (71). Therefore, an inadequate root filling should be replaced before bleaching, and the new filling material should be allowed to set for at least 7 days after obturation before starting the bleaching procedures (39).

Deficient restorations should be identified and replaced; carious lesions should be restored. If restorations do not match the shade of the tooth, they should be replaced at the end of the treatment with materials matching the whitened tooth. The final shade of the tooth as a result of bleaching cannot be reliably predicted, and this makes it difficult to select the correct shade of filling material before bleaching. Therefore, it is advisable to restore carious lesions or replace deficient fillings with temporary materials before treatment or to replace restorations after completion of bleaching. It should be emphasized that the tooth be restored with high quality fillings to ensure the effectiveness of the bleaching agent and to avoid leakage of the agent into the oral cavity.

Furthermore, it is of great importance to apply rubber dam to isolate the treated tooth, to prevent reinfection of the root canal, and to protect the adjacent structures from the bleaching agent. For difficult cases it is possible to use a liquid dam.

## Walking Bleach Technique

The first description of the walking bleach technique (Fig. 1) with a mixture of sodium perborate and distilled water was mentioned in a congress report by Marsh and published by Salvas (72). In this procedure, the mixture was left in the pulp cavity for a few days, and the access cavity was sealed with provisional cement. The mixture of sodium per-
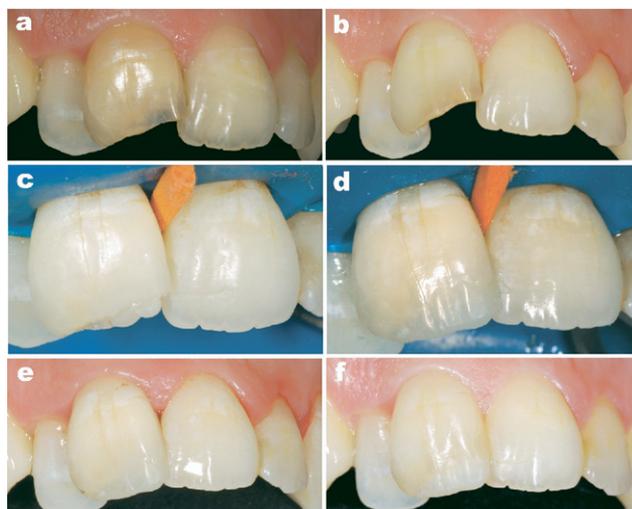


**Figure 1.** (*a*) Pre-treatment photograph of right maxillary central incisor showing severe discoloration due to a necrotic pulp caused by trauma. Endodontic treatment was performed before bleaching. (*b*) Appearance after bleaching with the walking bleach technique for 3 consecutive treatments shows considerable whitening. (*c, d*) Esthetic restoration was completed 7 days after bleaching. (*e*) Immediate postoperative view after placement of a composite resin. (*f*) Esthetic appearance after 1 year.

borate and water was reconsidered by Spasser (73) and modified by Nutting and Poe (74), who advocated the use of 30% hydrogen peroxide instead of water to improve the bleaching effectiveness of the mixture. A mixture of sodium perborate and water or hydrogen peroxide continues to be used today and has been described many times as a successful technique for intracoronal bleaching (62, 75–77).

There are numerous studies that have reported on the successful use of the walking bleach technique for correction of severely discolored teeth caused by incorporation of tetracycline (68, 78–84). This procedure starts with intentional devitalization and root canal treatment of the tooth to enable application of the bleaching agent into the pulp chamber. Because the methods of intentional devitalization and root canal treatment have risks, the advantages and disadvantages of this therapy should be assessed. Restorative treatment options such as ceramic veneers should be considered as an alternative procedure. Furthermore, there is now evidence that prolonged bleaching with carbamide peroxide can also reach the desired results (38, 85–88).

## Preparation of the Pulp Cavity

Before preparation of the access cavity, rubber dam should be applied to protect the adjacent structures. The access cavity should be shaped in such a way that remnants of restorative materials, root-filling materials, and necrotic pulp tissue are completely removed. For this reason, in particular for maxillary incisors, it is very important to include the mesial and distal pulp horns in the access cavity, because they can contain necrotic pulpal remnants, which can cause discoloration. Additional cleaning of the pulp cavity with sodium hypochlorite is also recommended (39). In some reports, conditioning of the dentin surface of the access cavity with 37% orthophosphoric acid is suggested to remove the smear layer and to open the dentinal tubules. This promotes the penetration of the bleaching agent deep into the tubules and increases its effectiveness (89). It has also been recommended to clean the pulpal cavity with alcohol before application of the bleaching agent to dehydrate dentin and reduce surface tension; consequently the bleaching agent will penetrate with greater ease into the dentin, achieving improved efficacy (39). However, studies have shown that removal

of the smear layer with 37% orthophosphoric acid does not improve the bleaching effectiveness of either sodium perborate or a high concentration of hydrogen peroxide (90, 91). Furthermore, the pre-treatment of dentin with acid might lead to an increased diffusion of bleaching agents into the periodontium (92). Therefore, removal of the smear layer from the dentin of the pulp chamber before the bleaching procedures is still a controversial issue.

## Cervical Seal

The root filling should be reduced 1–2 mm below the CEJ. This can be determined by using a periodontal probe placed in the pulp cavity, while reproducing the corresponding external probing to the CEJ. To remove filling material up to this level, Gates-Glidden or Largo burs can be used. It is important to clean the cavity surfaces from debris and remnants of endodontic materials, because the presence of contaminants on the surfaces might negatively influence the efficacy of the bleaching agent.

A root filling does not adequately prevent diffusion of bleaching agents from the pulpal chamber to the apical foramen (93, 94). Hansen-Bayless and Davis (95) indicated that a base is required to prevent radicular penetration of bleaching agents. Therefore, sealing the root filling with a base is essential, for which a variety of dental materials such as glass-ionomer cements, intermediate restorative material (IRM), hydraulic filling materials (Cavit, Coltosol), resin composites, photo-activated temporary resin materials (Fermit), zinc oxide–eugenol cement, and zinc phosphate cement have been suggested as an interim sealing agent during bleaching techniques. McInerney and Zillich (96) found that Cavit and IRM provided better internal sealing of the dentin than did zinc phosphate cement, whereas Hansen-Bayless and Davis (97) reported that Cavit was a more effective barrier to leakage than IRM. Furthermore, hydraulic filling materials (Cavit and Coltosol) provided the most favorable cavosurface seal when they were firmly packed into the cavity space to prevent microleakage, when compared with a photo-activated temporary resin material (Fermit), zinc oxide–eugenol cement, and a zinc oxide phosphate cement (98).

Temporary sealing materials need to be removed before providing the final restoration of the access cavity. Rotstein et al (99) demonstrated that a 2-mm layer of glass-ionomer cement was effective in preventing penetration of 30% hydrogen peroxide solution into the root canal. Thus, the use of this material as a base during bleaching presents the additional advantage that it can be left in place after bleaching and can serve as a base for the final restoration.

The sealing material should reach the level of the epithelial attachment or the CEJ, respectively, to avoid leakage of bleaching agents into the periodontium (100). The shape of the cervical seal should be similar to the external anatomic landmarks, thus reproducing CEJ position and interproximal bone level. A flat barrier, level with the labial CEJ, leaves a large portion of the proximal dentinal tubules unprotected. Therefore, the barrier should be determined by probing the level of the epithelial attachment at the mesial, distal, and labial aspects of the tooth. The intracoronal level of the barrier is placed 1 mm incisal to the corresponding external probing of the attachment. With this method the coronal outline of the attachment defines an internal pattern of the shape and location of the barrier (100). However, the impact of the bleaching agents on the discolored dentin should not be hampered by the cervical seal. Dentin tubules at the coronal third of the root run in an oblique direction from the apex to the crown, so that the tubules at the CEJ are originating more apically inside the root canal. If bleaching of the cervical region of the tooth is required, a stepwise reduction of the labial part of the seal and use of a mild bleaching agent are recommended for the final dressings (99).

The placement of a piece of rubber dam has been suggested to act as a further barrier to isolate filling material from the bleaching agent. However, Hosoya et al (101) reported no significant differences between the groups with and without the placement of this barrier.

## Application of the Bleaching Agent

Sodium perborate (tetrahydrate) mixed with distilled water in a ratio of 2:1 (g/mL) is a suitable bleaching agent (102). In case of severe discoloration, 3% hydrogen peroxide can be applied in lieu of water (74). The bleaching agent can be applied with an amalgam carrier or plugger and should be changed every 3–7 days. Successful bleaching becomes apparent after 2–4 visits, depending on the severity of the discoloration. The patients should be instructed to evaluate the tooth color on a daily basis and return when the bleaching is acceptable to avoid "over-bleaching" (39) (Fig. 2).

## Temporary Filling

Before application of the bleaching agent, the enamel margins of the cavity should be etched with 37% orthophosphoric acid to accomplish an adhesive temporary filling. The walking bleach technique requires a sound seal around the access cavity with a resin composite or compomer to ensure its effectiveness and to avoid leakage of the bleaching agent into the oral cavity. This cannot be guaranteed if temporary filling materials are being used (103). In addition, a good seal prevents recontamination of the dentin with microorganisms and reduces the risk of renewed staining. It is often difficult to place filling materials on a soft bleaching agent. A small sterile cotton pellet impregnated with a dentin bonding agent, placed on the bleaching agent and then light-
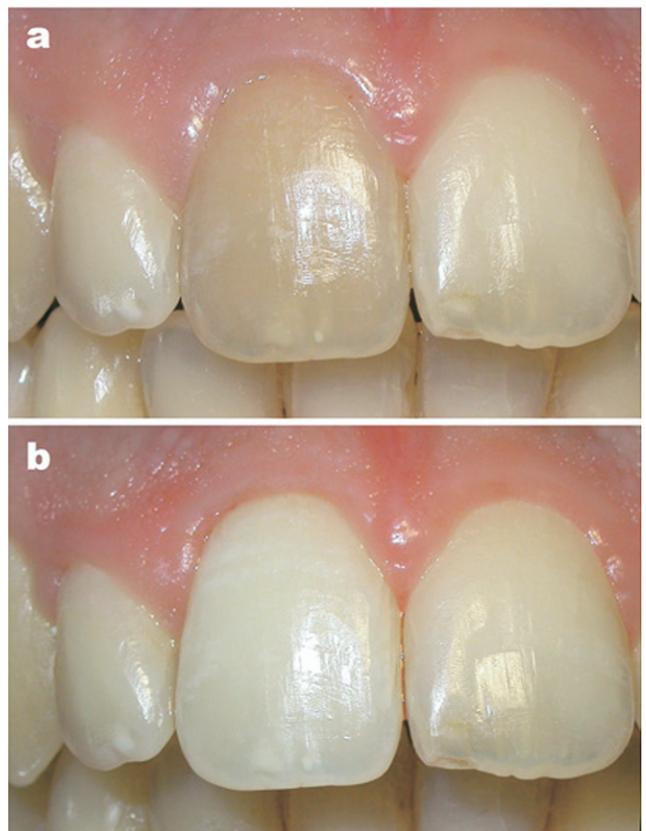


**Figure 2.** (*a*) Pre-treatment photograph shows a yellow-brown discoloration of tooth #8 caused by endodontic treatment. (*b*) Clinical results after 3 applications of the walking bleach technique, resulting in a slightly overbleached tooth.

cured, simplifies the placement of a filling material. The temporary filling should only be attached to the enamel margins of the access cavity. During this phase of the treatment, the pulp chamber is filled with the bleaching agent and not with an adhesively attached restorative material, so that no internal stabilization of the tooth is provided. Therefore, the patient should be informed about an increased risk of fracture (71).

## Restoration of the Access Cavity and Postoperative Radiograph

After bleaching, the access cavity should be restored with a resin composite, which is bonded by means of the acid-etch technique to enamel and dentin. This avoids recontamination with bacteria and staining substances and improves the stability of the tooth. A sound restoration with sealed dentinal tubules is a prerequisite to successful bleaching therapy (71, 80). Some authors (80, 104) recommend using resin composites with lighter shades to compensate for bleaching that was not completely successful. The adhesive strength of resin composites and glass-ionomer cements to bleached enamel and dentin is temporarily reduced (105–112). It has been established that remnants of peroxide or oxygen inhibit the polymerization of resin composites (109, 113). It is less likely that changes in the enamel structure might influence resin composite adhesion (114, 115). Nevertheless, the appearance of the hybrid layer in bleached enamel is less regular and distinct than in unbleached enamel (116). This might explain why access cavities of bleached teeth that are restored with resin composite occasionally show marginal leakage (117). The negative influence of hydrogen peroxide–containing bleaching agents on adhesion can be reduced by moderate bevelling of the cavity before acid etching (118). The same can be achieved by pre-treatment of enamel with dehydrating agents such as alcohol and the use of acetone-containing adhesives (119, 120). To dissolve remnants of peroxide, the cavity can also be cleaned with sodium hypochlorite (62). A contact time of at least 7 days with water is recommended to avoid the reduction of adhesion of composites to enamel (115, 121, 122). Optimal bonding to bleached dental hard tissue can be achieved after a period of about 3 weeks (123, 124). During this period, the color of the bleached tooth should be stable and a calcium hydroxide dressing placed in the pulp cavity for buffering the acid pH that can occur on cervical root surfaces after intracoronal application of bleaching agents (71, 125). The calcium hydroxide suspension temporarily placed into the pulp chamber after completion of the bleaching procedure does not interfere with the adhesion of composite materials used for final restoration of the access cavity (126). Furthermore, compromised bonding to bleached enamel can be reversed with sodium ascorbate, an antioxidant (127).

A postoperative radiograph after bleaching and regular follow-up radiographs are recommended (128).

## Thermocatalytic Technique

This technique (Fig. 3) has been proposed for many years as the best technique to bleach nonvital teeth because of the strong interaction between hydrogen peroxide and heat (44, 45, 77, 129–133). Moreover, a common clinical technique is to use 30%–35% hydrogen peroxide placed in the pulp chamber between appointments (134–136).

Preparation of the access cavity consists of cleaning, removal of filling materials, and all the preparation procedures described for discolored teeth when using the walking bleach technique. However, this technique involves placement of 30%–35% hydrogen peroxide in the pulp chamber followed by heat application by electric heating devices or specially designed lamps. It has been observed that heat application causes a reaction that increases bleaching properties of the hydrogen peroxide (2). Heat might be applied by using a heated metal instrument or other commercial heat applicators (Touch'n Heat, System B; Analytic



**Figure 3.** (*a, b*) Pre-treatment photograph demonstrates dark discoloration of right upper canine (#6). Root canal treatment had been completed many years ago. (*c, d*) Post-bleaching photograph before replacement of the stained distal composite resin restoration. A thermocatalytic intracoronal bleaching technique was used. The distal composite resin was replaced 2 weeks after bleaching. (*e, f*) Two-year postoperative/bleaching results show very nice esthetic appearance.

Technology, Orange, CA). Heat application is repeated 3 or 4 times at every appointment, changing the pellet with "fresh" bleaching agent at each visit. When heat is applied, a reaction produces foam and releases the oxygen present in the preparation.

At the end of each appointment the bleaching agent is sealed into the pulp chamber for additional bleaching between appointments as in the walking bleach technique.

## In-Office Technique

Some authors have described the successful clinical use of external bleaching of nonvital root-filled teeth (Fig. 4) with carbamide peroxide gels or hydrogen peroxide at high concentrations (15%–35%) (137–139). The whitening gel is applied by means of a bleaching tray and is placed directly on the tooth, which is isolated with rubber dam or with other techniques (Fig. 4*b*), without an access opening. Other authors recommended that the pulp chamber should be accessible during bleaching to enable the penetration of the gel into the discolored tooth (140, 141). In this case, the whitening gel is applied by means of a bleaching tray to bleach both buccal surface and pulp chamber through the access opening. There are certain risks with this technique, in that an unsealed access opening enables bacteria and stains to penetrate into dentin. Even with a good root filling, the passage of bacteria through the tooth can be observed (142). Therefore, a restorative material such as glass-ionomer cement or resin composite should be used to seal the root filling at the orifice.

The in-office procedures can also be used when the walking bleach technique does not produce satisfactory results after 3–4 applications (71).

## Prognosis of Nonvital Bleached Teeth

Despite many clinical reports, there are few scientific evidence-based studies on tooth whitening (143). Some in vivo and in vitro studies are summarized in Tables 1 and 2. Most reports present optimal initial results after bleaching, with complete color matching of the bleached tooth (teeth) with the adjacent one(s) (2, 45, 68, 80, 84, 102, 104, 130, 132, 143, 144). However, occasionally darkening after inter-
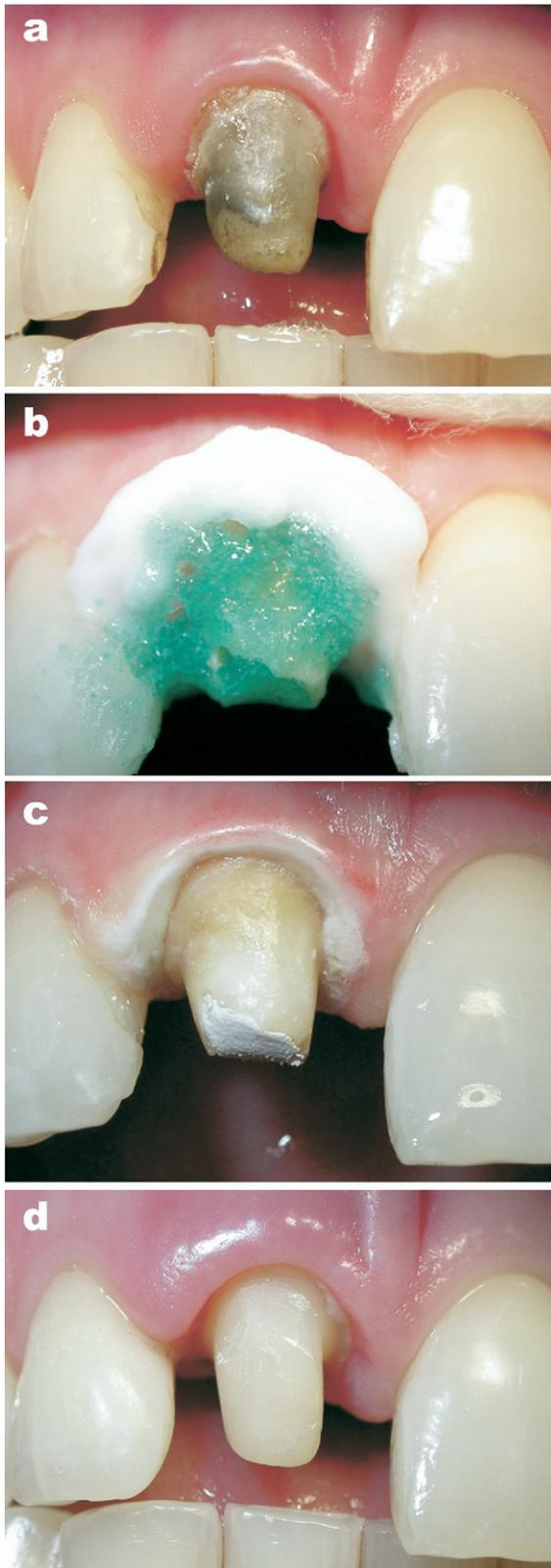
**Figure 4.** Clinical appearance of tooth #8 shows a dark discoloration of the crown preparation. (*b*) Root canal treatment was completed, and the tooth was isolated with a liquid dam. An in-office technique was used, combining an internal and external approach with 37% hydrogen peroxide in 1 visit. (*c*) Despite the use of a liquid dam, leakage of the peroxide caused bleaching of the gingival margin. (*d*) A resin composite core was fabricated 2 weeks after bleaching. Note healthy gingival margin.

nal bleaching can be observed (145), which is presumably caused by diffusion of staining substances and penetration of bacteria through marginal gaps between the filling and the tooth. It is worth noting that the opinion of the patient regarding the success of the therapy is often more positive than the opinion of the dentist (84, 104). One study reported an 80% rate of success after 1 year and 45% after 6 years of 20 cases that were chemically bleached by using the thermocatalytic technique (145).

Some authors have suggested that teeth that have been discolored for several years do not respond as well to bleaching as teeth that are stained for a short period of time (2, 46). Howell (2) could not confirm this claim. Furthermore, it is uncertain whether darkening after bleaching is more likely when the tooth is heavily or mildly discolored (2, 46, 131). Discoloration caused by restorative materials has a dubious prognosis (49). Certain metallic ions (mercury, silver, copper, iodine) are extremely difficult to remove or alter by bleaching. Brown (46) reported that trauma- or necrosis-induced discoloration can be successfully bleached in about 95% of the cases, compared with lower percentages for teeth discolored as a result of medicaments or restorations (36). There is a difference in opinion as to whether teeth that respond rapidly to bleaching have a better long-term color stability prognosis (102, 131, 143). Some studies have reported that stained teeth in young patients are easier to bleach than discoloration in older patients (8, 22, 79, 143), presumably because the wide open dentinal tubules in young teeth enable a better diffusion of the bleaching agent. However, not all studies are in agreement with age-related success of bleaching (46, 131). Teeth with internal discoloration caused by root canal medicaments, root-filling materials, or metallic restorations such as amalgam have a poor prognosis, because this type of discoloration is difficult to bleach and tends to reappear over time because of the tenacity of the oxidizing products to dental tissues (40, 46). Anterior teeth with interproximal restorations occasionally show less optimum results than teeth with a palatal access cavity only (103). This might be attributed to the fact that resin composites cannot be bleached (146). In these cases, replacement of existing restorations after the whitening treatment is recommended to get optimal results.

## Complications and Risks

Bleaching can have adverse effects, both localized and systemic (toxicity, free radical, etc) (147). Possible localized adverse effects are on dental hard tissues and mucosa, tooth sensitivity when the bleaching material is in contact with vital teeth, interaction with adhesive mechanisms, external cervical resorption risk, damage to composite restorations, and dental material solubility.

One of the most important local adverse effects is the changes in enamel and dentin, in particular the reduction of enamel microhardness (148). One study also reported that bleaching agents were mainly associated with surface changes in the cementum, which exhibited more changes than the other tissues (149). It has been suggested that peroxides might cause a modification in chemistry of dental hard tissues (150–154), changing the ratio between organic and inorganic components. The free radicals produced from the breakdown of the bleaching molecules might be active against the pigmenting molecules (150, 155). Several studies on vital teeth have shown that these modifications appear not to be permanent (156–159). These studies reported that the modification in enamel surface hardness was reduced by the application of fluoride before or during remineralization, because the application of highly concentrated fluorides favors the formation of a calcium fluoride–like layer on enamel surfaces (159–162). This deposit is later dissolved, allowing fluoride to diffuse into the underlying enamel and saliva and/or plaque to cover the tooth (162). It is assumed that some of

**TABLE 1.** *In Vivo* Studies on the Success Rate of Nonvital Bleaching

| Authors | Bleaching agent | Success | Complications and others |
|---|---|---|---|
| Brown (1965)[46] | Thermocatalytic: 30% hydrogen peroxide, followed by walking bleach: 30% hydrogen peroxide | 75% Success (39% complete, 46% partial); 25% failure (17.5% no Improvement, 7.5% refractory discoloration) | None |
| Tewari and Chawla (1972)[129] | Thermocatalytic: 30% hydrogen peroxide | 95% Success; 5% failure | The only failure was successfully bleached again |
| Howell (1981)[131] | Thermocatalytic: 30% hydrogen peroxide, followed by walking bleach: 30% hydrogen peroxide | 97% Success (53% complete, 44% partial); 3% failure | The only failure was associated with an insufficient filling |
| Feiglin (1987)[145] | Thermocatalytic: 130 volume hydrogen peroxide following walking bleach: sodium perborate + mixture of 3/4 water and 1/4 130 vol hydrogen peroxide | 45% Success; 55% failure | Teeth of younger patients showed better success rates |
| Friedman et al (1988)[144] | Three different techniques: (1) thermocatalytic: 30% hydrogen peroxide; (2) walking bleach: 30% hydrogen peroxide; (3) thermocatalytic + walking bleach: 30% hydrogen peroxide | 50% Success; 29% acceptable; 21% failure | Highest percentage of failure occurred between 2–8 years after whitening treatment |
| Holmstrup et al (1988)[102] | Walking bleach: sodium perborate + water | 90% Success (63% good, 27% acceptable); 10% failure | 3 Teeth with translent pain |
| Anitua et al (1990)[84] | Walking bleach: sodium perborate + 110 vol hydrogen peroxide | Assessment of the dentist: 100% success (98% complete, 2% partial success). Assessment of the patient: 99.4% success; 0.4% failure | None |
| Waterhouse and Nunn (1996)[228] | 30% Hydrogen peroxide solution mixed with sodium perborate granules | 83% Success | None |
| Abou-Rass et al (1998)[80] | Walking bleach: sodium perborate + 30% hydrogen peroxide | 93% Success; 7% failure | Failure because of internal cervical deposit that could be successfully bleached |
| Bizhang et al (2003)[229] | Extracoronal (10% carbamide peroxide); walking bleach (sodium perborate + 3% hydrogen peroxide); extracoronal + walking bleach (10% carbamide peroxide) | Whitening effect of extracoronal bleaching + walking bleach (10% carbamide peroxide) was as effective as walking bleach (sodium perborate + 3% hydrogen peroxide) | Extracoronal bleaching + walking bleach reduced the treatment time in comparison to the walking bleach by 50% |
| Amato et al (2006)[230] | Mixture of sodium perborate and 120 vol hydrogen peroxide | 69.9% Success; 37.1% failures | 22.2% of the failures showed fistula, pain, and periradicular and/or lateroradicular bone lysis |

the fluoride is supporting the remineralization of enamel (160). Chemical irritations of the oral mucosa are due to the bleaching agent's active ingredients (Fig. 4c). This irritation is usually mild and transient (Fig. 4d). Curtis et al (163) reported no adverse effects on oral soft tissues from a 10% carbamide peroxide bleaching material. Bleaching agents affect enamel and dentin bond strengths because they cause a change of enamel and dentin, resulting in free radical–induced damage (110, 164).

Occurrence of external cervical resorption is a serious complication after internal bleaching procedures (145, 165). The first 4 reported cases were published by Harrington and Natkin (166) in 1979. Cervical resorption is an external resorption with an inflammatory origin caused by trauma or intracoronal bleaching (144).

Heithersay (167) analyzed cervical resorption cases and reported that 24.1% were caused by orthodontic treatment, 15.1% by dental trauma, 5.1% by surgery (eg, transplantation or periodontal surgery), and 3.9% by intracoronal bleaching. A combination of internal bleaching with one of the other causes is responsible for 13.6% of cervical resorption cases. The combination of bleaching and history of trauma is the most important predisposing factor for cervical resorption (168). Several studies reporting on long-term follow-up evaluations show an association between external resorption and bleaching of nonvital teeth, even many years after bleaching (68, 80, 84, 102, 169–171).

Animal studies have shown histologic evidence of resorption after 3 months of bleaching (172, 173). However, after 1 month no changes were detected. Cervical resorption is mostly asymptomatic and is usually detected only through routine radiographs (174). Sometimes swelling of the papilla or percussion sensitivity can be observed (169, 171). Teeth that were root-filled as a result of trauma more often show cervical resorption (2, 46, 68, 80, 84, 102, 104, 129, 131, 143, 144).

# Review Article

**TABLE 2.** *In Vivo* Studies on the Efficacy of Nonvital Bleaching

| Authors | Bleaching agent | Success | Complications and others |
|---|---|---|---|
| Ho and Goerig (1989)[64] | Group 1: new sodium perborate + fresh Superoxol | 93% Success | Color regression after 6 months was found in 4% of cases |
| | Group 2: new sodium perborate + 1-y-old Superoxol | 73% Success | |
| | Group 3: new sodium perborate + distilled water | 53% Success | |
| | Group 4: old sodium perborate + distilled water | 53% Success | |
| Casey et al (1989)[90] | Group 1: dentinal etching of the pulp chamber + walking bleach: 30% hydrogen peroxide/sodium perborate. | | |
| | Group 2: no etching, walking bleach: 30% hydrogen peroxide/sodium perborate | No statistically significant difference between the groups | None |
| Warren et al (1990)[65] | Superoxol; sodium perborate; Superoxol + sodium perborate | Superoxol + sodium perborate was found to be more effective in decolorizing the crown and the roots | Effectiveness of IRM cervical seal has been questioned |
| Horn et al (1992)[91] | 35% Hydrogen peroxide + sodium perborate; sterile water + sodium perborate | Teeth bleached with 35% hydrogen peroxide + sodium perborate were significantly lighter | Presence or absence of the smear layer did not influence the outcome of bleaching |
| Lenhard (1996)[231] | 10% Carbamide peroxide | Most significant total tooth color change was observed in the incisal section of the crown, followed by the middle and the cervical sections | The observed tooth color change was found to be dependent on the bleaching time, the specific bleached section, and the initial color |
| Leonard et al (1998)[88] | 5%–10%–16% Carbamide peroxide | Quicker color change for the 10% and 16% groups than the 5% group. Continuation of the 5% treatment to 3 weeks resulted in shades that approached the 2-week 10% and 16% values | Lower concentrations of carbamide peroxide take longer to whiten teeth but eventually achieve the same result as higher |
| Marin et al (1998)[232] | 30% Sodium perborate | Most efficient removal of staining occurred after application of 30% hydrogen peroxide, with sodium perborate being 75% as effective | All bleaching agents realized their optimum efficacy within the first 3 days |
| Jones et al (1999)[233] | 35% Hydrogen peroxide; 10% and 20% carbamide peroxide | Exposure to 20% carbamide peroxide produced the greatest perceivable change in color | None |
| Ari and Ungor (2002)[25] | Group 1: sodium perborate monohydrate + water | No statistically significant difference between the groups | None |
| | Group 2: sodium perborate trihydrate + water | | |
| | Group 3: sodium perborate tetrahydrate + water | | |
| | Group 4: sodium perborate monohydrate + hydrogen peroxide | | |
| | Group 5: sodium perborate trihydrate + hydrogen peroxide | | |
| | Group 6: sodium perborate tetrahydrate + hydrogen peroxide | | |
| Joiner et al (2004)[234] | 6% Hydrogen peroxide | Hydroge peroxide does not have any significant effect on enamel and dentin microhardness | None |

The mechanism responsible for resorption in bleached teeth has not yet been adequately explained. There is speculation that hydrogen peroxide can diffuse through the dentinal tubules, cement, and periodontal ligament and can reach bone (175, 176). Harrington and Natkin (166) postulated that hydrogen peroxide directly induces an inflammatory resorption process. On its own, hydrogen peroxide is not very reactive, and the body has mechanisms in place to deal with it (177). However, in the presence of inflammation, proinflammatory agents activate reduced nicotinamide adenine dinucleotide phosphate oxidase, which produces superoxides that can react with hydrogen peroxide. It is speculated that the resultant hypochlorous acid, N-chloroamines, and reactive hydroxyl ions might initiate some disease processes (178).

Lado et al (171) suggested that application of bleaching agents led to denaturation of dentin proteins by the oxidizing agents, which induces a foreign body reaction (64). It has been postulated that this denaturation can be caused by heat (66, 169, 179) or by pH variation caused by bleaching agents (126, 180, 181). Price et al (182) investigated the pH of some bleaching agents and found that the in-office bleaching products were acidic. The low pH value of highly concentrated hydrogen peroxide can be considered a tissue damage–inducing factor because an acidic environment is optimal for osteoclastic activity resulting in bone resorption (144, 183). Lee et al (184) found that it is possible to specifically relate the changes in pH of the extraradicular medium to the quantity of hydrogen peroxide detected in the extraradicular environment. Furthermore, in vitro studies demonstrated that pH in extraradicular medium surrounding the root increased with bleaching time (184–186).

Lee et al (184) reported that it is unlikely that cervical root resorption is the result of an acidic extraradicular pH environment produced by the bleaching agent. Bleaching agents cause superficial structural changes to dentin (187), and the acid pH probably produces an acid-etch effect on dentin, opening up the smear layer that covers the cut surface of dentinal tubules, thus increasing its permeability (188). This in turn permits greater diffusion of hydrogen peroxide through the dentinal tubules. Perhaps if the level of hydrogen peroxide goes beyond the critical level, then destructive cervical root resorption can take place. According to Halliwell et al (189), levels of hydrogen peroxide that are less than 20 $\mu$mol/L should be safe; however, when it exceeds 50 $\mu$mol/L, it is cytotoxic to most living cells.

Diffusion of hydrogen peroxide to cervical tissues is increased by different predisposing factors. Studies and case reports indicate that these factors are related to the occurrence of cervical resorption (71, 143, 144). Patients who had bleaching therapy at a young age often have external resorption (68, 80, 84, 102, 144, 169–171). A possible explanation is that hydrogen peroxide can more easily penetrate into the periodontium because of wide open dentinal tubules in young teeth. Increased permeability of dentin is associated with both decreasing dentin thickness and high surrounding temperature (190). Application of heat (thermocatalytic method) leads to widening of dentinal tubules and facilitates diffusion of molecules into the dentin (191). This explains the increasing dissemination of hydrogen peroxide into dentin with an increase in temperature (192). Moreover, application of heat resulted in generation of hydroxyl radicals from hydrogen peroxide that are extremely reactive and have been shown to degrade components of connective tissue (193).

As a consequence, today the thermocatalytic technique is used less because of the high risk of external root resorption that is associated with heat application (173–179). In contrast, the walking bleach technique with a sodium perborate–hydrogen peroxide solution did not cause cervical resorption, even 1 year after bleaching (179). This observation might be explained by the fact that sodium perborate inhibits the function of macrophages; macrophages stimulate both osteoclastic

bone resorption and destruction of dentin and cementum induced by lytic processes in periodontal tissue (194). The results of an in vitro study reported that even a sodium perborate solution, which is considered to be a relatively safe bleaching agent, proved to be toxic to the periodontal ligament cells (195). Furthermore, it has also been established that formulations with either 30% hydrogen peroxide alone or in combination with sodium perborate are more toxic to periodontal ligament cells as compared with a perborate-water suspension (195). Nevertheless, correlation of the present data to the clinical situation is not possible and cannot be used as a factor to argue in support of risking cervical resorption.

Carbamide peroxide has been more recently recommended for use in intracoronal bleaching (196). Thirty-five percent carbamide peroxide showed the lowest levels of extraradicular diffusion, whereas 35% hydrogen peroxide showed the highest, with sodium perborate having intermediate values (184). Considering the low levels of extraradicular diffusion and its effectiveness as an intracoronal bleaching agent (197), 35% carbamide peroxide might be regarded as the intracoronal bleaching agent of choice.

Clinically, a natural anatomic defect at the CEJ can be found in about 10% of all teeth, thus causing dentin to be exposed (198). When bleaching teeth with exposed dentinal tubules at the CEJ, as a result of anatomic defects or cervical erosion, the use of bleaching agents containing a high percentage of active oxidizing compounds should be avoided. In addition, the time of action should be reduced because laboratory studies have demonstrated that the penetration of hydrogen peroxide into the cervical region can be facilitated by cemental root defects or particular morphologic patterns at the CEJ (199–201). According to Rotstein et al (185), lack of root cementum resulted in diffusion of up to 82% of hydrogen peroxide (30% concentration), which had been applied in the pulp chamber. However, dissemination of hydrogen peroxide into dentin cannot be totally prevented by using mixtures of sodium perborate with 30% hydrogen peroxide or water. The amount of hydrogen peroxide diffusion is significantly lower when a mixture of sodium perborate–tetrahydrate and water is used, compared with application of 30% hydrogen peroxide mixed with different sodium perborates (202). Although in these cases there is less diffusion of peroxide into the surrounding tissues, a valid cervical seal is still necessary. The lack of a cervical seal represents another predisposing factor for an enhanced diffusion of hydrogen peroxide into the periodontal tissues. This corroborates the conclusion by MacIsaac and Hoen (165) in their extensive literature review of intracoronal bleaching that the common thread through all reported cases of external cervical root resorption was the lack of an intermediate base. This is an effective means of reducing the diffusion of hydrogen peroxide into the extraradicular environment (99).

It has also been reported that there is an increased diffusion of hydrogen peroxide to cervical tissues after pre-treatment of dentin in the pulp chamber with 5% NaOCl (203).

A follow-up radiograph of the bleached tooth within the first year after treatment is recommended to diagnose possible cervical resorption as early as possible.

Treatment prognosis depends mainly on the extent of the resorption process. The extent of resorption serves as a guide for the clinician in selecting the correct treatment (204).

Extraction is often inevitable in cases of severe external root resorption and when the lesion cannot be controlled (205, 206). In these cases an implant-supported restoration is an acceptable treatment. Careful space evaluation of the implant site must be performed with model-based planning (207).

Inflammatory osteolytic lesions have a low pH value that is optimal for hard tissue resorption (208). Root canal dressings consisting of

calcium hydroxide are able to induce a higher pH in dentin (209). If resorption occurs, Friedman et al (144) suggested that calcium hydroxide recalcification treatment should be attempted. Tronstad et al (209) postulated that reparative hard tissue formation would be stimulated by this treatment. Clinical cases have shown that an intracoronal dressing with calcium hydroxide can sometimes prevent progression of external resorption (180, 181). However, on a radiograph only osseous regeneration of the defect and no hard dental tissue regeneration could be detected. Recalcification treatment will fail if there is communication between the resorption and the oral cavity (183). In these cases, surgical repair should be considered.

Cervical resorption can also be treated with a direct restoration after gaining surgical access to the defect (210–212). This does not offer the advantage to induce biologic changes in the periodontal tissues, effectively allowing continued resorption after surgical repair. (181). It has been speculated that this might also happen when the area of resorption is not completely instrumented during surgical treatment (183). Another disadvantage is the significant compromise in periodontal health and esthetics that often results after surgical repair (181).

If recalcification or surgical repair is not feasible, or if the results of surgical repair are esthetically or periodontally unsatisfactory, the option of surgical crown lengthening combined with appropriate restorative treatment is still available (181). On the negative side, one has to accept an increase in crown-root ratio and removal of supporting tissues from adjacent teeth.

If a lesion can be easily accessed, a limited labial flap might be raised to permit cleaning of the lesion, thus exposing sound tooth structure. Then, it is recommended to place 90% trichloroacetic acid on the affected margins to necrotize granulation tissue. The area of resorption should be restored with an appropriate material, dictated mostly by esthetic demands (213).

In severe cases in which the lesion is not only subgingival but subcrestal as well, a labial flap must be raised to permit cleaning of the lesion, exposing sound tooth structure and sealing with a temporary filling material. After this initial treatment, it is recommended to use (rapid) orthodontic tooth extrusion combined with fiberotomy followed by definitive restorative treatment (214–216). This treatment will result in a shorter root, potentially leading to an increase in tooth mobility. Loss of marginal attachment as result of crown lengthening is more detrimental than loss of an equivalent amount of root length by apical resorption or orthodontic extrusion. According to Kalkwarf et al (217), 3 mm of apical root resorption is equivalent to approximately 1 mm crestal bone loss.

A case has been reported in which a novel combined endodontic/periodontal treatment was performed (218). Reconstruction of the defect was achieved by using resin composite to restore the coronal portion of the defect up to the CEJ followed by mineral trioxide aggregate cement below to the bone.

The interdisciplinary treatments described above offer a systematic approach to invasive cervical resorption, which continues to be a clinical challenge because it is difficult to detect during its early stages.

It has been reported that bleaching can increase resin solubility, decrease enamel bond strength, and consequently increase marginal leakage (219–221). Ten percent carbamide peroxide has been reported to adversely effect the physical properties of zinc phosphate and glass-ionomer luting agents (222). Finally, bleaching techniques do not bleach synthetic materials; thus, existing restorations might need replacement to improve color matching after successful bleaching (223–227). One study has documented an increase in mercury release from amalgam restorations that were exposed to carbamide peroxide (31).

It can be concluded from this review that bleaching is an important and valuable adjunct in endodontic treatment. Proper diagnosis, selection of bleaching materials, placement techniques, and an understanding of the biologic interaction with soft and hard tissues are all factors that determine not only immediate success but also long-term success, safety, and patient satisfaction as well.

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