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Tooth whitening procedures: A narrative review

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ABSTRACT

Objectives: To provide a comprehensive review of the available literature on the subject of tooth whitening and to provide a snapshot of where we as a dental profession are regarding this topic today. To provide a detailed account of the different tooth whitening procedures, their specific indications, success rates and potential side effects.
Data: Data was obtained using the following keywords: tooth whitening, tooth bleaching, color, adverse effects, pediatric dentistry, enamel hardness, restorative materials, whitening pH, whitening concentration, success rates.
Sources: A comprehensive literature search was conducted on PubMed and Scopus databases. A separate search was made on a Google Search Engine. The references from the reviewed material were used to locate other relevant publications.
Study Selection: A total of 158 articles were included in this review after reviewing the literature that resulted from the initial search.
Conclusion: Tooth whitening procedures have proven to be a conservative and viable option for improving dental esthetics.
Clinical Significance: With the increasing need for esthetic treatment among dental patients, it is important for dentists to have a good understanding of tooth whitening procedures, their specific indications, potential adverse effects, and limitations. These procedures are a minimally invasive way to improve dental esthetics significantly.

1. Introduction

A great majority of the population is becoming increasingly aware and interested in dental esthetics today. Tooth whitening procedures provide a conservative means to improve dental esthetics. These whitening procedures can be useful on their own or as an adjunct to other restorative procedures. Tooth whitening is a blanket term for the process resulting in a material becoming similar in color to a preferred or standard white regardless of the means used. Tooth bleaching has been defined as chemically induced whitening due primarily to the effects of carbamide peroxide which releases about one third of its content as hydrogen peroxide [1]. As the general population becomes more aware of dental esthetics this may be accompanied by an increase in the demand for esthetic procedures as well as increased expectations for treatment outcomes. It is therefore pertinent for dental providers to understand the science behind tooth whitening procedures, their specific indications, success rates, rates of rebound, potential side effects and limitations.

The aim of this paper is to provide a summary of the available literature on tooth whitening procedures, their specific indications, limitations as well as side effects

2. Classification of dental staining

Dental discoloration is generally classified as extrinsic or intrinsic. Extrinsic staining is of external origin and is often superficial in nature (Table 1).

Iatrogenic discoloration can occur due to dental treatment such as pulp extirpation which induces hemorrhage into dentin, remaining pulpal tissue during root canal procedures, root canal irrigants or root canal restorative materials.Combining irrigants containing sodium hypochlorite and chlorhexidine may lead to a reddish-brown precipitate. Some endodontic materials that contain tetracycline for example Ledermix, Endofill, Zinc Oxide Eugenol, Tubuliseal, Gutta Percha, Grey Mineral Trioxide Aggregate can lead to intrinsic discoloration [1–11].

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Table 1
A table summarizing the extrinsic and intrinsic causes of dental staining.

Extrinsic staining	Intrinsic staining
• Consumption of certain foods, beverages such as coffee and red wine, or tobacco products	• Hemorrhage of the pulp which leads to blood entering the dentinal tubules. The blood then decomposes leading to deposition of chromogenic blood degradation products such as hemosiderin and hemine.
• Inadequate oral hygiene can also result in extrinsic staining.	• Systemic use of tetracycline antibiotics
	• Necrosis of the pulp
	Calcification of the pulp through obliteration of dentinal tubules and buildup of tertiary dentin. Triggers for calcification are abrasion, erosion, or iatrogenic irritations.

3. Tooth whitening procedures

3.1. Dental prophylaxis

Professional hygiene procedures and polishing are performed to eliminate extrinsic staining by use of an abrasive paste and a rubber cup on a slow speed rotary instrument. Extrinsic stains can influence tooth color assessment and it has been shown that performing dental prophylaxis has a positive effect on patients' perception of the whiteness of their teeth [12].

3.2. Microabrasion

Microabrasion is a safe, conservative and atraumatic esthetic procedure for managing superficial enamel stains or defects [13]. Indications for microabrasion include intrinsic discolouration or texture alteration that is limited to the outer layer of enamel due to enamel hypoplasia, amelogenesis imperfecta or fluorosis [14]. Microabrasion was first introduced by Croll et al in 1986 [15]. The technique removes the surface enamel layer by the combined erosive and abrasive effect of a gel containing both an acid as well as abrasive particles. This is applied mechanically using a low-speed micro-motor [16]. The recommended acid concentration has varied over time with earlier formulations containing as high as 36% Hydrochloric acid [17]. Croll recommended the use of 18% Hydrochloric acid with abrasives in a water-soluble mixture on a low rotational handpiece [16].

Some of the commercially available products include Prema Compound (Premier Dental company, Philadelphia, PA, USA), which consists of 10% hydrochloric acid and silicon carbide abrasive particles, Opalustre (Ultradent Products Inc., South Jordan, UT,USA) which contains 6.6% hydrochloric acid and silicon carbide abrasive particles.

Because lesions that are successfully managed using the microabrasion technique must be limited to enamel, a transillumination unit can be used to examine the enamel stain by placing the light source on the lingual or palatal aspect of the tooth. A darker color would indicate deeper staining [18]. Clinical examination of the lesion under dry and wet conditions can also aid in determining ideal candidates for the procedure. A lesion that remains visible on a wet tooth is more likely deeper than one that disappears. This is because the difference in the refractive index between air and enamel is greater than that between water and enamel [14].

Enamel microabrasion can result in the loss of 25um-200um of enamel which is clinically acceptable [14]. Fluoride therapy is recommended after microabrasion procedures to promote remineralization [13,18]. Enamel microabrasion can be supplemented with bleaching as micro abraded teeth can obtain a yellowish appearance because of a thinner enamel layer, exposing more dentin. Bleaching can also aid in reducing the contrast between any remnant white spots and the tooth [19,20,21].

3.3. OTC products

There are several available over the counter (OTC) tooth whitening agents that patients can purchase and apply independently. The percentage of bleaching agent contained within a product dictates whether the product can be made available over the counter. The allowed concentration varies among different jurisdictions and is governed by the respective regulatory bodies. The formulations for OTC tooth whitening agents are as follows, dentifrices, mouth rinses, intraoral strips, varnishes, gels and toothbrushes among others.

Historically, it has been demonstrated that the most effective component of whitening dentifrices has been abrasives. These act by eliminating and preventing the formation of extrinsic stains [22,23].

Because of the potential effect that abrasives may have on the dentition, there are regulations on the maximum allowable abrasive content thus limiting the amount of whitening that can be achieved using these prdoucts [24]. Whitening tooth pastes can also contain low concentrations of either carbamide peroxide or hydrogen peroxide whose effect is limited by not only the low concentration but also the limited contact time with the teeth during brushing [25]. Combining bleaching with concurrent use of whitening toothpastes as well as continuing use post-bleaching seems to facilitate the whitening process [26]. A pigment, blue covarine, has also been incorporated into whitening dentifrices. This theoretically creates an optical illusion of whitening by applying blue pigment onto enamel. Covarine containing toothpastes have been found to be just as efficient as conventional whitening toothpastes and non-whitening toothpastes [27].

Whitening mouthwashes contain a low concentration of hydrogen peroxide (1.5%) and have generally been shown to be ineffective in improving tooth color, even after up to 30 days of exposure [28].

Whitening strips typically contain 5-14 % hydrogen peroxide. This is applied to teeth via the use of an adhesive agent which releases the active bleaching agents slowly over a 6–10-minute period [29].

A systematic review on OTC whitening products included a total of 24 articles and concluded that among the available OTC agents, dentifrices were effective in effecting a change in color but were not as effective as whitening strips. In fact, whitening strips were found to be the most effective OTC whitening agents [30].

3.4. Bleaching procedures

3.4.1. The Chemistry of chemical bleaching

The common chemicals used for dental bleaching are hydrogen peroxide and carbamide peroxide in varying concentrations. Carbamide peroxide is a stable chemical that reacts with water to release its active components (hydrogen peroxide and urea) while hydrogen peroxide is an unstable chemical that decomposes into water and reactive oxygen free radicals [31]. Bleaching agents may contain hydrogen peroxide as an active agent, glycerine as a carrier, carbopol as a thickening agent and a number of flavoring agents [32,33]. Chromophores/color producing agents are organic compounds with extended conjugated chains of alternating single or double bonds or as metal containing organic compounds, with the latter being more difficult to whiten. Bleaching works by destroying one or more of the double bonds within the conjugated chain often through an oxidative process [34]. Peroxide has been shown to have the ability to diffuse through the enamel into the enamel-dentin junction and the dentin. Some evidence has demonstrated that low levels of peroxide do reach the pulp chamber after 15-30 minutes of exposure. The clinical implications of this, however, seem to be insignificant [35–40].

3.3.1.1. In-office bleaching. In office bleaching is performed under the direct supervision of a dentist. This typically involves application of a high concentrations of hydrogen peroxide (35-40%) for 15–20-minute periods over a 45-60-minute clinical session. This procedure can be repeated for multiple sessions until the desired whitening effect is achieved. Care must be taken to avoid contact of the bleaching agent with the soft tissues as this may be caustic [41]. In-office bleaching often results in a faster bleaching effect due to the high concentration of bleach that is applied. One week of at home bleaching with 10-16% carbamide peroxide gel usually results in a change of 2-4 shade guide units [42–46] while a similar change is noted after a single in office bleaching session with 35% hydrogen peroxide [42,45,47,48].

Though home bleaching may take a longer time to attain the desired whiteness, both in-office and home bleaching are equally effective whitening agents [49].

Some in-office bleaching systems are marketed to be used with an activating light source that allegedly enhances the whitening effect. The light source theoretically produces heat that in turn accelerates the catalytic decomposition of the bleaching agent to form free oxygen radicals. The different sources of light include Light Emitting Diodes (LEDs), lasers, Plasma Arc lamps and halogen lamps. A systematic review and metanalysis was conducted to establish whether there were differences in the bleaching efficacy and tooth sensitivity of bleaching protocols performed with or without light using low and high hydrogen peroxide concentrations. It was found that light did not significantly increase color change in delta E or Shade Guide Units. There was also no difference in tooth sensitivity between the two test groups though they did report high heterogeneity in the data [50].

3.4.4.2. At-home tray bleaching. Night guard vital bleaching is indirectly supervised by the dentist but is administered at home by the patient. It is a widely used technique. This procedure entails application of low concentration of bleaching agents (10-20% carbamide peroxide which is the equivalent of 3.5-6.5% hydrogen peroxide) loaded into a customized bleaching tray. These trays are often worn overnight or 3-4 hours daily for a 2–6-week period [51]. It is important to ensure adequate exposure time for carbamide peroxide as only 50% of it breaks down to its active components in 2 hours [52,53] (Figure 1). The advantages of the at-home technique include reduced chair-side time, fewer adverse effects, and low associated cost. Cons for this technique are mainly linked to the high dependence on patient compliance [54].

Though incorporating reservoirs into bleaching trays was initially recommended, it has been shown that presence of reservoirs had no effect on color change, tooth sensitivity or gingival irritation in dentist supervised at-home bleaching using 10% carbamide peroxide [55]. At-home tray bleaching can also be performed accompanying orthodontic treatment by utilizing either Invisalign aligners or Vivera retainers as custom bleaching trays [56].

Fig. 1. An image showing discolored maxillary dentition after full arch at home tray bleaching with 10% carbamide peroxide for 6 months with the untreated mandibular dentition as a reference.

3.4.4.3. Non-vital bleaching. This procedure is indicated for intrinsically discolored teeth that have undergone endodontic treatment. Bleaching of non-vital teeth was first mentioned by Garretson in 1895 using chlorine [57]. In 1951, hydrogen peroxide was used for non-vital tooth bleaching [58]. Currently both carbamide peroxide and sodium perborate (mixed with distilled water or hydrogen peroxide) can be used for non-vital bleaching. Though hydrogen peroxide is an effective bleaching agent, high concentrations of greater than 30% should be used with caution [59]. Sodium perborate is available in monohydrate, trihydrate or tetrahydrate forms and its bleaching effect is not diminished when mixed with distilled water instead of hydrogen peroxide [60,61].

Teeth indicated for non-vital bleaching should be asymptomatic with a good quality root filling. Rubber dam isolation is required before preparation of the access cavity. Access cavity design should be aimed at ensuring remnants of restorative materials root filling materials and necrotic pulp tissue are eliminated. Verifying that all remaining pulp tissue is removed from the coronal pulp chamber is important as remnant pulpal tissue in the pulp horns in the more incisal area of the tooth will cause tooth darkening. This is followed by reducing the root filling by 1-2mm apical to the CEJ which can be done using a Gates Glidden bur. Ensuring the cavity surfaces are free of any debris provides conditions for optimum penetration by the bleaching agent [62].

It is of paramount importance that an exceptional coronal seal is ensured after shortening the root filling 1-2 mm apical to the cemento-enamel junction. This is indicated to prevent radicular penetration of bleaching agents [63]. A 2mm layer of glass ionomer cement has been shown to be effective in preventing penetration of 30% hydrogen peroxide into the root canal and can therefore be left in place after the bleaching process and used as a base for the final restoration. The coronal extension of the seal should be at the level of the CEJ to prevent leakage of the bleaching agent into the periodontium [64]. The coronal seal should also follow the natural anatomical contours of the CEJ [65]. Once an adequate coronal seal has been established, the bleaching agent can be delivered in one of the following ways: the walking bleach technique, the inside-out bleaching technique or in-office bleaching. Single tooth tray bleaching can also be performed to avoid opening of the root canal access.

The walking bleach technique was first described by Spasser in 1961 where sodium perborate was mixed with water into a paste and then inserted into the access cavity [66]. Nutting and Poe modified this by

mixing sodium perborate with hydrogen peroxide [67] with no noted superiority of one technique over the other [60,61]. Mixing sodium perborate with carbamide peroxide showed improvement in vitro regardless of the concentration of carbamide peroxide used [68]. Once the bleaching agent is inserted into the tooth, the access cavity is then sealed on the outside using a provisional filling material such as Cavit, resin modified glass ionomer or resin composite. After a few (2-3) days the bleaching result is assessed and if needed, the bleaching gel can be refreshed. Once the desired bleaching result has been reached or slightly exceeded, calcium hydroxide may be applied to diminish oxygen inhibition of the resin composite polymerization when restoring the access cavity definitively [69].

The inside out bleaching technique was first described by Settembrini et al in 1997 [70] and later modified by Liebenberg in 1997 [71]. This technique entails applying bleaching agent on both the internal and external tooth surfaces by keeping the access cavity open during the entire treatment process. A vacuum formed splint is fabricated with reservoirs on the facial and lingual aspects of the teeth to be bleached. Using a syringe, the patient is instructed to fill the access cavity as well as the corresponding areas on the suck-down splint with 10% carbamide peroxide. The splint should be worn overnight, and the patient should clean the access cavity regularly. The color change should be monitored every 2-3 days until the desired color is achieved. The access cavity should then be cleaned and restored provisionally with resin modified glass ionomer material. A definitive resin composite restoration can be placed after 7-10 days. One of the benefits of this technique is that it allows for low concentrations of bleaching agent to be used [72]. This technique can be beneficial where other vital teeth are being bleached simultaneously [73]. The inside out bleaching technique has demonstrated greater success initially in comparison to the walking bleach. However, after 6 months the treatment results are comparable following rehydration of the tooth [74]. The shortcomings of this technique include the potential for bacterial contamination of the root canal as the access cavity remains open as well as its heavy reliance on patient compliance.

The in-office bleaching technique is performed using 30% hydrogen peroxide that is applied onto the tooth as well as into the access cavity of the tooth. After a 15–20-minute application time, the bleaching gel is rinsed off and reapplied if necessary. Subsequent closure of the access cavity should be performed at a later appointment as there will inevitably be remnants of hydrogen peroxide in the access cavity. This process with Hydrogen peroxide in these high concentrations (35-40%) has been linked to root resorption and is no longer recommended [72].

Single tooth tray bleaching entails using low concentration carbamide peroxide via a custom bleaching tray with the bleaching gel being applied solely on the tooth to be bleached.

4. Bleaching of tetracycline-stained teeth

Historically, tetracyclines were used extensively as a broad-spectrum antibiotic until 1958 when their dental adverse effects were reported [75]. Tetracyclines that are administered during tooth development can disturb enamel formation and lead to discoloration of the dentin. A history of tetracycline intake either during pregnancy and/or ages 1-3 years can lead to deposition of the tetracycline fluorophore within the collagen and mineral components of dentin. The severity of the staining is dependent on the tetracycline type, dosage, and duration of exposure. Tetracycline staining patterns are either unihued or multihued. With unihued discoloration, the teeth are uniformly stained with one solid color, while with multihued discoloration, the teeth have bands of discoloration with the darkest brown usually at the cervical zone. This may be because of the thinner enamel cervically. Multihued discoloration is more difficult to correct in comparison to unihued patterns [76]. Prior to the discovery of at-home tray beaching in dentistry, the recommended treatment for tetracycline-stained teeth was elective endodontic treatment and bleaching using sodium perborate powder and 30% hydrogen peroxide by walking bleaching [77,78].

Long term tray bleaching with 10% carbamide peroxide is recommended for tetracycline-stained teeth.

It has been shown that more than 55% of the maximum lightening that occurred over 6 months happened during the first month of bleaching with some relapse occurring in the 3rd month post-bleaching. Cervical areas of the teeth may require longer than 6 months to bleach satisfactorily [79] Haywood et al found that the tooth whitening effects were long lasting for up to 90 months when 10% carbamide peroxide was used for tray bleaching over a 6-month period [80,81]. A randomized clinical trial suggested that a 3-month regime of either 6% hydrogen peroxide strips or 15% carbamide peroxide tray system were effective in whitening of tetracycline-stained dentition [82].

5. Factors affecting the rate of tooth whitening

The factors that may affect the rate of tooth whitening are the concentration of the bleaching agent, the exposure time, and the type of intrinsic stain. The efficacy of tooth whitening using either hydrogen peroxide or carbamide peroxide increases with an increase in the concentration of bleaching agent as well as exposure time [83–86]. With regards to the type of staining, severe tetracycline staining responds slower to chemical bleaching [87]. The darker the teeth are at baseline, the longer the tooth whitening process becomes [88]. Gray or blue staining is less amenable to bleaching than yellow staining [89,90].

6. Clinical measurement of tooth whitening

This can be done by either of the following methods:

Comparison with a value-oriented shade guide. This is a subjective method that can be affected by lighting conditions, experience, age, fatigue of the human eye, make up, room decor and color blindness [91–93].

Colorimeters are more objective tools for color assessment. Color is expressed in terms of CIEL*a*b* color space. L is scored from 0-100 and a perfect black will have an L of 0. Use of a custom positioning jig is helpful to allow for repeatable measurements that are standardized [94].

Non- contact camera based digital imaging and analysis systems can also be used. Images are usually taken under controlled lighting conditions by a digital camera with suitable calibration tiles and then computer software is used to generate L* a* b* values [95].

7. Effect of diet on bleaching

Ingestion of tea, coffee and red wine can lead to tooth discolouration [96–98]. It has been common practice for dentists to advise patients to refrain from smoking and/or drinking tea, coffee or red wine while undergoing tooth whitening procedures. The term ‘white diet’ has been used to describe this recommended diet [99]. The stability of tooth whitening can be negatively impacted by drinking coffee post treatment [100] and therefore tea and coffee drinkers may benefit from a specialized post-treatment maintenance regimen [101]. However, failing to adhere to a white diet does not seem to affect the effectiveness of tooth bleaching. Strictly adhering to a white diet during tooth bleaching is therefore not mandatory but caution should be taken after the bleaching treatment as this may affect the rate of rebound [99].

8. Effect of bleaching on bonding

Bleaching has a deleterious effect on the bond strength of resin materials [102–104]. This has been attributed to reactive oxygen species that are released by the bleaching agent which then accumulate on the tooth surface. This oxygen then reacts with the forming polymer chains in dental adhesives thus terminating the elongation of the polymer chain

and reducing the degree of conversion of the adhesive and resin composite [105]. It is therefore recommended that adhesive dental procedures are delayed for 1-3 weeks after bleaching [106]. Application of various antioxidant products such as sodium ascorbate and proanthocyanidin onto bleached tooth structure has been recommended. Use of sodium ascorbate for 10 minutes has been shown to be effective for reversing the reduced bond strength [107–112].

9. Effect of bleaching on restorative materials

Restorative materials, just like the teeth, can take up stains from diet. Composite resin discoloration can occur at 3 levels: surface, sub-surface and intrinsic. Accumulated food, beverages and plaque contribute to surface staining. Sub-surface staining occurs when surface stains diffuse into superficial resin layers with pigments attaching to and reacting chemically with the composite. Intrinsic staining is because of physicochemical reactions occurring deep within the composite. An in vitro study demonstrated that 15% carbamide peroxide bleach was effective in returning composite stained with both wine and coffee to its baseline color.They hypothesized that peroxide based whitening systems may be more effective due to their ability to penetrate the resin composite and decompose the double bonds of the chromogens [113].

Patients should therefore be advised that there may potentially be a mismatch between their resin composite restorations and their natural dentition after bleaching. Some laboratory studies have found that bleaching resin composites using both carbamide peroxide and hydrogen peroxide can increase surface roughness as well as the streptococcal biofilm formation. The clinical implications of that are not clear. The data on the effect that bleaching has on the microhardness of resin composite is contradictory with some studies revealing softening of the resin composite [114,115] and others finding no significant hardness changes [116,117]. Other studies demonstrated and increase in the surface hardness [118,119].

With dental ceramics, a study by Turker and Biskin observed that 10-16% carbamide peroxide gels applied for 8 hours a day for 30 days was able to significantly decrease the surface hardness of the feldspathic porcelain material they tested. They found that surface roughness was not affected by the bleaching procedure [120]. A more recent in vitro study demonstrated that after exposure of 1mm thick lithium disilicate blocks to 16% carbamide peroxide bleach for 6 hours per day for 7 days, there was a significant change in the translucency parameter [121]. Another in vitro study assessed a variety of CAD/CAM ceramic materials and the effect of various bleaching regimens on their stainability. They concluded that home and over the counter bleaching agents may increase the stainability of some ceramics (a resin nanoceramic) with lithium disilicate being the least affected among the materials they tested [122]. Bleaching externally stained monolithic zirconia with either 40% hydrogen peroxide or 20% carbamide peroxide has been shown to result in a clinically acceptable color change and insignificant alterations to the surface roughness or hardness [123].

Provisional crown materials also undergo color alterations when exposed to bleaching agents. After 14 days of bleaching with 10% carbamide peroxide, methacrylate materials showed a shift to orange or dingy whereas polycarbonate and bisacryl composite resin did not discolour [124,125].

In vitro studies on amalgam have associated carbamide peroxide bleaching with release of mercury vapor with the amount of mercury vapor released being directly proportional to the concentration of carbamide peroxide used [126–128]. The clinical relevance of this is not known, however.

10. Success rates

A common question asked by patients prior to undergoing dentist supervised whitening procedures is about the longevity of the results. This question should be answered with caution as the rate of color relapse post bleaching is unpredictable and is dependent on the frequency of consuming dietary pigments, smoking habits and the oral hygiene level [129]. A clinical study evaluating the 12 month stability of bleaching results after bleaching with either 6% hydrogen peroxide strips, 15% carbamide peroxide gel or 38% hydrogen peroxide gel showed that the delta E values decreased significantly from baseline versus 6 months post treatment [129]. Another study reported a reduction in delta E values by 45% at 6 months post treatment. Haywood reported regression of whitening in 26% of cases at 18 months [130]. The longevity of both in office and tray bleaching is good with reported stability for up to 2 years. This however does not occur in all patients [49].

At 4.5 years post long-term bleaching with carbamide peroxide, tetracycline-stained teeth retained more than 65% of the initial whitening result. Rebleaching is therefore recommended at this time point [79].

The success rate for non-vital beaching has been quoted as 80% after 1 year, 45% after 6 years [131]. Teeth that have been discolored for long have a reduced prognosis in comparison to those that have been stained for a short period of time [132,133]. Certain metallic ions such as mercury, silver, copper, and iodine are more difficult to remove. Necrosis induced discoloration can be successfully bleached in 95% of the cases [133].

11. Tooth whitening in children and adolescents

Research on tooth whitening in children is scarce to non-existent. The American Academy of Pediatric Dentistry acknowledges that tooth whitening procedures have been shown to be safe and may be beneficial in this age group. This treatment can have a big impact on children's self-esteem if they have traumatized a anterior tooth that is discolored. Tooth whitening in children can serve as a powerful tool to regain self-confidence when the child's personality has been affected because of their darkened tooth or teeth.Dentists are encouraged be particularly cautious when bleaching the teeth of children and adolescents as they may be more prone to adverse effects. It is recommended that at home bleaching is supervised by an adult under the guidance of a dentist. They also discourage full arch cosmetic bleaching for patients in mixed or primary dentition. Lower concentrations of bleach with shorter exposure times are recommended [134].

12. pH of various bleaching agents and the clinical relevance

An in vitro study measured the pH of 26 commercially available tooth whitening products in Canada. The results showed that the pH of the various products ranged from 3.67 -11.13, [135] thus raising concerns over the potential detrimental effects of exposing teeth to acidic or alkaline chemicals. Neutral hydrogen peroxide has been formulated by incorporating sodium hydroxide or hydroxyapatite. These neutral formulations have been demonstrated to be less destructive to enamel because of the alkaline salt which adheres onto the enamel surface therefore limiting the direct contact between hydrogen peroxide and enamel. Alkaline and neutral bleaching agents have been shown to not only be less detrimental to enamel but are also more effective whitening agents [136].

13. Potential adverse effects

In general, the severity of the adverse effects of tooth whitening are dependent on the whitening technique followed, the concentration of whitening agent used and the duration of treatment.

Tooth sensitivity is a common adverse effect. It is often transient lasting 2-3 days and moderate to mild in severity. It is believed to be a result of byproducts of bleaching agents diffusing through the dentinal tubules and inducing a transient pulpal reaction [137–139]. Desensitizing agents such as potassium nitrate have been incorporated into bleaching agents to combat bleaching induced tooth sensitivity. This how-

ever has not yielded significant results [140]. Application of a calcium phosphate-based desensitizer prior to in office bleaching was shown to reduce slightly the incidence of tooth sensitivity [141].

Gingival irritation is another potential adverse effect of bleaching. The incidence of gingival irritation during at home bleaching ranged from 5-50%. The most common risk factor when using tray bleach is the use of an ill-fitting tray. When performing in office bleaching, failed gingival barrier protection is the leading cause of gingival irritation. Gingival irritation can also occur when patients use excessive amounts of bleaching material that over-flow out of the tray. When it occurs, the irritation is often tolerable, self-limiting and is not a barrier to completing treatment [142].

Laboratory studies have demonstrated that tooth bleaching affects enamel morphology by increasing porosities in enamel and subsequently the surface roughness. Bleaching has also been shown to alter the mineral content in enamel with laser activated tooth bleaching being particularly damaging. These alterations can be reversed by the application of remineralizing toothpastes that contain calcium phosphate [143,144].

The potential detrimental effects of bleaching on restorative materials were discussed earlier in this article. External cervical resorption (ECR) is a potential adverse effect of non-vital bleaching. 10% of teeth have natural anatomic defects in the cementum at the CEJ (Rotstein) which could allow hydrogen peroxide to reach the external tooth surface via dentinal tubules during intracoronal bleaching. Once the hydrogen peroxide comes into contact with the periodontal tissues, dentin is denatured, and the host immune response is initiated [145,146]. Younger patients may be more susceptible due to larger tubules [147]. The number of reported cases with external cervical resorption has decreased over the years and this can be attributed to the use of lower concentrations of bleaching agent, placement of proper cervical seals as well as a reduction in the use of the thermocatalytic technique [148–150]. The risk of ECR related to internal bleaching is increased by either a history of trauma, orthodontic treatment, high concentration of hydrogen peroxide or the thermocatalytic method [151].

14. Developments in whitening agents

Newer developments in tooth whitening include incorporation of sweet potato enzymes into hydrogen peroxide as they contain a number of antioxidant molecules which theoretically are free radical scavengers that target chromogens. In vitro studies on these enzymes are promising [152]. Other advancements involve the incorporation of chemical, bioactive and natural organic additives into hydrogen peroxide with the aim of elevating the pH and therefore delaying the decomposition of hydrogen peroxide. In vitro studies of these agents are also promising and open the field to more extensive clinical trials [153–158].

15. Conclusion

Tooth whitening procedures provide a conservative means to improve esthetics. These whitening procedures are not only effective on their own but also as an adjunct to other restorative procedures. Tooth bleaching is a safe and effective method to whiten teeth, and its efficiency is determined by the concentration of bleaching agent and the exposure time. Some of the potential adverse effects of bleaching are tooth sensitivity, gingival irritation, changes in the enamel microstructure and external cervical resorption.

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Declaration of Competing Interest

The authors have no relevant financial or non-financial competing interests to report

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