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CURRENT APPROACHES TO TEETH WHITENING: A COMPREHENSIVE REVIEW

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Abstract

In contemporary dentistry, the pursuit of an esthetically harmonious smile has garnered increasing emphasis, elevating the role of teeth whitening to a cornerstone of minimally invasive esthetic interventions. While traditional oral care products have long focused on preventing dental caries and periodontal diseases, there has been a marked shift toward formulations specifically designed to enhance dental brightness. This evolving demand has catalyzed the development and widespread use of whitening techniques, both within clinical practice and through patient-directed, at-home applications. The present review seeks to explore the most frequently used whitening agents and products by examining their chemical composition, mechanisms of action, and clinical efficacy. An extensive literature analysis was undertaken to assess current whitening protocols through both scientific and practical lenses. The insights derived from this evaluation are intended to serve as an evidence-based guide for dental students and practitioners alike, supporting informed decision-making and the effective implementation of dental whitening strategies in daily practice.

Keywords: Devital bleaching, Dentistry, Endodontics

1. Introduction

The growing demand for a whiter and more refined smile has catalysed the continuous evolution of teeth whitening technologies. Numerous techniques have been developed, each tailored to address specific aetiologies of dental discoloration. Common contributing factors include intrinsic aging processes, dietary habits such as the consumption of coffee, tea, and tobacco, systemic conditions like fluorosis or tetracycline-induced staining, trauma-induced pulpal changes, and aesthetic considerations related to pre- or post-restorative procedures. In such scenarios, the judicious application of appropriate whitening therapies plays an essential role in restoring and enhancing the visual harmony of the dentition. The selection of the whitening technique, the bleaching agent of choice, and the duration of the treatment must be carefully adapted to the patient's unique clinical presentation, the clinician's professional experience, and established evidence-based protocols. A methodical approach not only enhances the efficacy of treatment but also minimizes potential adverse effects—thus underscoring the significance of personalized care in aesthetic dentistry. Modern dental practice no longer focuses solely on restoring lost function; rather, it increasingly prioritizes the enhancement of facial aesthetics and smile dynamics as essential components of patient-centred care (Ucuk, 2024). It is equally important to assess the clinical effectiveness and safety profile of whitening modalities used in practice. As Pontillo (2017) has emphasized, the individualization of bleaching protocols is central to achieving predictable outcomes. Furthermore, complications involving gingival irritation, dental hypersensitivity, and even pulpal damage have been reported in the literature, warranting caution and patient-specific risk assessment (Vrbic, 2015).

2. Types and Caueses of Discoloration

2.1 Intrinsic discoloration

Intrinsic discolorations arise when chromogenic molecules become incorporated into the dental hard tissues either during their development or following tooth eruption. Such pigmentation typically reflects structural alterations within the enamel or dentin and is considered intrinsic in nature. For instance, the administration of tetracycline antibiotics during tooth development in children can result in permanent discoloration, with shades ranging from yellow to brown or gray, depending on the specific drug, dosage, and the child's body weight (Sánchez, Rogers, Sheridan, 2004). Discolorations of intrinsic origin may also result from pulp obliteration and the deposition of tertiary dentin. Prolonged or repeated exposure of the pulp tissue to irritants can compromise pulpal vascularization, leading to acute or chronic inflammation. Chronic inflammation, in turn, may culminate in pulpal necrosis, further contributing to internal discoloration (Polat, Temizyurek, 2021). In erupted teeth, acute trauma can lead to intrapulpal haemorrhage, which imparts a reddish hue to the crown as blood by products diffuse into the dentinal tubules (Basar, Cikman 2024). High levels of systemic fluoride exposure, developmental disturbances such as amelogenesis imperfecta, dentinogenesis imperfecta, and dentin dysplasia—often of genetic origin—are also implicated in intrinsic discoloration patterns (Kavan, Guven). Another example, the use of inappropriate irrigants during root canal procedures may lead to internal staining, potentially even resulting in medicolegal implications when malpractice is considered (Ucuk, Dincer, 2024). Dental fluorosis, in particular, is a developmental defect that manifests as enamel opacity or porosity when fluoride is ingested in excess of optimal doses—systemically during tooth formation or topically after eruption. The resulting enamel exhibits varying degrees of hypomineralization and surface irregularity, affecting both aesthetics and structural integrity (Akyildiz, Ucar, 2024). Although intrinsic discolorations stem from within the tooth and often demand more complex interventions, it is important to recognize that not all staining originates internally. In many cases, surface-level (extrinsic) discolorations arise from daily habits and exposures, and fortunately, these can often be managed with more accessible, routine dental care.

2.2 Extrinsic discoloration

Extrinsic discolorations originate from the accumulation of stains on the enamel surface and are typically associated with chromogenic bacteria (Kwon, Goldstein, 2018). These surface-level discolorations may be classified into metallic and non-metallic types, and can manifest in a wide spectrum of hues—ranging from orange and green to brown or even black (Kwon, Goldstein, 2018). Common causes of extrinsic staining include the frequent consumption of pigmented foods and beverages, use of tobacco products, certain mouth rinses, and the presence of soft or hard deposits on the tooth surface. These exogenous factors lead to color changes that remain confined to the enamel and are generally categorized as extrinsic in origin (Basar, Cikman 2024). In cases of metallic discoloration, compounds such as iron, copper, potassium permanganate, and silver nitrate are implicated, particularly in environments where these elements are introduced through occupational exposure or therapeutic use

(Gurdere, Atabek, 2024). Fortunately, most extrinsic stains can be effectively managed through routine prophylactic procedures. Professional cleaning, coupled with tailored oral hygiene instructions, has been shown to significantly reduce surface staining and help patients maintain optimal aesthetic outcomes over time (Freedman 2011, Ritter, Boushell, Walter 2018).

3. Tooth Whitening-Bleaching

Tooth whitening refers to the application of chemical agents to stained teeth with the objective of oxidizing organic pigments within the enamel and dentin, thereby lightening the intrinsic color of the tooth structure (Oktay, 2006). The primary goal of whitening procedures is to achieve a perceptible enhancement in tooth color without inducing morphological or chemical damage to the dental hard tissues. The composition of resin materials also plays a pivotal role. In a recent investigation incorporating various boron-based additives, it was observed that different boron formulations yielded varying degrees of staining (Ucuk, Ucuncu 2024). In that case, materials also have role in coloring.

The chromogenic compounds responsible for discoloration—commonly known as chromophores—are typically organic molecules containing conjugated double bonds, which allow them to absorb light in the visible spectrum and impart coloration to the tooth (Atali et al., 2020).

Whitening techniques may be classified according to the vitality status of the tooth, distinguishing between vital and non-vital (devital) bleaching procedures. Additionally, they can be categorized based on the setting in which they are performed—either in-office under professional supervision or as take-home regimens for patient self-application (Turp, Tuncel, Turp, Usumez, 2024).

3.1 Whitening agents and their mechanisms

Although the precise mechanism of action of tooth whitening agents has not yet been fully elucidated, it is well recognized that the whitening process varies according to the nature of the discoloration and the physicochemical conditions present during application. The efficacy of whitening agents is primarily influenced by several key factors, including the concentration of the active ingredient, the duration of contact with the tooth surface, and the frequency of application (Benahmed et al., 2020). These agents, most of which exhibit oxidizing properties, function by altering the organic components embedded within the tooth's hard tissues particularly in enamel and dentin—resulting in a perceptible lightening of shade. Furthermore, the adjunctive use of heat or light activation appears to enhance the rate of oxidation reactions, thereby accelerating the overall bleaching effect (Friedman, 1989, Hodosh et al.1970, Zaragoza, 1984).

The most commonly utilized whitening agents can be classified into several functional categories, each targeting specific components of extrinsic or intrinsic dental discoloration:

- Abrasive agents: Used to mechanically remove surface stains through physical friction.
- Anti-redeposition agents: Designed to inhibit the re-accumulation of chromophores on the enamel surface.
- Colorants: Used to create an optical illusion of whiteness by modifying light reflection.

- Proteolytic enzymes (proteases): Break down organic protein matrices within discolored areas.
- Peroxides: Act by oxidizing organic chromophores embedded within the enamel or dentin, resulting in a bleaching effect.
- Surfactants: Facilitate the removal of hydrophobic compounds from the tooth surface by lowering surface tension.

These agents, either alone or in combination, contribute to the efficacy of various over-the-counter and professional whitening formulations currently in clinical use and It's imperative to pay attention to maintaining the natural structure of teeth to ensure form in function and integrity in addition to aesthetics (Handa A, Bhullar K K,2023).

Hydrogen peroxide (H_2O_2) is the most commonly used active ingredient in dental bleaching procedures, with a molar mass of approximately 34.01 g/mol (Hess, 1995). It is a colorless, low-molecular-weight liquid with greater viscosity than water. In dentistry, hydrogen peroxide is used in concentrations ranging from 3% to 35% as a potent oxidizing agent. Owing to its small molecular size, it readily diffuses through dentin and releases oxygen molecules, which disrupt the double bonds in both organic and inorganic components within the dentinal tubules (Seghi, Denry, 1992), leading to a visible whitening effect (Usta, Gozukara, 2023).
The released oxygen penetrates the dental tissues and breaks down pigmented molecules, facilitating the bleaching process. The application of heat or light sources has been observed to accelerate this oxidative reaction, thereby enhancing the overall efficacy of hydrogen peroxide-based whitening treatments.
Carbamide peroxide ($CH_6N_2O_3$) is a white crystalline substance that releases oxygen upon contact with water and is typically used in concentrations between 10% and 35%. When exposed to oral fluids or tissue, a 10% carbamide peroxide formulation decomposes into 3.5% hydrogen peroxide and 6.5% urea. The urea component may further degrade into ammonia and water, slightly increasing the pH of the solution and potentially offering certain clinical advantages (Ekici, 2023). Most carbamide peroxide products are formulated with carbopol or glycerin-based gels. The inclusion of carbopol acts as a controlled-release agent, slowing down hydrogen peroxide liberation and prolonging its bleaching activity. (Usta, Gozukara , 2023).
Sodium perborate ($NaBO_3$) is a water-soluble, odorless, powdered compound that decomposes to release hydrogen peroxide upon activation. It is highly stable in dry form but breaks down into oxygen, hydrogen peroxide, and sodium metaborate when exposed to moisture, acid, or elevated temperatures (Plotino et al., 2008). Compared to concentrated hydrogen peroxide solutions, sodium perborate is generally considered easier and safer to handle (Basar, Cikman 2024). However, due to its classification by the European Union as a carcinogenic, mutagenic, and reprotoxic substance, its use has been prohibited since April 2015 (Nezir, M., , Ozcan, S. (2023)). If the use of a treatment does not benefit the patient, it may lead to harm and consequently result in a malpractice lawsuit (Ucuk, Dincer, 2024). On the other hand, even with prolonged use (up to three years), mouth rinses containing peroxide or perborate have not been clinically proven to cause potential chronic systemic toxicity (Ahmetoglu, 2024). In addition to carbamide peroxide and hydrogen peroxide, sodium perborate has also been reported to be equally effective in the bleaching of non-vital teeth, offering a comparable outcome in terms of whitening efficacy(Acar et al., 2024).
Ozone, though capable of inducing noticeable tooth color change as a bleaching agent, has been found to be less effective than hydrogen peroxide gels. Moreover, it does not demonstrate a synergistic effect when used in

combination with hydrogen peroxide (Basar, Cikman 2024). Comparative studies have shown that whitening agents containing hydrogen peroxide or carbamide peroxide produce more effective bleaching outcomes than ozone-based treatments (Tuzel, Can, 2022).

Chlorine dioxide (ClO_2) is a powerful and selective oxidizing agent widely used in water purification and bleaching applications (Ekici, Set al. 2023). While clinical whitening with peroxide-based agents has demonstrated significant effectiveness, it may also lead to adverse effects such as dental sensitivity or potential disruption of the organic matrix within enamel and dentin.

4. Whitening Procedures

4.1 Vital tooth Whitening

Vital tooth whitening is a procedure used to lighten teeth that have become discolored due to factors such as aging, trauma, medication use, or other intrinsic and extrinsic influences (Ritter, Boushell , Walter, 2018). This technique involves the application of chemical bleaching agents to the external surfaces of vital teeth and is particularly effective in addressing age-related and diet-induced discolorations, mild to moderate tetracycline staining, fluorosis, nicotine-related staining, and cases in which patients are dissatisfied with the natural shade of their teeth.

The effectiveness of the treatment largely depends on the nature of the discoloration. Yellow or orange stains typically respond most favorably to bleaching, while bluish-gray discolorations and white opacities caused by fluorosis tend to be more resistant and may require extended or alternative approaches. (Ritter, Boushell , Walter, 2018).

Vital whitening techniques can be categorized into three main types:

(1)In-office bleaching, performed entirely by a dental professional;

(2) Professionally supervised take-home bleaching, in which patients apply whitening agents at home under a dentist's guidance;

(3) Over-the-counter home bleaching, carried out independently by the patient without professional supervision. (Basar, Cikman, 2024)

4.2 In-office whitening

In-office tooth whitening is a professional bleaching procedure performed by a dentist within the clinical setting. It is often indicated in cases where rapid results are desired, when only specific teeth or a single arch require treatment, or when patients demonstrate poor compliance with home-use tray systems (Kwon , Goldstein, 2018). This approach offers a fast and efficient means of achieving esthetic improvement, with minimal risk of soft tissue exposure. Typically, a whitening gel containing a high concentration of chemically or light-activated hydrogen peroxide (HP) is applied for a short period, ranging from approximately 45 minutes to one hour (Alkahtani et al., 2020). To ensure patient safety during the procedure, precautions must be taken to protect the eyes, lips, and surrounding oral tissues from heat and light exposure (Ritter, Boushell, Walter, 2018). The teeth are carefully isolated, and gingival tissues are covered with a protective barrier. The bleaching agent is then applied in a 1–2 mm layer to the buccal surface of the target teeth, and its activity may be enhanced using a light or laser source (Basar, Cikman 2024). Various devices—including halogen lights, plasma arc lamps, LED systems, and dental lasers—are used to activate the bleaching process. The theoretical advantage of light activation lies in its ability to raise the temperature of hydrogen peroxide, thereby increasing the rate at which it decomposes into free radicals capable of oxidizing complex organic molecules (Nezir, Özcan, 2023). Laser handpieces designed for broader application areas may distribute the beam across multiple teeth. While this may result in a slight reduction in some beam characteristics, it has the benefit of lowering the risk of localized tissue damage (Freedman, 2011; Yilmaz Atali et al., 2020).

4.3 Dentist-supervised home bleaching

At-home bleaching is a whitening method in which carbamide peroxide serves as the primary active agent (Basar, Cikman 2024). In this approach, the whitening procedure is performed by the patient at home under the supervision of a dental professional. Typically, a 10% carbamide peroxide gel is applied using a custom-fabricated tray for a duration of four to six weeks (Colak, Uğurlu, 2024). The standard protocol involves applying bleaching agents containing 20–22% carbamide peroxide into the tray and placing it intraorally for approximately 30 minutes per session. This regimen can be adapted for daytime use, offering flexibility based on patient preference and lifestyle. While low-concentration systems containing 10–15% carbamide peroxide are commonly used, formulations with higher concentrations—ranging from 20% to 30%—are also available for enhanced efficacy (Tuzel, Can, 2022).

4.4 Devital bleaching

Non-vital bleaching should be planned with a patient-centered approach, taking into account proper indications and contraindications. Throughout the treatment process, clinicians must remain mindful of contraindications and ensure that appropriate precautions are taken to safeguard surrounding tissues and the structural integrity of the tooth (Ekici, Sakalli, 2024).

For devital teeth exhibiting discoloration, restorative options such as crowns, composite veneers, or porcelain veneers may also be considered to restore aesthetic harmony (Basar, Cikman 2024). Nonetheless, internal bleaching remains a commonly used method in teeth that have undergone endodontic treatment (Oliveira Ribeiro, 2018).

Prior to initiating bleaching, it is essential to hermetically seal the canal orifices with a suitable cement to prevent apical diffusion of the bleaching agent. Additionally, to minimize the risk of peroxide leakage through lateral canals or dentinal tubules into the periodontal ligament, it is advised that the bleaching agent be applied only within the incisal-crown region of the tooth, without extending below the level of the periodontal attachment (Ritter, Boushell, Walter, 2018).

Non-vital bleaching techniques can be categorized into two major approaches: the walking bleach technique, performed outside the dental office over a period of days; and in-office methods, such as the thermocatalytic technique or a combination of both approaches (Coelho et al., 2020; Ritter, Boushell, Walter, 2018).

Walking Bleach Technique

The walking bleach technique involves placing a bleaching agent directly into the pulp chamber of an endodontically treated tooth, aiming to achieve aesthetic improvement through a minimally invasive approach (Basar, Cikman 2024). It is widely regarded as the safest method for non-vital bleaching (Cerovac, 2017). Once the desired shade is achieved, the definitive restoration is completed. However, due to the inhibitory effect of residual oxygen on resin infiltration and polymerization, a delay is recommended before placing the final restoration (Da Silva Machado et al., 2007). Additionally, to reduce the risk of cervical resorption, it is advised that a mixture of calcium hydroxide and sterile saline be placed in the pulp chamber for two weeks following the bleaching process (Yilmaz Atali et al., 2020).

Thermocatalytic Technique (Non-Vital Power Bleaching)

In this method, the effectiveness of the bleaching agent is enhanced through the application of heat and light. The thermocatalytic technique targets intense internal discolorations by focusing the whitening effect within the tooth structure. In contrast, inside–outside bleaching techniques aim to improve both internal and external coloration for comprehensive aesthetic results (Anthony Irawan et al., 2015). During thermocatalytic bleaching, the access cavity remains open, and the patient is responsible for daily replacement of the bleaching material. This places a higher demand on patient compliance and increases the risk of structural compromise, such as crown fracture (Zimmerli, Jeger, Lussi, 2010). A high-concentration hydrogen peroxide gel (30–35%) is applied to the pulp chamber and activated using heat or light. The gel is typically applied in five-minute intervals, repeated up to five times. Afterward, the cavity is rinsed and dried. However, due to the use of elevated temperatures and the associated risk of internal resorption, this technique is now less frequently recommended (Katirci, Bulut).

Inside–Outside Bleaching Technique

The inside–outside bleaching technique involves the simultaneous application of 10% carbamide peroxide both within the pulp chamber and into a custom-made tray fabricated by the clinician. In essence, it represents a combination of internal (intracoronal) bleaching and professionally supervised at-home whitening, offering enhanced aesthetic outcomes through dual application (Katirci, Bulut).

4.5 Uncontrolled bleaching cases

A variety of whitening agents are available to consumers without dental supervision, often purchased over-the-counter from pharmacies, supermarkets, or online platforms (Tuzel, Can, 2022). These unsupervised at-home whitening methods include products such as whitening toothpastes, mouth rinses, sprays, “paint-on” gels, whitening strips, and LED light-activated kits—all designed for direct application by the patient, without the involvement of a dental professional.

Whitening mouth rinses typically contain low concentrations (approximately 2%) of hydrogen peroxide. “Paint-on” systems involve the application of hydrogen peroxide or carbamide peroxide gels directly onto the enamel surface using a small brush. Whitening strips, usually containing low concentrations of hydrogen peroxide, are placed over the anterior teeth to deliver bleaching effects in a targeted manner (Basar, Cikman 2024).

These products generally contain bleaching agents in the range of 3% to 6% and are often recommended for use twice daily over a two-week period. However, due to their limited concentration and surface-level action, such products are generally ineffective in addressing developmental or intrinsic discolorations (Tuzel, Can, 2022).

5. Unwanted results

Tooth whitening is generally considered a safe and effective esthetic intervention; however, certain complications may arise, particularly when protocols are not carefully followed. The most common is temporary dentin hypersensitivity, often caused by increased enamel permeability. Gingival irritation can also occur, especially if bleaching agents come into contact with soft tissues (Manti, Kivanc, 2024). In some cases, prolonged or excessive use may lead to enamel porosity, surface degradation, or, rarely, pulpal damage. Moreover, interactions with restorative materials—such as amalgam or composites—may result in surface changes or compromised bonding. The most common complication following whitening treatments is tooth sensitivity (Karabay, 2023). While systemic toxicity is rare, accidental ingestion of peroxide should not be overlooked. With proper technique and clinical guidance, these risks remain minimal, allowing patients to benefit from the procedure safely and comfortably.

6. Conclusion

In light of the growing demand for aesthetic dental care, tooth whitening has emerged as a pivotal component of contemporary minimally invasive treatment paradigms. This comprehensive review underscores the multifaceted nature of whitening agents and techniques, highlighting the chemical diversity, mechanisms of action, and clinical performance of widely used products. By synthesizing current evidence from the literature, this work provides dental professionals and students with a scientifically grounded framework for selecting and applying whitening modalities in a safe, effective, and patient-centred manner. As aesthetic expectations continue to evolve, an in-depth understanding of whitening systems will remain essential in achieving optimal outcomes while preserving the biological integrity of dental tissues.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

AUTHOR STATEMENT

The authors declare that if there is no need to any ethical approval, consent to participate, consent for publication, availability of data and material, and code availability etc.

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